STRUCTURAL AND ECONOMIC ANALYSIS OF CAPESIZE BULK CARRIERS

by

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MEng., Mechanical Engineering with Transport Engineering, Imperial College London (2006)
S.M., Transportation, Massachusetts Institute of Technology (2007)
S.M., Naval Architecture and Marine Engineering, Massachusetts Institute of Technology (2009)

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Abstract

Structural failures of bulk carriers continue to account for the loss of many lives every year. Capes are particularly vulnerable to cracking because of their large length, their trade in high density cargos, and the high rates of cargo operations. Rapid loss often occurs allowing little reaction time which has alarmed the industry. The Cape market is extremely volatile with ship values appreciating in some cases by over 500% and then returning to original levels, all within a few years. Recent market changes have rendered conventional pricing methods inaccurate and often inapplicable, resulting in a pressing need for alternate valuation models. Very little research combines the closely interlinked technical and financial elements which are crucial for valuation and decision making by various parties in the shipping industry.

The present research involves the collection and analysis of one of the largest ship cracking surveys. It is focused specifically on capes which lie at the core of the problem and is based on the records of ship owners, classification societies and shipyards. A location coding system was specifically designed to analyze the data and present the frequency, size and estimated crack growth rates with respect to location and ship age. The results were compared with existing knowledge based on surveys conducted over the past 50 years, the stress distribution based on an investigation of loading patterns, and theoretical fracture mechanics predictions. They were then combined with the frequency of crack failures, derived from an investigation of an extensive fleet sample, to develop a reliability model

which yields the hazard function throughout the ship's life. Repair procedures and design modifications were also examined and a model was designed to assess their cost effectiveness based on the present value of projected crack costs. The crack repair costs were calculated as a function of ship age to be used in conjunction with the safety assessment for decision making by ship owners, insurance companies, classification societies and others.

A new state of the art valuation model was developed combining both technical and financial aspects in a fundamental valuation based on risk-adjusted discounting of expected cash flows. A forward view of the main parameters was obtained from derivatives and financial securities that include shipping futures, FFAs, options, interest rate swaps and inflation protected bonds. The inherent risk of cracks is treated as a fictitious credit risk, derived from the reliability model, and is incorporated into the discount rate along with other risk premiums. Other inputs include repair costs and off-hire time, which were calculated with respect to ship age using a database of repairs, while the records of public and private companies were used along with surveys to estimate operating expenses. The resulting valuations were found to be in very close alignment with recent transaction prices across all ship ages. The model also estimates the volatility of the ship value and uses it to price optionalities that are often included in ship transactions.

The combination of technical and financial analysis of this thesis is valuable to many involved in the shipping industry including brokers, accountants, analysts, shipping banks and investors interested in valuation; ship owners when making managerial or investment decisions; shipyards when designing ships, setting prices and deciding payment structures and options; insurance companies when covering total loss or emergency repairs; the IMO when setting regulations; and classification societies when scheduling inspections and deciding which areas to focus on.

Thesis Supervisor: Henry Marcus

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To,

My Parents &

in loving memory of my grandfather Cpt. Nicholas J. Nomikos,

for inspiring my fascination in ships

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Nomenclature

Chapter 2

Roman Upper Case

AR:	Average revenue
ATC:	Average total cost
$EndVal$:	End value of vessel after the charter
I:	Interest rate
MC:	Marginal cost
MR:	Marginal revenue
NPV_{prof} :	Net present value of profits
P:	Profit
P(F) :	Prior probability that a hypothesis is false
$P(F \mid I)$:	Posterior probability that a hypothesis is false given information "I"
Prof:	Average annual profits
P(T) :	Prior probability that a hypothesis is true
$P(T \mid I)$:	Posterior probability that a hypothesis is true given information "I"

Roman Lower Case

n:	Number of years of the time-charter

Chapter 3

Roman Upper Case

A:	Paris-Erdogan Law coefficient OR Influence function OR Area under stress/strain curve
A_o:	Cross sectional area of plating
A_c:	Cross sectional area involved by cracking damage
$A_{i=0:3}$	Functions of material properties and the peak stress
B:	Specimen breadth OR Influence function OR Ship beam
C:	Empirical Constant
C_b:	Block coefficient at summer load waterline
C_i:	Stress combination factors
C_M:	Germanischer Lloyd (GL) Distribution Factor
C_1:	Coefficient defining the corrosion rate
C_2:	Coefficient defining corrosion progress OR Function of block coefficient
E:	Young's modulus under plain stress
E':	Young's modulus under plain strain
F:	Fahrenheit temperature (degrees) OR Correction factor
F_e:	Joint geometry factor
F_g:	Stress gradient
F_s:	Front free surface correction
F_t:	Finite thickness
F_w:	Back free correction
G:	Strain energy release rate
G':	Material Shear Modulus
G_c:	Critical energy release rate of the material
H:	Wave parameter depending only on ship length L
J:	Elastic-plastic crack tip parameter
J_c:	Critical elastic-plastic crack tip parameter

J_e: Elastic crack tip parameter

J_p: Plastic crack tip parameter

K: Stress intensity factor

K_b: Function of block coefficient

K_c: Critical stress intensity factor

K_{eff}: Effective stress intensity factor

K_{max}: Maximum stress intensity factor

K_{th}: Threshold stress intensity factor

K_I: Mode I (crack opening mode) stress intensity factor

K_{II}: Mode II (shearing mode) stress intensity factor

K_{III}: Mode III (tearing mode) stress intensity factor

K_1: Constant relating to the mean S-N curve

L: Scantling length OR Ship length

M_k: Correction factor

$M_{k,b}$: Correction bending factor

$M_{k,m}$: Correction membrane factor

M_w: Wave-induced bending moment

N: Number of stress cycles OR Number of cycles to failure

$N_{f,i}$: Number of cycles to failure

P: Load

R: Stress ratio

R_{xc}: Factor of reduction due to crack damage

S: Surface OR Stress range

T: Time in years

T_c: Life of coating in years

T_e: Time in years

T_i: Traction vector

T_t: Transition time

U: Potential energy

V: Volume

W: Strain energy density OR corrosion wastage in millimeters

W': Specimen width (along direction of crack)

Y: Geometry factors

Y_b: Geometry bending factor

Y_m: Geometry membrane factor

Z_{min}: minimum Hull Girder Section Modulus

Z: Original section modulus of deck or bottom

Z': Final section modulus of deck or bottom

Roman Lower Case

$a_{1,2,3}$: Tabulated constants depending on the ship type and dimensions

b/B: Ratio of damaged to total length

degC: Celsius temperature (degrees)

f: Crack opening function OR Ship service factor

k: Ramberg-Osgood constant

m: Inverse slope of S-N curve

n: Paris-Erdogan Law coefficient OR Empirical constant OR Ramberg-Osgood constant

n_i: Number of stress cycles

p: Empirical constant

q: Empirical constant

r: Distance from crack tip

r(t) : Corrosion rate in millimeters per year

s: Distance along Γ

t: Traction vector (normal to the contour)

t_r : Corrosion wastage

s_i: Stress amplitude

u: Displacement

u_i: displacement vector

v_o: Ship Speed

Greek Upper Case

Γ:	Path independent contour enclosing the crack tip
Δ:	Displacement
$\Delta\varepsilon$:	Cyclic strain
Π:	Potential energy

Greek Lower Case

a:	Crack length
a_c:	Critical crack length
β:	Applied load angle
δ:	Crack tip opening displacement
δ_c:	Critical crack tip opening displacement
ε:	Strain
η:	Tabulated geometry factor (For tension ~ 0.5, bending ~ 1)
θ:	Angle measured anticlockwise from the crack plane
$\hat{\theta}$:	crack branching angle
ν:	Poisson ratio
σ:	Applied stress OR crack opening stress OR standard deviation of log(N)
$\sigma_{A,B}$:	Stresses or other measurements at two convenient locations A, B
σ_b:	Bending stress
σ_i:	Stress component
σ_L:	local stress in a critical area which is to be determined
σ_m:	Membrane stress
σ_T:	Total stress
σ_{xu}:	Ultimate axial strength of cracked plating
σ_{xuo}:	Ultimate axial strength of un-cracked plating
σ_θ:	Hoop stress

Chapter 4

Roman Upper Case

A:	Paris-Erdogan Law material constant OR Bathtub curve constant
A_c:	Cracked Area
AGE:	Ship age (in years)
A_R	Ship reliability model parameter for current repair period
A_{R-1}	Ship reliability model parameter for previous repair period
A_0:	Area of intact plate
B:	Alternative model dimensionless parameter OR Bathtub curve constant
$\%\overline{BM}_\ell$:	Average percentage of allowable bending moment at location " ℓ "
$\%BM_{\kappa,\ell}$:	Average percentage of allowable bending moment at location " ℓ " under loading condition "κ"
C:	Alternative model dimensionless parameter OR Bathtub curve constant
C_1:	Criticality parameter 1
C_2:	Criticality parameter 2
D:	Alternative model dimensionless parameter
$D_{A,i}$:	Danger contribution of location "i" in ships of age "A"
$D_{A,i=10:13}$:	Danger contribution of locations 10 to 13 in ships of age "A"
$D_{A=6:10,j}$:	Danger contribution of compartment "j" in ships of age 6 to 10
D_c:	Danger value of crack "c"
$D_{c\in A,i,j}$:	Danger of crack "c" in location "i" and compartment "j" of ship age "A"
D_j:	Danger contribution of location "j" in all ships
D_R	Mean ship danger value (D_s) at the end of repair interval R
D_s	Ship danger value

F(T):	Weibull cumulative probability density function
F(t)	Cumulative distribution function (c.d.f.)
I:	Second moment of area (in longitudinal direction)
K:	Geometric constant of Modified Paris Law 3 OR Stress intensity factor
$LDG_{Si,j}$:	Location Danger
$L_{i,j}$:	Alternative Danger Model location factor
M:	Vertical Bending Moment
M_w:	Wave induced (global/principal) bending moment
N:	Number of stress cycles
P:	Load
P(x)	Probability of event "x" occurring
P(fail)	Probability of failure
$P_C(fail)_R$	Probability of failure implied by D_R for a given repair interval
$P_M(fail)_R$	Measured probability of failure in repair interval "R"
R:	Longitudinal strength knockdown factor OR Repair interval
$\overline{R}$:	Mean crack growth rate of all cracks in the database
$\overline{R}_A$:	Mean crack growth rate in ships of age "A"
$\overline{R}_{Aij}$:	Mean crack growth rate in location "i", compartment "j", ship age "A"
$\overline{R}_{A,j}$	Mean crack growth rate in compartment "j" from all ships of age "A"
$R_{CorrosionEffect}$:	Contribution of corrosion to crack growth rate function
$R_{DesignEffect}$:	Contribution of repair design modifications to crack growth rate function
$\overline{R}_j$:	Mean crack growth rate of cracks in location "j" from all ships in database
$R_{Original}$:	Original (at ship age A = 0) value of mean crack growth rate function
$\overline{R}_S$:	Mean crack growth rate of cracks in ship "S"
R_{total}:	Mean crack growth rate function (Bathtub Curve)
S':	Ship safety parameter of alternative model
S_A:	Average ship safety parameter for ship age "A"

SCF_i: Stress concentration factor of location "i"

S_s: Ship safety parameter

S(t) Survivor function

$Strength(new)$: Strength of racked plate

$Strength(old)$: Strength of un-cracked plate

T: Time variable in Weibull function OR Wave period OR Repair interval

T_c^F: Time to failure of crack "c"

T_c^*: Dimensionless time margin of crack "c"

T_f Time to failure

V: Ship velocity

Y: Geometric parameter

Z: Section modulus

Roman Lower Case

a Weibull distribution model parameter

a_C: Constant of $R_{CorrosionEffect}$ function

a_D: Constant of $R_{DesignEffect}$ function

a_R: Ship reliability model parameter corresponding to current repair interval

a_{R-1}: Ship reliability model parameter corresponding to previous repair interval

a_O: Constant equal to $R_{Original}$

b Weibull distribution model parameter

b_D: Constant of $R_{DesignEffect}$ function

b_R Ship reliability model parameter corresponding to current repair interval

b_{R-1} Ship reliability model parameter corresponding to previous repair interval

c_D:	Constant of $R_{DesignEffect}$ function
c_R	Ship reliability model parameter corresponding to current repair interval
c_{R-1}:	Ship reliability model parameter corresponding to previous repair interval
d:	Regression constant for relationship between $P_M(fail)_R$ and D_R
d_D:	Constant of $R_{DesignEffect}$ function
e	Regression constant for relationship between $P_M(fail)_R$ and D_R
f(t)	Probability density function (p.d.f.)
f(T):	Weibull probability density function (p.d.f.)
f_R	Total % drop of hazard function during repair just before repair interval R
f_{RI}	Percentage drop of hazard function due to imperfectly inspected areas
f_{RU}	Percentage drop of hazard function due to areas not inspected
g:	Gravitational acceleration ($9.81 m/s^2$)
h:	Water depth
k:	Wave number
k_f:	Knockdown factor to account for dynamic stress cycles
m:	Paris-Erdogan Law material power constant
$sac_{i,j}$:	Additional crack growth required to reach critical length for fast fracture
$sce_{i,j}$:	Distance from crack tip to the end of the component
$ss_{i,j}$:	Distance from crack tip to the side shell
t:	Time since crack was 1mm OR Time since last inspection OR Time vector
t':	Time since crack length was equal to the relevant measurement resolution
$\%t_\kappa$:	Average time under each loading condition "κ"
r:	Ratio of cumulative P(fail) half way through repair interval to final value
r_{DR}:	Ratio of average D_s half way through repair interval R to D_R
r_M:	Ratio of failures in first half of all intervals to total number of failures
r(t):	Expected residual lifetime function
w_1:	Weighting function for combining $P_M(fail)_R$ and $P_C(fail)_R$ to get P(fail)
w_2:	Weighting function for combining r_M and r_{DR} to get r_R
y:	Vertical distance from the neutral axis

Greek Upper Case

ΔK:	Applied stress intensity amplitude
$\Delta\sigma$:	Applied stress amplitude
$\Delta\sigma_i$:	Effective stress amplitude of location "i"

Greek Lower Case

a:	Crack length
$\bar{\alpha}$:	Mean crack size
a_f:	Final crack length
a_0:	Initial crack length
α_c:	Crack length of crack "c"
β:	Weibull parameter
η:	Weibull parameter
κ:	Loading condition
λ:	wavelength
λ(t):	Hazard function
μ:	Angle between propagating directions of ship and waves
σ_b:	Bending stress
σ_{xx}:	Bending stress in the "x" (longitudinal direction)
σ_{ult}:	Ultimate Tensile Strength (UST)
τ:	Temporary integration time variable
ω:	Wave frequency
ω_e:	Wave encounter frequency

Upper Case Subscripts

A:	Ship age
C:	Calculated
D:	Based on danger value data
M:	Measured
R:	Current Repair Interval
R-1:	Previous Repair interval
S:	Ship

Lower Case Subscripts

i:	Code of ship location within a compartment
j:	Ship compartment along the length from stern to bow
j	Area on ship
s	Ship
ℓ:	Frame or bulkhead location
k:	Crack size group in 50mm increments
c:	Crack

Lower Case Greek Subscripts

κ:	Loading condition

Matrices

$\tilde{\bar{a}}$: 2-D matrix of average crack lengths in all ships of the database

$\tilde{\bar{a}}_A$: 2-D matrix of average crack lengths in ships of age "A"

$\tilde{a}^c$: 2-D Matrix of critical crack lengths

$\tilde{a}^r$: 2-D matrix of crack length measurement resolutions

$\tilde{\bar{a}}_S$: 2-D matrix of average crack lengths in ship "S"

$\tilde{C}$: 3-D matrix of number of cracks in each location, compartment and crack size group in all ships of the database

$\tilde{C}_A$: 3-D matrix of number of cracks in each location, compartment and crack size group in all ships of age A

$\tilde{C}_S$: 3-D matrix of number of cracks in each location, compartment and crack size group in ship S

$\tilde{C}_1$: 2-D Matrix of Criticality parameters C_1

$\tilde{C}_2$: 2-D Matrix of Criticality parameters C_2

$\tilde{F}$: 1-D Matrix of adjustment factors of criticality parameters

$\tilde{L}$: 2-D matrix of total crack length in each location and compartment of ships of the database

$\tilde{L}_A$: 2-D matrix of total crack length in each location and compartment of ships of age A

$\tilde{L}_S$: 2-D matrix of total crack length in each location & compartment of ship S

$\tilde{N}$: 2-D matrix of number of cracks in each location and compartment of all ships of the database

$\tilde{N}_A$: 2-D matrix of number of cracks in each location and compartment of all ships of age A

$\tilde{N}_S$: 2-D matrix of number of cracks in each location & compartment of ship S

$\tilde{R}$: 2-D matrix of mean crack growth rates across all the ships of the database

$\tilde{R}_A$: 2-D matrix of mean crack growth rates for ships of age "A"

$\tilde{R}_S$: 2-D matrix of mean crack growth rates for cracks in ship "S"

$\tilde{S}$: 3-D matrix of crack sizes (varies only in one dimension)

$\tilde{T}_A^I$: 2-D matrix of inspection intervals for ships of age "A"

$\tilde{T}_{0A}^F$: 2-D Matrix of minimum failure times absent of visible cracks for ship age "A"

$\tilde{T}_{0A}^M$: 2-D Matrix of minimum failure time margins absent of visible cracks for ship age "A"

Matrix Elements

$\left[\tilde{\bar{a}}\right]_{i,j}$: Mean crack length in location i, compartment j, in all ships of database

$\left[\tilde{\bar{a}}_A\right]_{i,j}$: Mean crack length in location i, compartment j, in ships of age "A"

$\left[\tilde{a}^c\right]_{i,j}$: Critical crack length of location "i" and compartment "j"

$\left[\tilde{a}^r\right]_{i,j}$: Crack length measurement resolution for location "i" in compartment "j"

$\left[\tilde{\bar{a}}_S\right]_{i,j}$: Mean crack length of cracks in location i, compartment j, in ship "S"

$\left[\tilde{C}\right]_{i,j,k}$: Cracks in location "i", compartment "j", size group "k" in whole database

$\left[\tilde{C}_A\right]_{i,j,k}$: Cracks at location "i", compartment "j", size group "k" in ships aged "A"

$\left[\tilde{C}_S\right]_{i,j,k}$: Cracks at location "i", compartment "j", size group "k" in ship "S"

$\left[\tilde{C}_1\right]_{i,j}$: Criticality parameter C_1 corresponding to location "i" in compartment "j"

$\left[\tilde{C}_2\right]_{i,j}$: Criticality parameter C_2 corresponding to location "i" in compartment "j"

$\left[\tilde{F}\right]_j$: Adjustment factor of criticality parameters for compartment "j"

$\left[\tilde{L}\right]_{i,j}$: Total crack length at location "i", compartment "j", of whole database

$\left[\tilde{L}_A\right]_{i,j}$: Total crack length at location "i", compartment "j" in ships aged "A"

$\left[\tilde{L}_S\right]_{i,j}$: Total crack length at location "i", compartment "j", of ship "S"

$\left[\tilde{N}\right]_{i,j}$: Cracks at location "i" and compartment "j" in whole database

$\left[\tilde{N}_A\right]_{i,j}$: Cracks at location "i", in compartment "j", of all ships of age "A"

$\left[\tilde{N}_S\right]_{i,j}$: Cracks at location "i", in compartment "j", of ship "S"

$\left[\tilde{R}\right]_{i,j}$: Mean crack growth rate in location i, compartment "j" of all ships

$\left[\tilde{R}_A\right]_{i,j}$: Mean crack growth rate in location i, compartment "j", ship age "A"

$\left[\tilde{R}_S\right]_{i,j}$: Mean crack growth rate in location i, compartment "j" of ship "S"

$\left[\tilde{S}\right]_{i,j,k}$: Crack size (in mm) corresponding to size group "k"

$\left[\tilde{T}_A^I\right]_{i,j}$: Crack inspection interval in location "i", compartment "j" at ship age "A"

$\left[\tilde{T}_{0A}^F\right]_{i,j}$: Minimum time to failure absent of a visible crack in location "i" and compartment "j" of ships of age "A"

$\left[\tilde{T}_{0A}^M\right]_{i,j}$: Time margins to failure for barely unidentifiable cracks in location "i" and compartment "j" of ships of age "A"

Chapter 5

Roman Upper Case

A:	Constant
Age_0:	Age of ship at time of valuation
$ARF(Age)$:	Earnings reduction factor due to ship age
B:	Annual operating cost OR Constants
BCI_j:	Equivalent daily revenues of a new (Baltic) Cape for year "j"
BCI_n:	Daily revenues of a Baltic Cape (new ship) in month "n"
C:	Value of call option today OR Constant
CAPEX:	Capital Expenditures
CC_0:	Combined operating costs
CF_j:	Cash flow in year "j"
CF_y:	Cash flow in year "y"
$\%Com$:	Address commission plus broker commissions
CP:	Cost parameter for ship
C_t:	Annual net charter rate at time "t"
CT:	Cost of time
D:	Effective duration of cash flows OR Debt OR Constant
Days:	Time in days
DEP:	Depreciation
Deposit:	Deposit amount
E:	Value of equity OR Constant
ECF:	Levered cash flow to equity holders
$ED(Age)$:	Earning days per month as a function of age
EBITDA:	Earnings before interest, tax, depreciation and amortization

$E(S_t)$: Expected value under the objective measure (not risk-neutral)

F: Price of option (either a put or a call option)

$FailCost$: Cost of failure due to cracks

FCF_t: Free cash flow (Unlevered) in year "t"

$F^M(t,T_m)$: Futures level for month "m" with maturity T_m

$F^Q(t,T_q)$: Futures level for quarter "q" with maturity T_q

F_t: Futures price

$F^Y(t,T_y)$: Futures level for calendar year "y" with maturity T_y

I_{cc}: Combined operating and dry dock cost inflation

IC_t: Invested capital in year "t"

I_n: Average US monthly inflation until month "n"

I_{oc}: Operating cost inflation

$I(t)$: Inflation from yield spread of TIPS and T-Bills until time "t"

K: Strike price

Life: Number of months in ship's life

LTAV: Long term asset value

M: Ship's age in months at the time when the operating costs are evaluated

MRP: Market risk premium

N: Month at which operating costs are evaluated OR Cumulative distribution function of standard normal distribution OR Number of assets in portfolio

$NetIC_t$: Net invested capital at year "t"

$NOPLAT_t$: Net operating profit less adjusted taxes for year "t"

NPV: Net present value of all cash flows

OC: Operating costs

$OC_{N(n)}$: Nominal Operating costs in $/day at "N" months from today

$OpExp_n$: Real operating expenses in $/day, "n" months from the valuation date

$P(fail)_n$: Probability of failure due to cracks during month "n"

$PV(K)$: The value of the strike price discounted from maturity

$PV(LongF)$: Present value of a long futures position

$PV(ShipRev)$: Present value of the expected earnings of the un-hedged ship

$\boldsymbol{PV(TS)}$: Present value of tax shields (from tax deductibility of interest payments)

$PV(x_{12m} = x_{1y})$: Present value of cash flow "x" in one year

RC: Repair cost

ROE: Return on equity

Rev_n: Daily Revenues during month "n"

Rev_0: Initial daily revenues

$RepCosts_n$: Repair costs during month "n"

RP: Risk premium over CAPM model

RT: Repair time

$RT_{NoCracks}$: Repair time without cracks

RW: Residual value of ship

S: Price of underlying stock option today

$ShipValue$: Ship value today

SRP: Systematic risk premium

$S(t)$: Survivor function OR Value of underlying asset of exchange option

T: Time (years) OR Time to maturity (tenure) OR Remaining life (years)

$Tons$: Weight of steel

TV: Terminal value of company at year "T" (PV of a growing perpetuity)

V: Value

$V_{BSPA-Cape}(t)$: Value of the BSPA-Cape index

$V_{S\&P500}(t)$: Value of S&P 500 index at time "t"

UCF_t: Unlevered cash flows at time "t"

Roman Lower Case

c:	Constant that defining risk averseness
$c_{1,j}$:	Constant to account for commissions, age and off-hire time in year "j"
$c_{2,j}$:	Constant to account for the non-revenue cash flows in year "j"
$\boldsymbol{d_t}$:	Dividends at time "t"
dt:	Incremental change in time
dV:	Incremental change in value
g:	Assumed annual growth of future cash flows
i:	Discount rate (constant)
i_n:	Discount rate for month "n"
m:	Index that denotes the month
m^2:	Area in m^2
n:	Months from valuation date OR Number of compounding periods per year
p:	Returns on portfolio
q:	Index that denotes the quarter
r:	Discount rate without ship risks
r_{CAPM}:	Capital asset pricing model returns
$\boldsymbol{r_D}$:	Cost of debt
$\boldsymbol{r_E}$:	Cost of levered equity
$r_e(t)$:	Cost of equity
r_f:	Continuously compounded risk free interest rate
$r_f(t)$:	Risk free rate
r_n:	Annual interest compounded "n" times per year
$\boldsymbol{r_u}$:	Cost of unlevered equity
r'_{WACC_t}:	Annual inflation adjusted continuously compounded WACC

$r_{WACC}(t)$: Weighted average cost of capital

$r'_{WACC}(t)$: Inflation-adjusted weighted average cost of capital

$r'^{m}_{WACC_t}$: Monthly inflation adjusted continuously compounded WACC

r_t : Continuously compounded interest rate (varies with time)

r_{λ_S} : Discount rate adjusted for ship risks

r_{∞} : Constant continuously compounded annual interest rate

t: Time variable (typically in years)

u: Utility of cash flow "x"

x: Principal amount

x' : Return on principal over an infinitesimal time increment

x_i : Returns of asset "i"

x_T : Cash flow at time T

x_{12m}: Cash flow in one year

x_{1y}: Cash flow in one year

w_i Percentage of portfolio in asset "i"

y: Year in the ship's life

z: Wiener Process

Greek Upper Case

$\Delta BVND$: Change in value of net debt

ΔNWC: Change in net working capital

Greek Lower Case

$\beta_e(t)$: Beta of equity

$\lambda(\tau)$: Hazard function (function of time variable τ)

$\lambda(n)$: Hazard function for ship age corresponding to month "n"

λ_S: Risk premium to account for ship risks

μ: Drift term

$\rho_{BSPA-Cape,S\&P500,T}$: Correlation between BSPA-Cape and S&P 500 over time "T"

ρ_{ij}: Correlation between returns of asset "i" and "j"

σ: Volatility

$\sigma_{BSPA-Cape,T}$: Black-implied volatility of BSPA Cape index for tenure "T"

σ_i: Volatility of returns on asset "i" (% volatility of asset "i")

σ_{ij}: Covariance of returns of asset "i" and "j"

$\sigma_{S\&P500,T}$: Black-Implied volatility for S&P 500 index for tenure "T"

$\sigma_{S,T}$: Black-Implied volatility of the exchange option with tenure "T"

τ: Time to expiration (years) OR Tax rate

Upper Case Subscripts

S: Ship OR Underlying asset

Lower Case Subscripts

e: Equity

i: Crack OR Portfolio Asset

j:	Ship Location with Crack OR Portfolio asset
k:	Repair process
m:	Month
n:	Month
t:	Continuous compounding
u:	Unlevered
y:	Year

Abbreviations

ABS	American Bureau of Shipping
AET	Acoustic Emission Technology
APV	Adjusted Present Value
AR	Average Revenue
ARA	Absolute Risk Aversion
ARF	Age Reduction Factor
BCI	Baltic Cape Index
BDI	Baltic Dry Index
BE	Book Value of Equity
BEM	Boundary Element Methods
BM	Bending Moment
BOD	Board of Directors
BPI	Baltic Panamax Index
BSPA	Baltic Sale and Purchase Assessment Index
BV	Bureau Veritas
BVND	Book Value of Net Debt
C.D.F.	Cumulative Distribution Function
CAGR	Cumulative Average Growth Rate
Cape	Capesize bulk carrier
CAPEX	Capital Expenses
CAPM	Capital Asset Pricing Model
CDF	Cumulative Distribution Function
CEO	Chief Executive Officer
CF	Cash Flows
COLREG	Convention on the International Regulations for Preventing
CoV	Coefficient of Variation

CPI	Consumer Price Index
CSRP	Company Specific Risk Premium
CTOD	Crack Tip Opening Displacement approach
DCF	Discounted Cash Flow
DD	Dry Dock
DNV	Det Norske Veritas
DRYS	Dryships
DSX	Diana Shipping
EBIAT	Earnings Before Interest After Tax
EBITDA	Earnings Before Interest Depreciation and Amortization
ECF	Equity Cash Flow
EndVal	End value of vessel after the charter
EOS	Economies of Scale
EPRI	Electric Power Research Institute
FCF	Free Cash Flows
FEA	Finite Element Analysis
FFA	Freight Forward Agreement
FTE	Flow to Equity
GDP	Gross Domestic Product
GL	Germanischer Lloyd
HAZ	Heat Affected Zone
HHI	Hyundai Heavy Industries
HIMP	Hull Inspection and Maintenance Program
HMX	Handimax
HTS	High Tensile Steel
I	Interest Rate
IACS	International Association of Classification Societies
IISI	International Iron and Steel Institute
ILO	International Labor Organization

IMO	International Maritime Organization
IPO	Initial Public Offering
ISM	International Safety Management
ISM	International Safety Management
LCN	Lifedream Compania Naviera
LEFM	Linear Elastic Fracture Mechanics
LL	Load Line
LNG	Liquefied Natural Gas
LOA	Length overall
LP	Longitudinally Profiled
LTAV	Long Term Asset Value
MC	Marginal Cost
MOU	Memorandum of Understanding
MR	Marginal Revenue
MRP	Market Risk Premium
MS	Market Share
MWC	Modified Wohler Curves
NAC5	New Anti-Corrosion No 5
NASL	North American Steamship Limited
NDT	Nil Ductility Temperature
NDT	Non-Destructive Testing
NK	Nippon Kaiji Kyokai
NOPLAT	Net Operating Profit Less Adjusted Tax
NPV	Net Present Value
NSC	Nippon Steel Corporation
NWC	Net Working Capital
NYSE	New York Stock Exchange
OBO	Ore Bulk Oil
OC	Operating Cost

OPEX	Operating Expenses
P.D.F.	Probability Density Function
P/E	Price-to-Earnings
PMX	Panamax
PNU	Pussan National University
PSC	Port State Control
PV	Present Value
RAFL	Risk Adjusted Forward Looking Ship Valuation Model
RC	Repair Cost
RO	Recognised Organisations
ROA	Return on Assets
ROE	Return on Equity
RP	Risk Premium
RT	Repair Time
S&P	Sale and Purchase
SCF	Stress Concentration Factor
SMX	Suezmax
SOLAS	Safety of Life at Sea
SRP	Systematic Risk Premium
SS	Special Survey
SS2	Second Special Survey
STCW	Standards of Training Certification and Watch-keeping
T-Bills	Treasury Bills
TC	Time Charter
TIPS	Treasury Inflation Protected Securities
TMCP	Thermo-Mechanical Control Process
TV	Terminal Value
TVR	Time Variant Reliability
UCF	Unlevered Cash Flow

UNCLOS	United Nations Convention on the Law of the Sea
USCG	United States Coast Guard
USD	US Dollars
VLOC	Very Large Ore Carrier
WACC	Weighted Average Cost of Capital
WS	World Scale
WTO	World Trade Organization Collisions at Sea

CHAPTER 1

Introduction

1.1 Capesize Bulk Carriers

The overwhelming majority of the world's commodities and raw materials are transported by sea. Since this is unlikely to change in the future, the safety of bulk carrier ships is of outmost importance to society.

Bulk carriers were introduced in the 1950s for the more efficient transportation of cargo in the form of bulk. They are divided into various size-groups whose definitions have changed over time following technological developments and the shift to greater sizes for economies of scale.

Traditionally the three main groups starting from the smallest are the Handysizes (typically geared), the Panamaxex (maximum size that can transit the Panama Canal), and the Capesizes which are larger and hence have to sail around the cape. Today the groups most commonly referred to, are the Mini-bulker (<10,000dwt), Handy-size (>10,000dwt), Handymax (>40,00dwt), Supramax (~52,000dwt), Panamax (~75,000dwt), Kamsarmax (~82,000dwt), Post-Panamax (~90,000dwt), Capesize (>100,000dwt), Newcastlemax (~206,000dwt Coal Carriers) and VLOC (very large ore carriers).

The design of bulk carriers in general has remained more or less the same since they were introduced in the mid 1950's. What is even more interesting is that apart from scantlings and size, the cross section of a large Capesize bulk carrier (Cape) is almost identical to that of a Handy. The structural details in the cargo hold region of a typical bulk carrier are outlined in Fig 1.1-1 while Fig 1.1-2 provides an outline of the whole cargo hold configuration.

Capesizes started with deadweight of about 110,000 dwt in the 1960s and gradually progressed to the typical size of 172,000dwt. They are typically gearless with 9 cargo holds of approximately the same size, equal to about 25 meters deep. Their overall length (LOA) is typically 292 meters and the beam is about 50m, which exceeds the permissible required for transiting the Panama Canal. Therefore, they need to sail round the Cape Horn and that is where the name "Capes" originates from. When loaded, they also have to sail around the Cape of Good Hope instead of transiting the Suez Canal. They are used mainly in the

transport of high density cargos such as iron ore or coal within specific trade routes. Most common destinations include China, Australia, Holland, Brazil and South Africa.

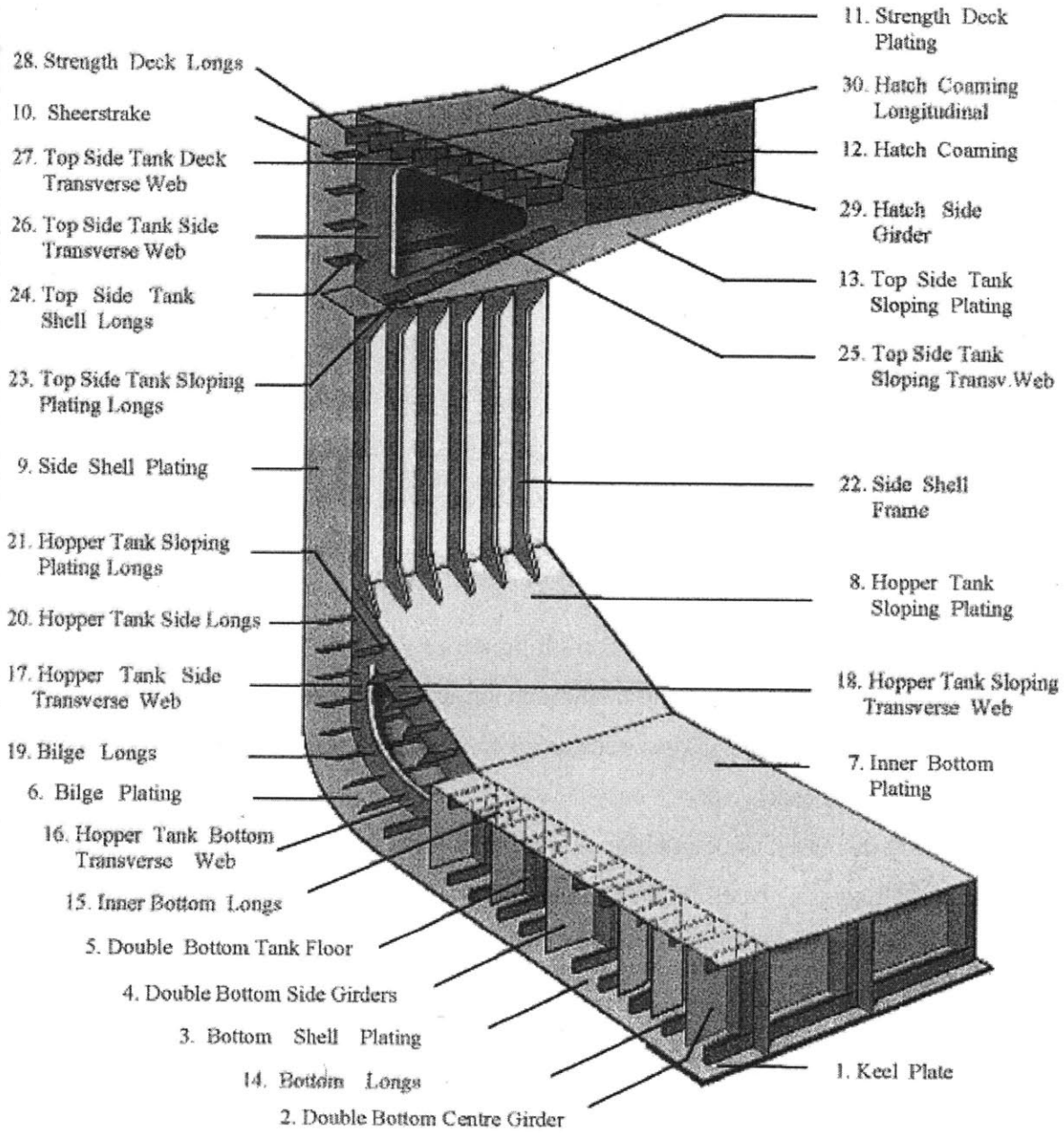


Fig. 1.1-1: Capesize Bulk Carrier Mid-Ship section, Structural Items [Loukakis 2005]

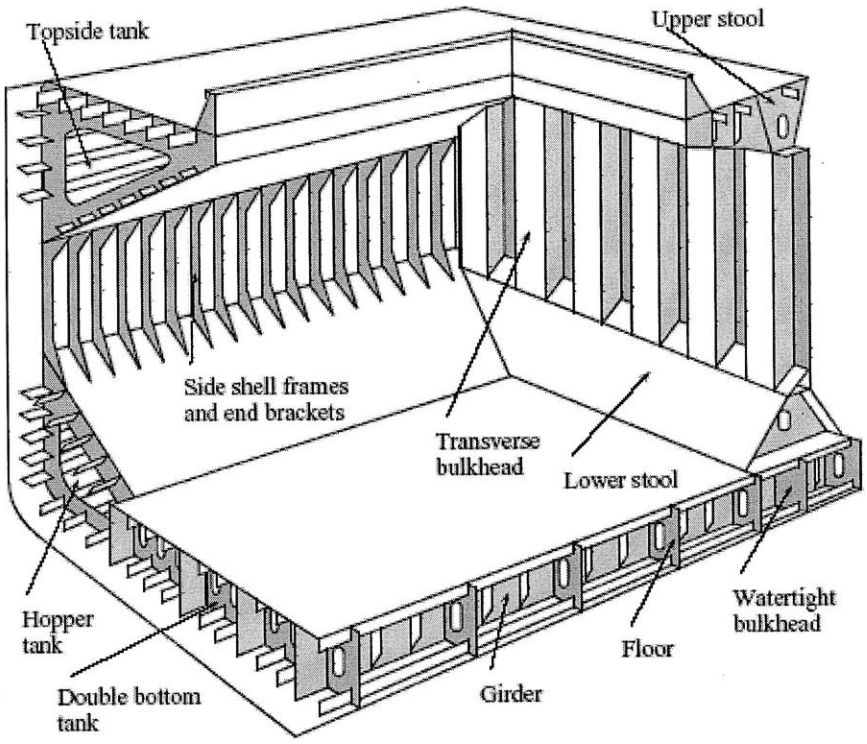


Fig. 1.1-2: Typical cargo hold configuration [IACS (a)]

These ships today are designed for a fatigue life of about 30 years. Their trading life however is affected both by structural and economic factors and often exceeds this. Life extension is worthwhile as long as returns over the projected remaining life of a ship outweigh the required costs.

A steady increase has been observed in the world fleet of Capes since the early 1970s (Fig 1.1-3) and this is projected to continue given the high orderbook. As of April 15th 2010, the world fleet stands at 1,001 Capes of 178.6Mdwt while there are another 768 of 146.8Mdwt on order including VLOCs of 400,000dwt.

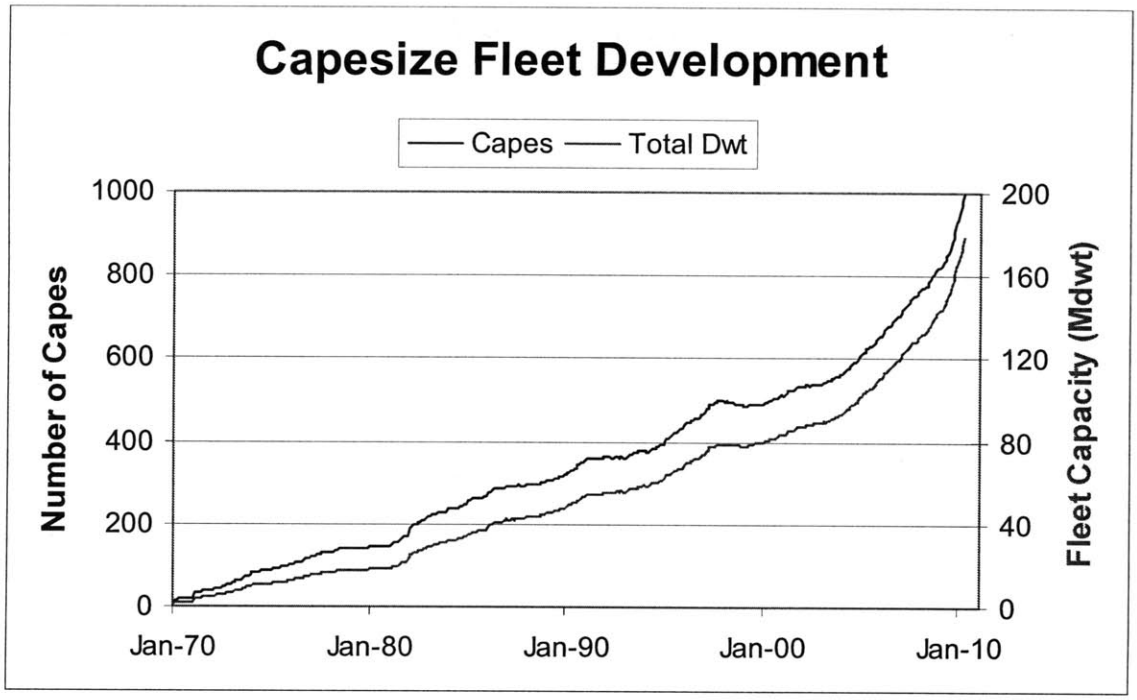


Fig. 1.1-3: The *Capesize Fleet* Development since 1970 [Clarksons 2010]

1.2 The Problem of Cracks

Structural failures of bulk carriers continue to account for the loss of many lives every year. The problem is particularly important in Capes which are vulnerable to cracking for three main reasons: (a) their large size/length, (b) their trade in high density cargoes (such as iron ore), and (c) the exceptionally high rates of loading and discharging. As a consequence, there have been several dramatic casualties in the past where there was not enough reaction time available to even send an SOS message. Naturally, this has attracted public attention and it has caused great concern about fractures particularly in Capes.

The problem of fractures is more severe in Capes than in smaller ships because of their large size and the consequent large bending moments and stresses. This is illustrated in Fig 1.2-1 which compares the number of cracking and fatigue incidences between the various bulk carrier size groups. While this is the case, no extensive survey has ever been carried out focusing specifically on cracking in Capes.

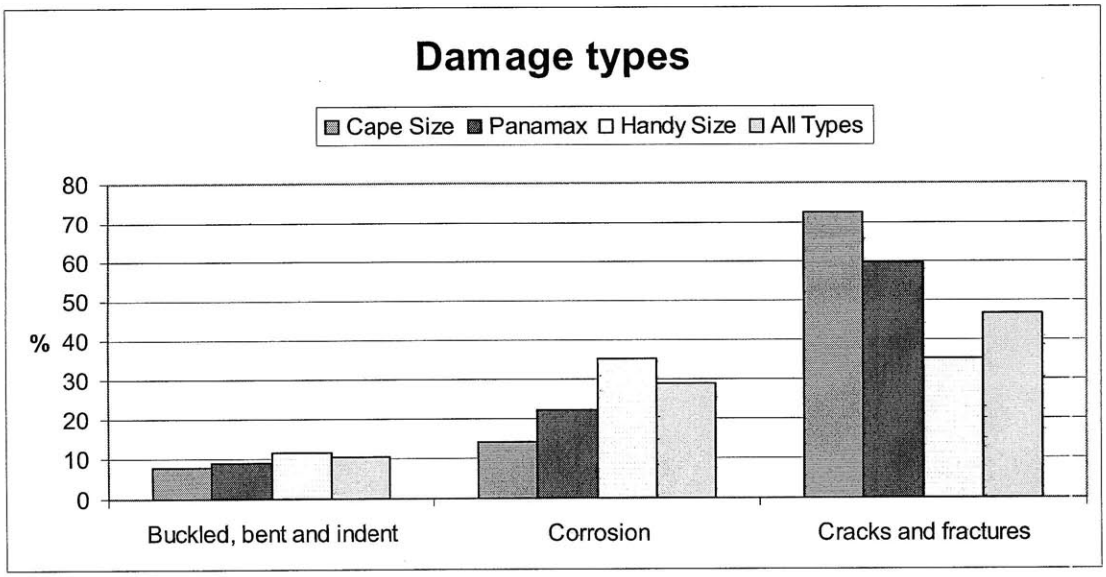


Fig. 1.2-1: Comparison of Cracks as a percentage of total damages between the three main Bulk Carrier Size Categories [DNV 2002]

Capes have a relatively standard size and configuration and they are also used in specific trades as discussed above. This means that they are all subjected to similar loads

throughout their service life and it is possible to make direct comparisons between different ships regarding their fracture behavior.

Cracks have been of great concern for many decades to all parties involved in shipping including ship owners, charterers, classification societies, the IMO, insurance providers, and shipyards – each for different reasons. Owners are concerned with the safety of their ship and crew, repair costs and time lost in port while ship yards are constantly trying to pin-point the problem in order to improve design and introduce new ships. The big trade-off which designers and owners often face in the construction of a new ship is whether to invest in a fatigue resistant design, or to produce a lower cost structure and incur the repair costs as cracks emerge later in the ship's life. This kind of choice has to be made for hundreds of locations throughout the ship's hull. Shipowners also need an understanding of the cost and safety implications of cracks as a ship ages in order to make decisions such as buying, selling, repairing or scrapping ships of a certain age given the market level and expectations. Banks that finance ship acquisitions, other investors, brokers and analysts have similar concerns when estimating the value of a ship.

Charterers and cargo owners are concerned about cargo damage and delays. They are often called to choose between chartering a new ship or an older one at a lower cost. Occasionally, they also make decisions such as restricting some trades to particular ships for safety purposes, in which case they usually make distinctions by ship age or design specifications. Iron ore terminals, continuously try to increase loading rates in order to improve productivity but this can have serious consequences related to cracks and ship losses.

Regulatory groups such as the International Maritime Organization (IMO) are responsible for the seaworthiness of ships, the safety of the crew and protection of the environment. They are highly concerned with cracks as it is their responsibility to ensure safety through regulations regarding design, loading rates, minimum inspection standards etc. Insurance companies rely on existing knowledge about the likely crack costs and probability of failure when deciding the insurance premiums for repairs or ship loss. Classification societies are concerned about the safety implications of cracks and use their existing knowledge to set the frequency of inspections and examine the right locations in each survey.

Inspectors of flag authorities and the port state control also need guidance as to where cracks are likely to be found depending on the ship's age.

Cracks develop and propagate due to corrosion or fatigue and may ultimately lead to failure and sinking of the ship. Corrosion cracks manifest by the well-known mechanism of stress corrosion cracking. Furthermore, the structure is fatigued by the alternate loads due to sea waves, and during cargo operations with rates often exceeding 16,000 tons per hour. There is practically no ship entirely free of cracks. Their origin, type and size however may differ widely from one ship to another. Some cracks develop at an early stage, for example due to bad design, while others may develop later as a result of fatigue. Since it is impossible to prevent the development of cracks throughout the ship's life, it is essential to minimize this effect in the vulnerable areas, and to detect cracks before they grow to a critical size. This is possible by improving design, minimizing stresses during operation and through regular inspections and repairs.

Due to the high stakes involved by a wide range of parties, a lot of work has been carried out to assess the problem of cracks. Theoretical, analytical and numerical methods have been developed to assess the problem in many ways. Modeling of the marine environment however and accurately predicting the actual conditions and stresses which a ship encounters throughout its service life is practically very difficult to materialize. It is therefore essential to take direct measurements from ships and any conclusions derived as such will be much more reliable for the time being.

Several statistical studies have been carried out using ultrasonic gauge readings in order to assess corrosion wear distribution throughout the ship hull. Similar studies on cracking however are very limited due to the high confidentiality and unavailability of data. Most are performed by classification societies using data from their fleets in order to develop their rules. Furthermore, very few surveys have been performed specifically on cracks while most cover a wide range of damages or failures including dents, buckling, corrosion etc. The majority of the work also covers a wide variety of ship types and sizes.

Possible reasons for the scarcity of detailed information in the published literature include the fact that classification societies generally treat such information as confidential in order to protect the interest of their clients; ship-owners try to minimize the time spent in repairs which limits data acquisition while there is limited feedback to shipyards after the

guarantee period; damages are very often attributed to heavy weather, an accepted peril of the sea; and most importantly, fatigue cracking is not always regarded as a serious problem that may affect the overall ship integrity so there is no immediate need to document it. Furthermore, cracks in a large ship are so many that recording them by size, location and origin is not considered to be part of normal survey work.

1.3 The Cape Market

The capesize bulk carrier market is highly cyclical both in terms of charter rates and in terms of ship prices. This creates tremendous investment opportunities with exceptionally high returns over short periods for those who enter and exit at the right time. There are however many factors contributing to the outcome of the market, making it highly unpredictable. An extensive historical analysis of market cycles has been conducted by [Stopford 2009]. Fig 1.3-1 shows dry bulk shipping cycles since WW2, and Fig 1.3-2, which is based primarily on coal, goes back to the 18th century.

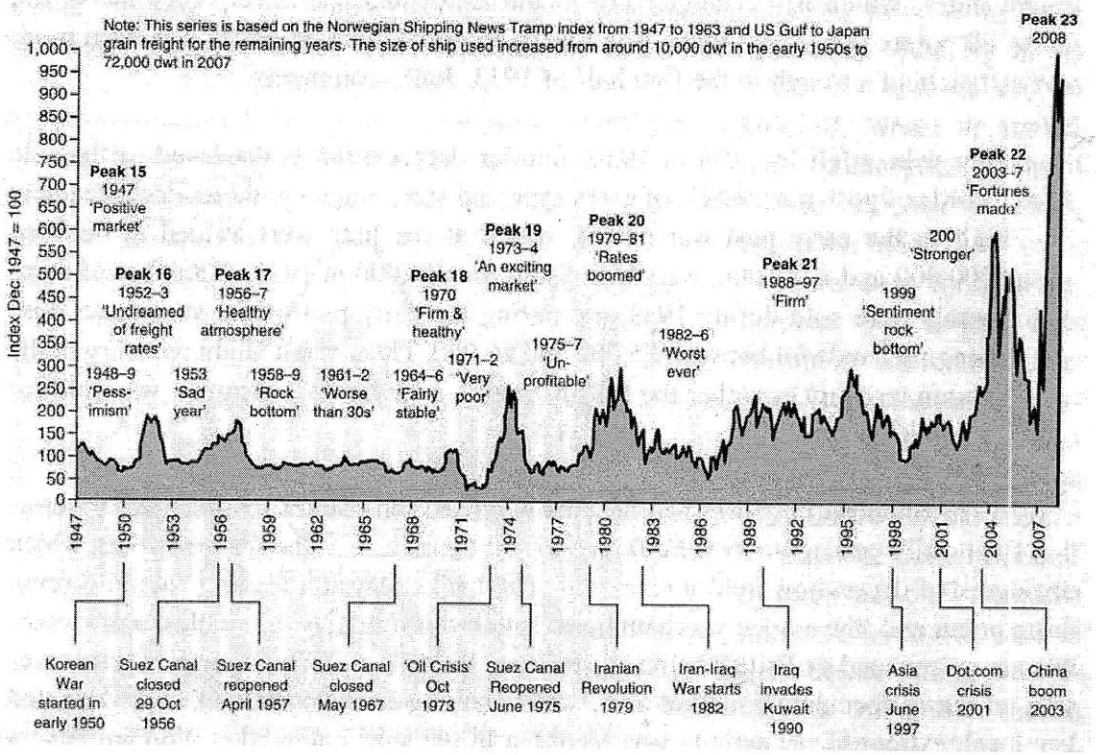


Fig. 1.3-1: Dry Bulk Market Cycles Since 1947 [Stopford 2009]

22 shipping cycles are identified over the past two and a half centuries, with an average duration of 10.4 years and a standard deviation of 4.9 years [Stopford 2009]. The Cape market is particularly volatile with ship values appreciating in some cases by over 500% and then returning to original levels, all within a few years. An investor is presented

with the decision of timing, what ship to buy (age is an important parameter), how to employ it (e.g. long term charter), when to sell it, and whether to hedge some of the risk through the futures market. A critical issue in these decisions is the safety and maintenance cost associated with the ship depending on its age.

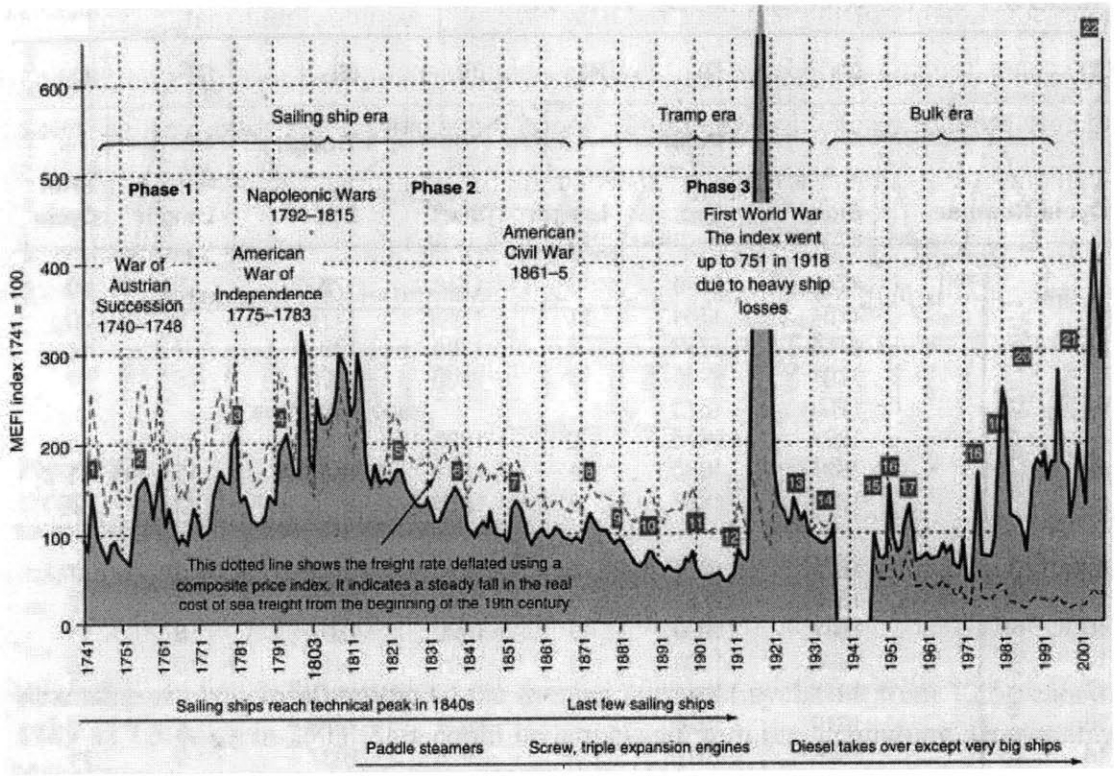


Fig. 1.3-2: Shipping Index Primarily Based on Coal [Stopford 2009]

Recent market changes have rendered conventional pricing methods inaccurate and often inapplicable, resulting in a pressing need for alternate valuation models. Very little research combines the closely interlinked technical and financial elements which are crucial for valuation and decision making by various parties in the shipping industry.

1.4 Objectives and Thesis Outline

The objective of this work is to examine the capesize industry both from a technical and a financial perspective and to analyze data to produce results that will be valuable to various constituents of the shipping industry. We will examine both market and structural safety characteristics of Capes as well as maintenance costs and hedging options to ultimately produce results that can guide important decisions and also to create a state of the art valuation model that is urgently needed in the industry. The work of this thesis is interdisciplinary and as such, goes into depth on various topics which may not be of interest to all readers. The main contributions are in Chapters 4 and 5. I encourage the readers to refer to the following outline and to the table of contents so they can be directed to the relevant chapters and sections.

In Chapter 2, the Cape market and the economics of the industry are analyzed. Historical market trends, in terms of ship-values and freight rates for Capes of various ages, are examined along with the factors that determine the market outcome. A database of previous fixtures, secondhand transactions and newbuilding orders is compiled and analyzed to derive conclusions regarding the charter-free/survey-passed value of ships of various ages as well as the employment opportunities that arise for each throughout the market cycles. The capesize paper market, which has been in existence since 2002, is also examined regarding its relation to the physical market and the hedging opportunities that it provides.

Chapter 3 presents the relevant technical background related to factors such as fracture mechanics, monitoring, repairing and designing against cracks, ship design, steels, operating stresses and cargo operations etc.

Chapter 4 presents the technical work related to cracks beginning with an analysis of cracks recorded in Capes. The purpose is to derive conclusions regarding the critical areas, frequency and distribution of cracks throughout the hull, crack size, the effect of age and the origins and repairs of the various types of cracks. Note that the terms "crack" and "fracture" are taken to be synonymous in the context of this investigation. The work presented involves the collection and analysis of one of the largest ship cracking surveys which is focused specifically on Capes that lie at the core of the problem. The data are sourced from the

records of ship owners, classification societies and shipyards. The size, location and repair procedure of each crack is extracted from the records and recorded into a database for further analysis. Fig 1.4-1 shows the cross section of a capesize bulk carrier compartment showing some of the possible locations for cracks or steel renewals.

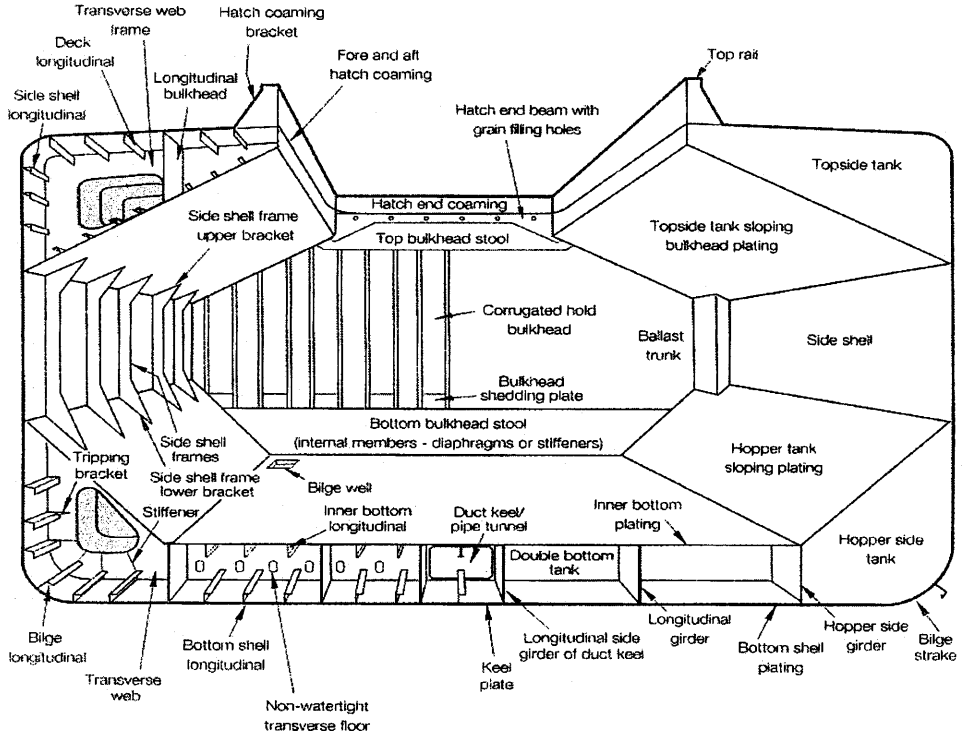


Fig. 1.4-1: Structural Configuration of a Typical Capesize Bulk Carrier [MER 2002a]

A location coding system is specifically designed to analyze the data and present the frequency, size and estimated crack growth rates with respect to location and ship age. The results are compared with existing knowledge based on surveys conducted over the past 50 years, the stress distribution based on an investigation of loading patterns, and theoretical fracture mechanics predictions. They are then used to develop a relative safety assessment model that yields a safety parameter as a function of ship age. The records of a large fleet sample are separately used to estimate the frequency of crack failures (emergency repairs and losses) as a function of ship age. The two sets of results are compared for validation purposes and ultimately combined to create a reliability model that yields the hazard function throughout the ship's life.

Chapter 5 combines the insights gained from earlier chapters, along with some new analysis to produce results and tools useful for important decision making by the various parties of the shipping industry. Repair procedures and design modifications of the crack database are examined and a model is designed to assess their cost effectiveness based on the present value of projected cracks. The crack repair cost is also developed as a function of ship age to be used in conjunction with the relative safety assessment for decision making that involves cost and safety tradeoffs.

Steel renewals account for a large fraction of repair costs and most of the remaining repair costs such as staging, cleaning, coating and sand blasting also scale with steel renewals. With that in mind, a large database of repairs is compiled and analyzed to estimate repair costs as a function of age. The operations of public and private companies are compared, before using records and conducting surveys with both types and carrying out an inflation analysis to project operating expenses.

A new state of the art valuation model is then developed combining both technical and financial aspects in a fundamental valuation based on risk-adjusted discounting of expected cash flows. A forward view of the main parameters is obtained from derivatives and financial securities that include shipping futures, FFAs, options, interest rate swaps and inflation protected bonds. The inherent risk of cracks is treated as a fictitious credit risk, derived from the reliability model, and is incorporated into the discount rate along with other risk premiums. Other inputs including repair costs, operating expenses and off-hire time, are sourced from the earlier analysis. The model is extended to also estimate the volatility of the ship value and uses it to price optionalities that are often included in ship transactions. Finally, the results are validated with real data, the possible uses of the results and methods developed are discussed and recommendations are made for future work.

CHAPTER 2
Economics of Capes

– Adapted from [Hadjiyiannis 2007][1]

[1] Note: With the exception of Sections 2.1 and 2.7, the bulk of the research presented throughout Chapter 2 was carried out in early 2007, with the data available at the time.

2.1 Market Overview

2.1.1 Introduction

The cape market has closely followed the dry bulk market since the introduction of capes in the late 1960s. It is highly cyclical, creating big investment opportunities with potential for high and fast returns. China's recent economic expansion has impacted capes in particular as they account for the vast majority of iron ore transportation. The rapid increase in demand combined with the short-run inelasticity of supply due to capacity constraints has led to a record-high market. This combined with lack of confidence has some very interesting implications. The price gap between newer and older vessels has narrowed significantly, while a modern cape is worth about 50% more than ordering a newbuilding. Since 1986 when a 9-year-old cape was of scrap value, the market has moved to the opposite extreme with a 13-year-old cape worth as much as a newbuilding.

The industry and its development will be analyzed before focusing on market prospects. Extensive analysis will be presented on a wide range of factors contributing to the outcome of the market in terms of freight rates, time charter rates, ship values and newbuilding prices. Examples include Chinese steel production and iron ore imports, Australian port congestion and queue lengths, oil prices, newbuilding orders and delivery times, the orderbook and the scrapping pool, all of which are at record high levels. Other factors include exchange rates, GDP growth, policies and demolition rates.

The analysis is carried out using databases of newbuilding orders, fixtures and S&P transactions as well as a wide range of numerical data from a variety of sources. The futures market will also be investigated, as well as its relation to the physical market. A wide range of current investment opportunities are finally considered from a buyer's and a seller's perspective. These are analyzed and compared before making the relevant recommendations.

2.1.2 Background on the Cape Market

Bulk Carriers are divided into five main size groups which focus of different trades though there is substantial overlap. The smallest ones are the Handysize vessels or "Handys", which are between 10Kdwt and 35Kdwt. These are usually geared, they are very flexible due to their size, and they are used in a wide variety of trades. Handymax vessels cover the range of 35Kdwt to 60Kdwt. These are also usually geared and transport a wide range of cargo.

Panamaxes are the largest vessels that can transit the Panama Canal, which imposes a restriction of 32.2m on the beam. Due to developments in design, materials and naval architecture, the permissible size in terms of capacity has grown substantially over the years and is currently about 75Kdwt. Panamaxes are mainly used in the transportation of coal, iron ore, grain and phosphates. Following the announcement of the Panama Canal expansion, which will be complete by 1914, there will no longer be a need for vessels of these particular dimensions. Other considerations will come into play and a new and larger Panamax design will evolve.

Bulk carriers larger than Panamaxes have to sail around Cape Horn and hence they are called "capesize bulk carriers" or "capes". They are typically around 175Kdwt and are mostly used for the transportation of coal and iron ore. Though Capes are not involved in the transportation of most cargos, changes in these markets can have a significant impact on the demand for capes through a knock-on effect. When Chinese steel exports increase for example, as in 2005, the demand for Handymaxes increases. More Handymaxes are used in this trade and Panamaxes become more heavily involved in trades that are shared between the two vessel types. This effectively reduces the supply of panamax ships in the grain or iron ore trades. The demand for capes therefore goes up as it did significantly in 2005 for this reason. The markets of the various size groups follow each other though there tends to be short periods of divergence. This is also shown in Fig. 2.1-1.

Fig. 2.1-1: Shows the ratio of cape earnings to panamax earnings over time. This has varied within the range 1.2 to 2.8 over the past five years. The average value is about 2.

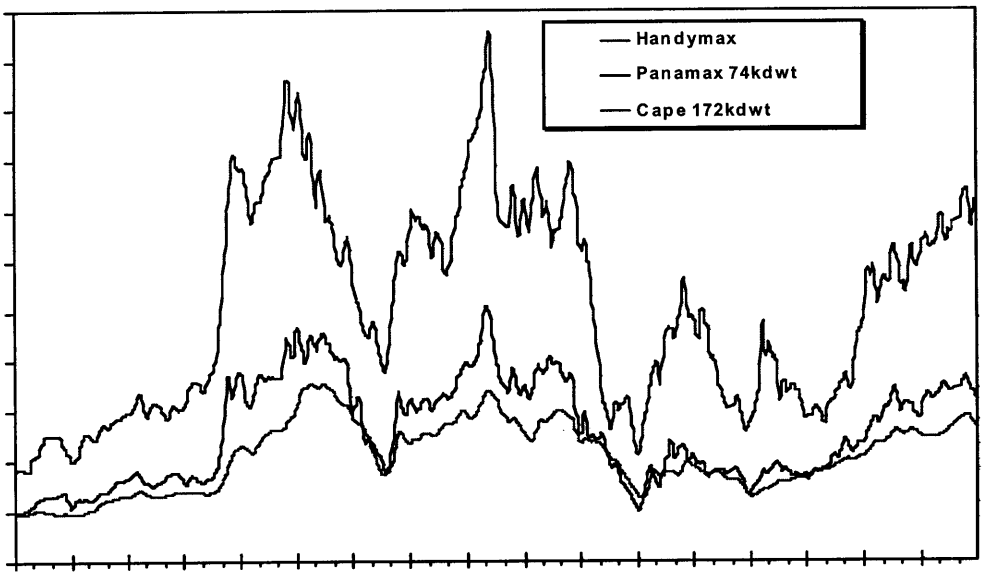


Fig. 2.1-1: Bulk Carrier Earnings tend to go Together [SSY 2007b]

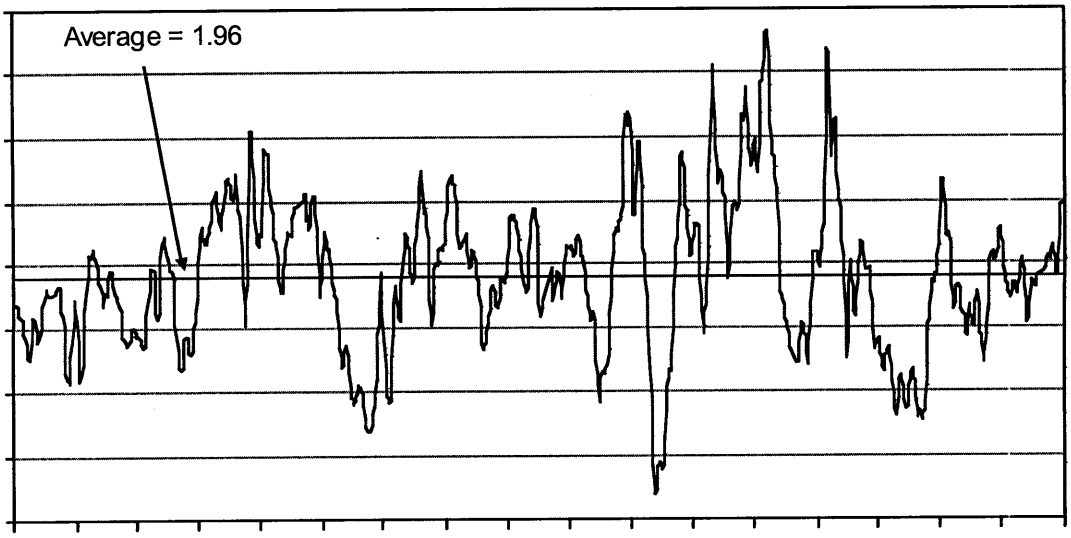


Fig. 2.1-2: Ratio of Cape to PMX Earnings Over Time [SSY 2007b]

Specialized ore carriers are designed specifically for high-density cargoes such as iron ore. Due to the high stowage factor of the cargo, these are compact and have a capacity

that often exceeds 300Kdwt with only a modest increase in overall dimensions. This however renders them inefficient for the transportation of the high stowing coal and has made them less profitable over the past few decades. They are therefore few in number and the majority of iron ore is transported in Capesize vessels. The largest iron ore carrier in the world is the *Berge Stahl*, built in 1986, shown in Fig. 2.1-3. It measures 343m long and its deadweight capacity is 364,767dwt.

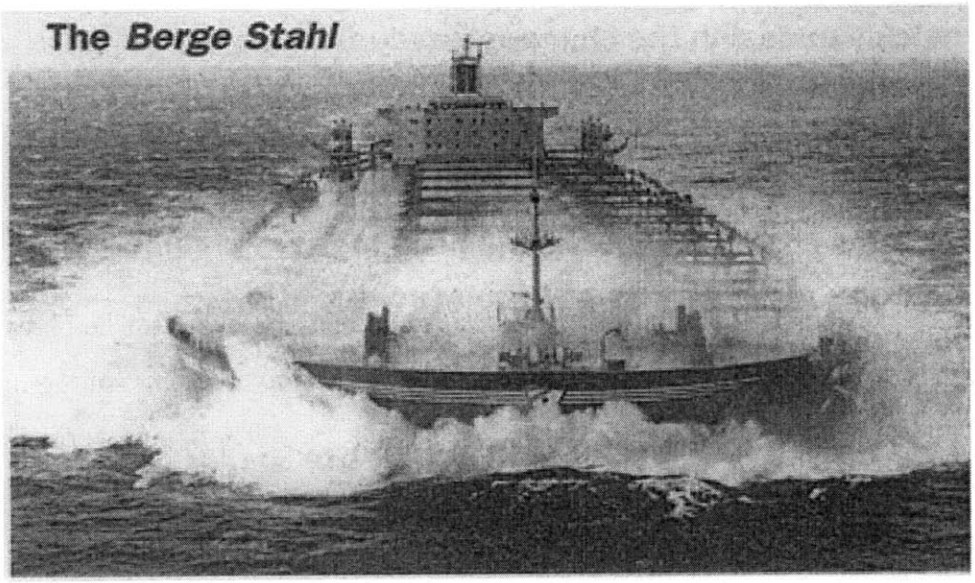


Fig. 2.1-3: *Berge Stahl* - The World's Largest Dry Bulk Carrier [Van Dyck 2004]

As of 2006, there were 711 capes in the world fleet with a total capacity of 120.6Mdwt. About 10% of these are over 200Kdwt and about 1% are over 300Kdwt. 185 capes of 37Mdwt are currently on order until 2012, of which 28 are large ore carriers and 17 are over 300Kdwt. Only 1 cape has been scrapped since last year so the capesize fleet is increasing at a high rate [Clarksons 2007b].

Capes are designed for a fatigue life of about 30 years. Their trading life however is affected both by structural and economic factors. Life extension is worthwhile when the market (or expected market) is such that predicted returns over the projected remaining ship life outweigh the required costs. Fig. 2.1-4 shows the age distribution of the fleet along with the current orderbook.

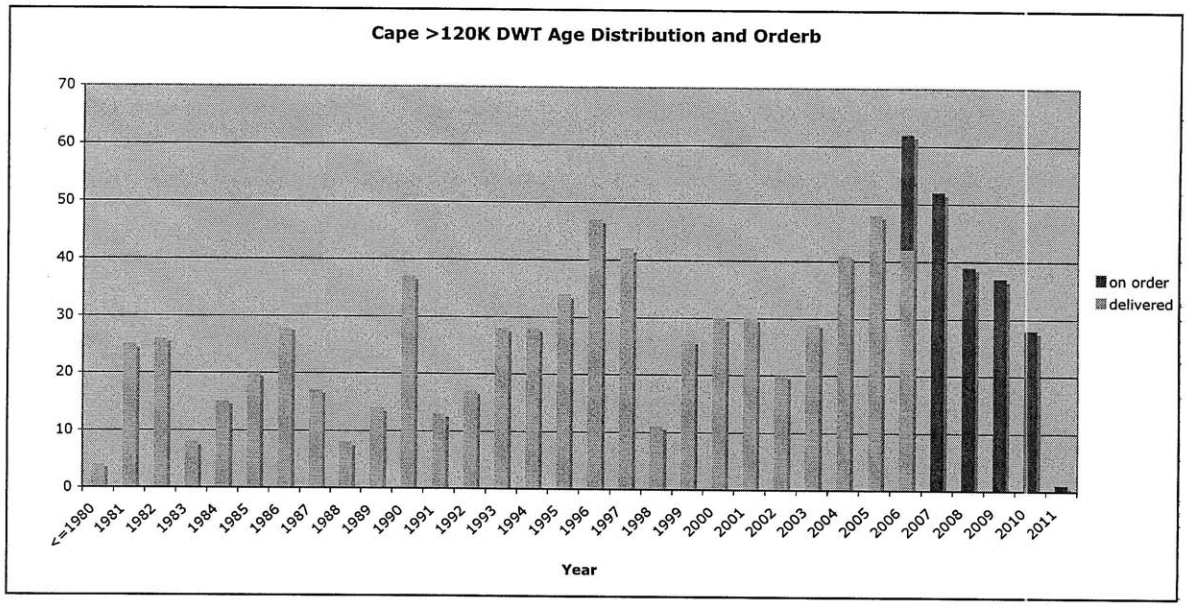


Fig. 2.1-4: The *Capesize Fleet* Development since 1970 – using data from [Braemar 2006]

The 711 capes in the world fleet are divided among 162 owners. The biggest one is Mitsui O.S.K. Lines with 35 vessels of an average 176Kdwt at an average age of 9 years. This fleet is worth about $3bn in today's market but only accounts for 4.9% of the world fleet. The top 50 owners own three quarters of the world fleet while the top 20 own about half and the top 10 own about a third. This is shown in Fig. 2.1-5, as the percentage owned by the top 5 owners (1^{st} to 5^{th}), the second five owners (6^{th} to 10^{th}) and so on.

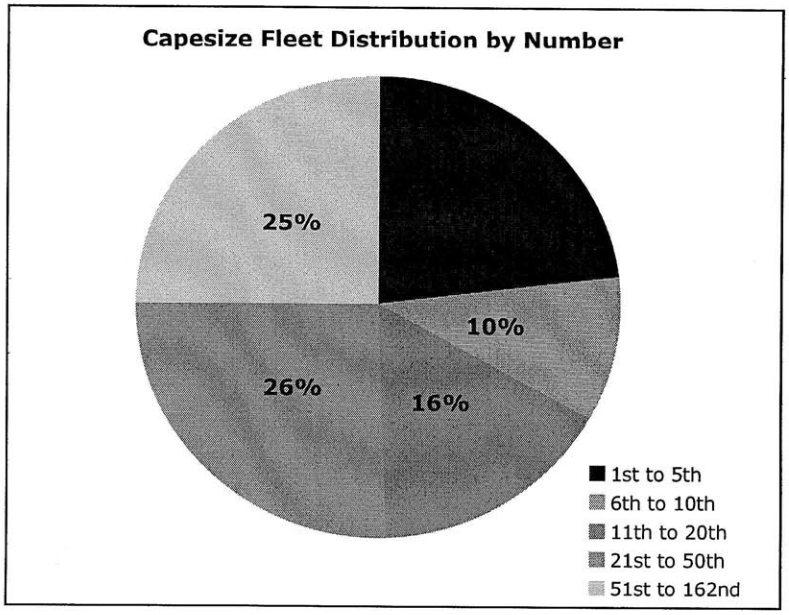


Fig. 2.1-5: The Capesize Fleet Distribution Among Owners using Data from [Clarksons 2006c, LR 2007]

The number of owners owning 4 to 35 vessels is indicated in Fig. 2.1-6, which shows the fleet distribution among the top 50 cape owners.

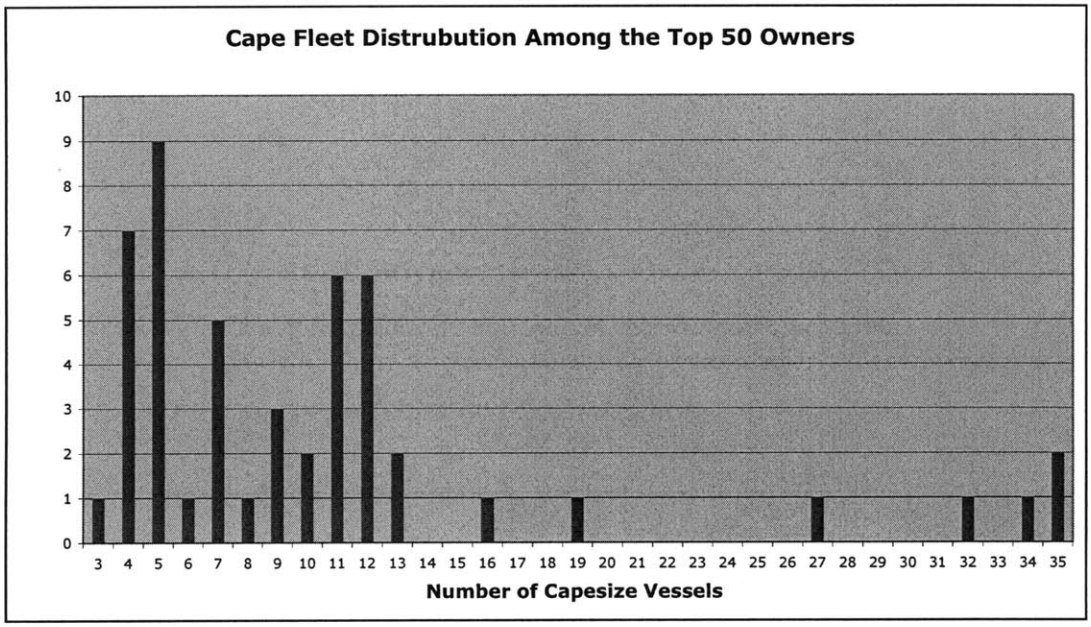


Fig. 2.1-6: The Capesize Fleet Distribution Among top 50 Owners by Number of Vessels - using Data from [Clarksons 2006 & GSD 2007]

As mentioned earlier, Capes are mainly used mainly in the transportation of iron ore and coal within specific trade routes. Most common destinations include China, Australia, Holland, Brazil and South Africa. The largest importer of iron ore is China while the largest exporters are Australia and Indonesia [LR 2005b]. The prevalence of iron ore over other cargos however is clear in Fig. 2.1-7, which shows the approximate shares of commodities transported by capes as tabulated by values from [Braemar 2007a] and [DNV 1997].

Iron ore as a commodity is crucial to economic development and its consumption per capita is an index measuring the standard of living. Many countries depend heavily on its transportation and since the sea separates producers from consumers, typically by a large distance, this makes marine transportation of iron ore a vital aspect of economic growth.

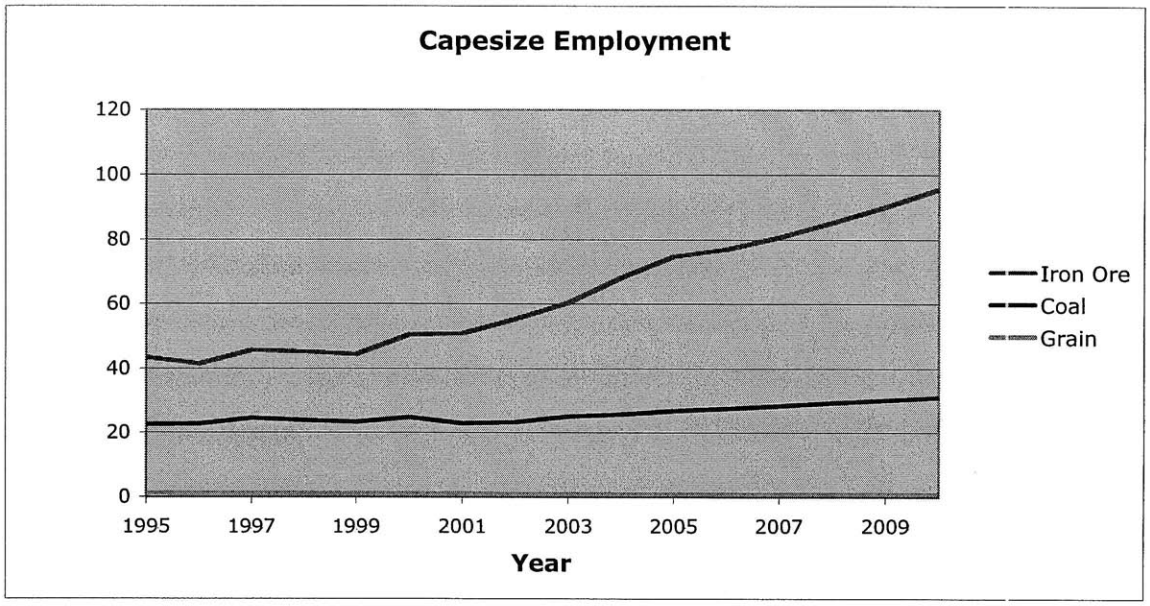


Fig. 2.1-7: Capesize Trading Cargoes using data from [Braemar 2006 & DNV 1997]

Marine transportation of iron ore has been increasing steadily for the past several years while China's expansion has caused a tremendous increase in demand since the start of the new millennium. Currently, 716 million tones (the vast majority) of iron ore are being transported by sea annually making it the largest dry bulk trade as shown in Fig. 2.1-8.

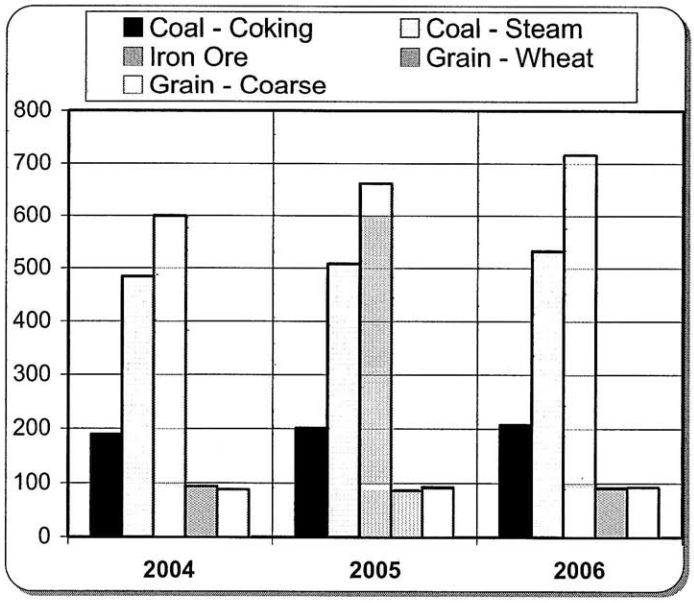


Fig. 2.1-8: Seaborne Dry Bulk Trades in Mt for the years 2004 – 2006 [SSY 2006a]

At its origin, iron ore is extracted from the ground in mine fields and then transported to nearby ports via trains. It is then stockpiled onto big land surfaces within the ports and from there loaded onto ships by means of conveyor belts. Ships then transport the cargo to other terminals in which it is unloaded using large grabs and then taken to close by steel plants (the final destination) by trains. Almost all iron ore (98%) is used to make iron and steel [Kirk 2006].

The dry bulk shipping is highly competitive with relatively low barriers to entry. These include knowledge, ISM certification and other regulations, high prices and economies of scale. Economies of scale however are much more significant on a ship and its size as opposed to the size of a firm and its fleet. A new entrant therefore also has access to these EOS reducing the significance of this barrier. The market consists of many relatively small charterers and shipowners and deadweight capacity is distributed relatively evenly amongst them. The influence of a single player on the market's outcome is therefore very limited creating a highly competitive environment.

To a great extent, the above also applies to the more specific cape industry. The cape fleet however is relatively small. Furthermore, the cape market is highly sensitive on supply and if that is reduced by say 15% when the market is already on an upward trend, this can have a big impact on rates. A Taiwanese owner, Nobuyoshi Morimoto managed to take advantage of this and cornered the market to some extent in 2005, making in excess of $1bn through a series of futures and subsequent charters.

Shipping is a highly cyclical market both in terms of charter rates and in terms of ship prices. This creates opportunities for high profits if one enters and exits at the right time. There are however many factors contributing to the outcome of the market and this makes it very unpredictable. Fig. 2.1-9 shows an overview of the dry bulk market over the past twenty years since the great shipping crisis in 1986. The main peaks and bottoms are then outlined below.

Fig. 2.1-9: The Baltic Dry Index since the 1986 crisis [Reuters 2006]

1970s: The first capes are constructed in the late 1960s / early 1970s

1976: The 1973 oil crisis leads to a world recession that results in the shipping crisis of 1976

1986: The 1979 oil crisis and the high interest rates of 1980/81 to counteract inflation lead to a world recession. This combined with the oversupply of ships results in the shipping crisis of 1982-1986

1988: Increasing demand as economies recover, combined with decreasing supply as yards shut down, lead to recovery of the shipping market towards the end of the 1980s

1995: Increase in demand from China leads to a boom in the shipping market

1999: The stock exchange crisis of 1998 in the Far East (the tiger markets) that was then followed by Russia and Brazil led to the 1999 crisis in the shipping market

2002: The 11th of September tragedy, which led to the economic depression and the Enron scandal that led to the deep stock market crisis, resulted in the 2002 shipping crisis

2003: The current boom was largely driven by China's expansion but America's demand in 2006 has led to an increase in backhaul rates. The increase in oil prices has also led to the economic expansion of oil producing countries and to increased use and transportation of steam coal

2.1.3 Market Characterization

2.1.3.1 Introduction

The type of market in which capes are operated and traded is of great importance to valuation. By market type, in this context, I refer to the economic definition of markets such as perfect competition, monopoly, oligopoly, collusive oligopoly, monopolistic competition etc. The market type and competition levels drive both the returns that an asset is expecting to generate in its lifetime (the asset's value), and the price that it can command.

The cape market is entirely dependent on supply (of ships) and demand (for cargo transportation) at any given time. There are many factors affecting the long and short term supply and demand for capes, which are discussed extensively in the next two chapters. For this reason the shipping market is very volatile and unpredictable. Furthermore, speculation is very important. If owners speculate that the market is improving they will act differently than if they are pessimistic, and this will have a significant effect on the market and ship values. Economies of scale (EOS) are more significant on a ship and its size as opposed to the size of a firm and its fleet.

2.1.3.2 Characteristics of Perfect Competition

Perfect competition consists of many small firms selling a homogeneous product or service. All firms are price takers facing a perfectly elastic demand curve. If an individual firm marginally increases its price, the demand it faces falls to zero. Their aim is to maximize profits, so they produce a quantity such that marginal cost is equal to marginal revenue (market price). There is perfect knowledge, factors of production are perfectly mobile and there are no barriers to entry.

The industry is in long-run equilibrium, when all firms make normal profits. Only in this case is there no incentive for firms to enter or leave the industry. In other words, MC = MR = AR = P = ATC. If firms make supernormal profits in the short run, new firms enter, shifting the industry supply curve to the right until price decreases, eliminating excess profits. If firms are making less than normal profit in the short run, some firms exit shifting the supply curve to the left so price increases until all remaining firms are making normal profits.

Perfect competition is productively and allocatively efficient but dynamically inefficient. Productive efficiency ensures minimum average costs while allocative efficiency means that the optimal amount is produced to maximize social welfare (consumer and producer surplus). Dynamic efficiency involves innovation which can improve quality and/or reduce costs. Perfect competition is dynamically inefficient because of free knowledge, which does not allow copyrights or patents.

2.1.3.3 Characteristics of Oligopolies

An oligopoly consists of a few firms who are price makers but the effect of a price change depends partly on the reaction of competing firms (strategic interaction). Various models have been studied in game theory including the Cournot oligopoly that involves simultaneous competition on Quantity, the Stackelberg oligopoly, which involves sequential

competition on quantity (sequential decisions on output by firms) and the Bertrand oligopoly with simultaneous competition on price.

An oligopoly is characterized by the fact that each firm is sufficiently dominant to influence the market, yet not dominant enough to ignore the actions of rival firms. Each firm's behaviour is therefore conditioned by its relationships with rival firms. This is the most common market structure in manufacturing. Oligopoly is usually measured with respect to concentration ratios. Perfect oligopoly exists when the product is homogeneous and imperfect when it is differentiated.

Another important characteristic of oligopolies is that prices are sticky (rigid) as they are in a monopoly. Firms face a kinked demand curve meaning that a price cut will be matched by rivals but a price increase may not, so price cuts are to some extent irreversible and can lead to price wars in which all suffer. Furthermore, price changes are expensive as they involve changing price lists and notifying customers as well as loss of consumer and retailer loyalty. Since cost curves are usually U-shaped because of the divisibility of fixed factors, firms can maximise profits by setting the profit-maximising price for normal demand. Variations in demand are then met by variations in output as opposed to price. Non-price competition involves competing on quality, product differentiation, after sales servicing and though marketing and distribution. Prices change when changes in costs or demand are expected to be permanent.

2.1.3.4 Collusive Oligopoly

Collusion refers to non-compete agreements between rivals to eliminate uncertainty and maximize joint profits. For example, firms may agree to maintain a common price or they may split the market and act as monopolists. Collusion can be tacit (informal) or explicit (formal). It is more likely to occur when there are few producers of a homogeneous product in an expanding industry with high barriers to entry (natural like EOS or man-made like predatory pricing) and with a dominant price leader which other firms follow. It comes to the expense of the consumer as it results in reduced output, higher prices, reduced consumer

choice as well as productive and allocative inefficiency. Technical economies of scale are also seldom achieved. A cartel is an organisation of producers like OPEC, in which producers limit competition by agreeing to restrict output and keeping prices high. Individual members of a cartel have an incentive to cheat by reducing their prices and increasing output.

2.1.3.5 Other Market Types

A monopoly involves only one firm selling a product or service. The firm maximizes its profit by producing a quantity at which its marginal cost is equal to its marginal revenue (MC=MR). This quantity is less than the optimal and results in a deadweight loss (net loss to social welfare compared to perfect competition). Producer surplus is maximized while consumer surplus is far less than optimal. The deadweight loss can be eliminated if the monopolist has the ability to apply perfect price discrimination, whereby the producer takes the entire surplus and each consumer pays an amount exactly equal to their willingness to pay. Some industries such as the army are natural monopolies meaning that an alternative model would not be feasible.

A duopoly is a special case of oligopolies in which only two firms compete. This can have interesting strategic implications on the Bertrand, Stackelberg and Cournot variations which are studied in game theory. An example is the PC industry where Macintosh and Windows are the two main participants.

Monopolistic competition includes many sellers of slightly differentiated products. An important characteristic is the lack of barriers to entry. This leads to more intense competition causing demand to be more elastic in the long run.

2.1.3.6 Classification of the Cape Industry

The cape industry is characterized by continuous heavy investments in improved ships and technologies. Short-run supernormal profits provide firms with the liquidity and the incentive to invest. Dynamic efficiency applies, as technology evolves, raising service quality and sophistication of operations. Technical EOS exist with increasing ship sizes but also financial EOS (cheaper borrowing for firms with higher revenues) favor big incumbent firms, particularly in high markets, helping them retain market share. Another entry barrier is the international safety management code (ISM), recently introduced by the IMO, which requires both the managing company and each ship in its fleet to be certified. In order to enter the industry, besides certification, one also needs to find experienced personnel to perform the required functions onboard and on shore, and wait up to several months for a ship to be delivered. In this sense, the cape market resembles oligopolistic structures. Furthermore, as shown by the market concentration ratios in Fig. 2.1-5, the top 50 owners own 3/4 of the world fleet. The industry could therefore actually be classified as an oligopoly.

On the other hand, the cape market is very competitive with no significant EOS as entry barriers on the fleet level. Having a fleet does not substantially reduce costs of operating each ship individually. Operators exit during market crises and new ones enter in market booms driving down supernormal profits. The latter was very pronounced during the past few years. Information flow and transparency is very high with real-time information on all ships, their characteristics and respective freight rates. Freight rates are uniform with little firm influence and only account for a small fraction of total cargo value. Firms operate with high productive efficiency, keeping costs down to remain competitive. These parameters show that the cape industry closely resembles perfect competition more than an oligopoly. Furthermore, due to the size of the market, collusion is very rare. Since the market is cyclical, prices are not sticky as in oligopolies and a kinked demand curve does not apply. As in perfect competition, the demand curve that each firm faces at any point in time is perfectly elastic.

One could also compare the industry to a monopolistic competition. Arguably, the services provided by firms are slightly differentiated based on the age and technology of the ship, its fuel consumption (paid by the charterer on period charters), reputation and track

record etc. Other similarities include the lack of significant entry barriers in the long run and the perfectly elastic demand curve faced by firms. Monopolistic competitive firms also face an elastic demand in the long run.

To conclude, the capesize bulk carrier industry behaves as a perfectly competitive market. However, the adjustment of supply is slow, resulting in the lack of normal profit equilibrium. Due to the continuous shifting of external factors, equilibrium is rarely sustained for considerable time at normal profit levels. Hence, there are periods of high investment and supernormal profits, or pronounced downward cycles.

2.1.4 Porter's 5 Forces Analysis

2.1.4.1 Introduction

Shipping is a very competitive and profitable industry. That is due to its high cyclicality and the inelasticity of supply which allows for very high short term profits. As we saw in Section, 2.1.2, the Capesize sector is fairly concentrated with the top 20 owners owning approximately half the world fleet. In this section, we will apply Porter's five forces to analyze the attractiveness of the industry:

1) Bargaining Power of Suppliers
2) Barriers to Entry
3) Threat of Substitutes
4) Degree of Internal Rivalry
5) Customer Power

The suppliers include the hired ship crew, the suppliers of spare engine parts, stores and food, and the providers of bunkers. However, note that under time charters, which are more common in Capes, bunkers are provided by the charterer. The customers are the

charterers who may be the cargo owners or intermediaries. Substitutes include existing and alternative transportation solutions for the same cargo, or alternative cargos.

2.1.4.2 Supplier Bargaining Power

- The dynamics between crews and ship-owners/managers are complex. The union of seafarers, ITF, has significant bargaining power and tries to maintain high standards and wages for crews. Its power has declined over the years but it has been known to arrest ships at ports following reports from its members
- Over the last 50 years, there has been a shift to crews from low cost countries. Deck crews are typically from the Philippines while Engineers are from former Soviet countries. Chinese operators use crews from China who are even lower cost, but due to language barriers, they are rare in non-Chinese companies
- In cases where a special flag is required, for the example in Jones Act trade which is only for US ships, the flag state may require a certain number of the crew to be of that nationality. The same applies with the Greek flag. This gives more bargaining power to the crew. However, there are "flags of convenience" such as the Panama, Malta, and Cyprus which have more lenient requirements
- As oil prices fluctuate daily, total transportation costs are impacted. The shipping company has limited power over the bunker suppliers. The ship can choose in which port to get fuel and bunker costs can also be hedged using derivatives. Note that fuel is covered by the charterer under period charters

2.1.4.3 Barriers to Entry

- High costs are involved in entering the market. CAPEX which include vessel acquisitions often prohibit new entrants in this sector. High operating expenses also require significant working capital
- Established relationships and a strong network is required for obtaining long term contracts at favorable rates is also very important. A new entrant has to establish the critical set of relations within the industry that will lead to profitable operations
- New entries also have limited access to loans with reasonable terms that are necessary to financing costly ship purchases. Lenders require established relations and a good reputation in the industry that is developed over time
- There are specialized companies providing technical management to owners who don't have a big enough fleet to justify managing their own vessels
- Economies of scale that established companies enjoy. These apply in financing, management costs, acquiring supplies and spare parts etc
- Brand identity of the company and of its classification society: High reliability is usually combined with IACS classification societies (DnV, ABS, BV etc) which leads to increased operating expenses
- Many cargo operators own their ships and limit the amount of cargo available for transport especially for new entries

2.1.4.4 Threat of Substitutes

- Seaborne transportation competes with mainland transportation (e.g. rail). However, seaborne trade is very cost effective and the transported volumes are much higher than feasible by other modes of transport. Substitutability of marine transportation is low and often impossible due to seaways

- The most important substitute for cargo owners is management of their own fleet of ships. This can be expensive as they lack the expertise and specialization, but it removes the market risk
- Another substitute is transporting cargo from closer locations to reduce ton-miles (e.g. China importing iron ore from Australia instead of Brazil)
- Port access limitations due to vessel size make smaller bulk carriers good substitutes. Their attractiveness will increase in 2014 after the Panama Canal is expanded to accommodate bulk carriers up to 120,000dwt
- Substitutes of coal for electricity generation include different energy sources such as oil natural gas and renewable energy

2.1.4.5 Degree of Rivalry

- Timing and competitive advantage are crucial and rivalry can be high between those competing for the same cargo. Differentiation in terms of reputation, ship age and reliability also play a role giving large companies the competitive advantage. This is supported by the industry concentration
- The volatile market can result in huge losses pushing companies to operate below cost and forcing them to shut down. The first to exit the market are usually companies that end up with low cash reserves and high leverage during a market crisis because of bad investment timing
- Reputation and relations with cargo operators are important. This requires long-term commitment to the industry and favors the big players
- Fixed costs are high and the value of an owning company lies mainly in its assets. Most of the value of an operating company lies in the management personnel

2.1.4.6 Customer Power

- Specialized vessels are often built (specialized ore carriers or Newcastlemax coal carriers etc.) to the specification of charterers, particularly when a long term charter is secured before the construction. This demonstrates the power of customers to shape the trends in the orderbook
- The Cape market ranges across all continents but the limited number of major charterers and the limited flexibility of the ships gives them bargaining power
- Demand is inelastic because reliability at the end of the supply chain is crucial. However, large iron ore companies try to hedge that risk by owning ships (backward integration), thereby removing the power of independent shipping companies
- Substitutes such as rail transport are limited, capital intensive, lack economies of scale and take time to construct. It is also costly to make changes in transportation needs by modifying the supply chain. This gives ship owners bargaining power

2.2 Demand for Capes

2.2.1 Economic Factors

Demand for shipping is closely related to the global economy. The domestic growth of any country requires imports and also increases its output thereby creating exports. A country's demand for shipping is therefore related to its gross domestic product (GDP). Fig. 2.2-1 shows how the GDP of China and the world average GDP has varied over the years.

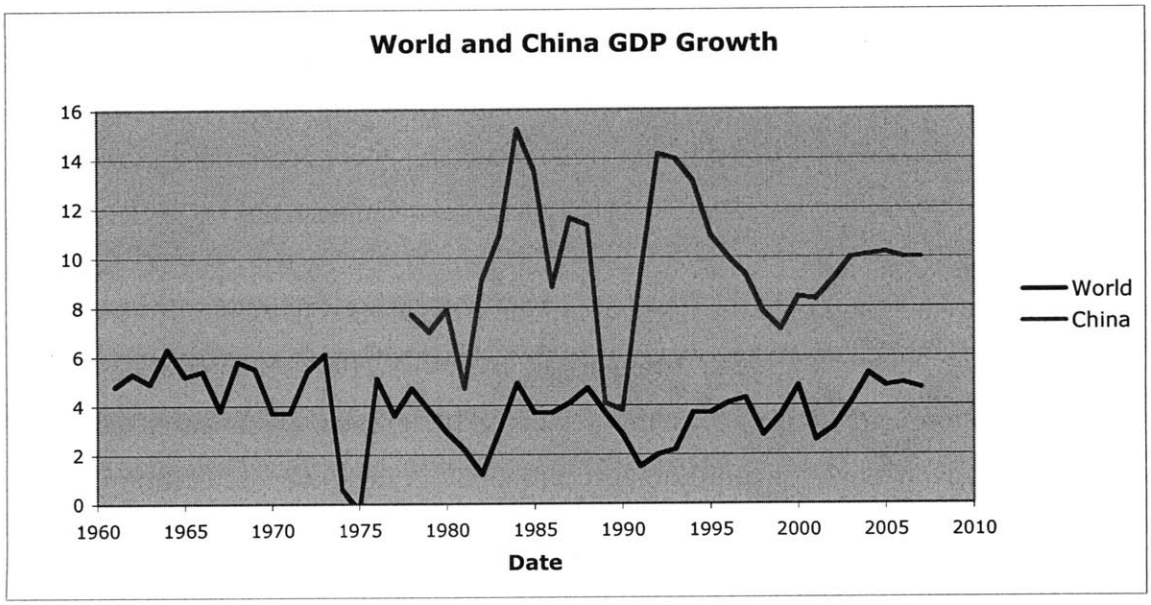


Fig. 2.2-1: World and China GDP Growth – using data from [Clarksons 2007a]

China is a developing country and therefore has a higher GDP growth rate than the world average. Its growth currently dictates the dry bulk shipping market and particularly the capesize market more than any other factor. The previous shipping boom was also driven by China's demand in 1995 when GDP was at high levels (see Fig. 2.1-9).

As one would expect, the world average GDP growth fluctuates less than that of China but is still far from stable and this has implications on the demand for shipping. Fig.

2.2-2 shows the world average GDP growth along with that of developing and advanced countries and the annual growth in dry bulk trade since 1997.

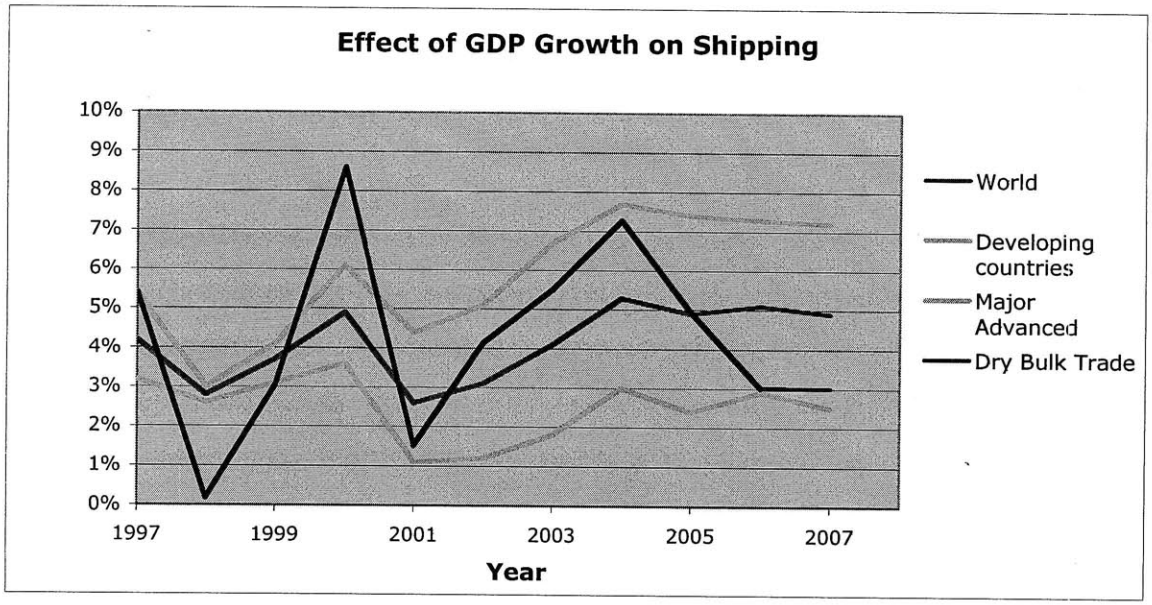


Fig. 2.2-2: Disproportionate effect of GDP on Shipping – using data from [Braemar 2007a]

It can see that not only is dry bulk trade related to GDP, but it is affected disproportionately with peak growth being as high as the GDP growth of developing countries and bottom growth being as low as the GDP growth of advanced countries. According to OECD, a slow down in European economic growth is expected from 2.6% in 2006 to no more than 2.2% in 2007. This is also supported by the unexpected slowing of the services sector (the largest sector in the European economy) in December and the reduction in manufacturing and retail sales [Clarksons 2007d]

GDP accounts for a number of sectors such as housing and services. The most relevant to shipping however is industrial production because it translates directly to imports and exports creating demand. China and the USA are big markets and therefore have a greater effect. Fig. 2.2-3 shows the industrial production of various big markets.

One can see by comparing Fig. 2.2-2 and Fig. 2.2-3, that industrial production has a similar trend to GDP growth. Chinese Industrial production has been high overall while Europe and the USA have been growing at similar levels.

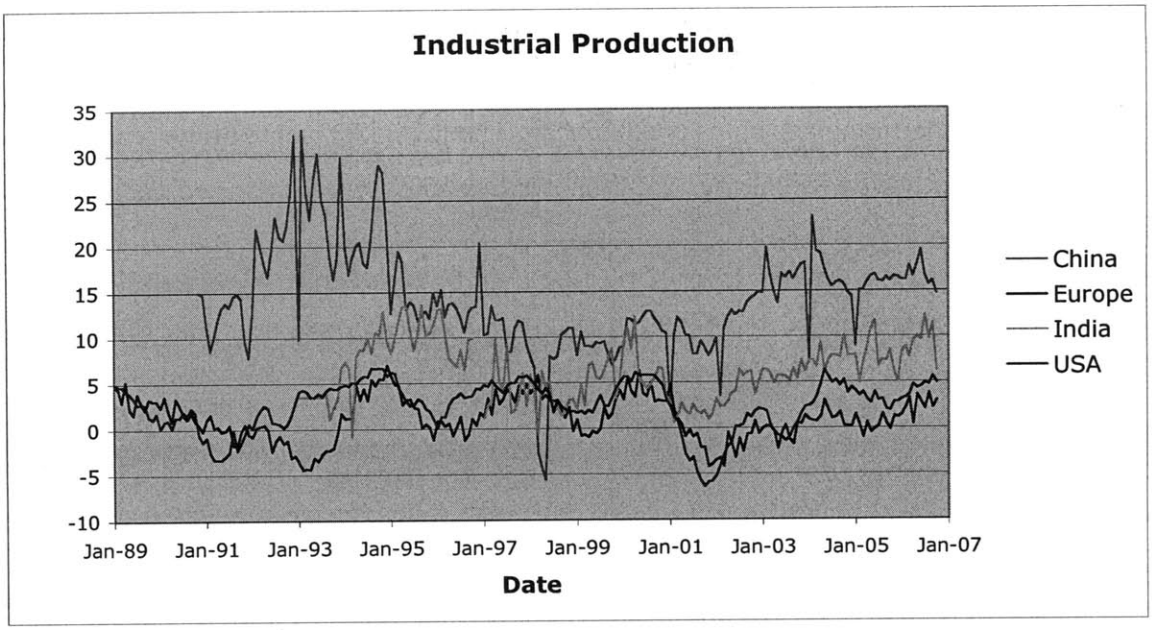


Fig. 2.2-3: Industrial Production Increase – using data from [Clarksons 2007a]

Economic activity is also closely linked to shipping. The stock market crises in 1998 and 2002 both resulted a shipping crisis in 1999 and 2002 respectively. Fig. 2.2-4 shows the major world market Indices. These are affected by GDP growth.

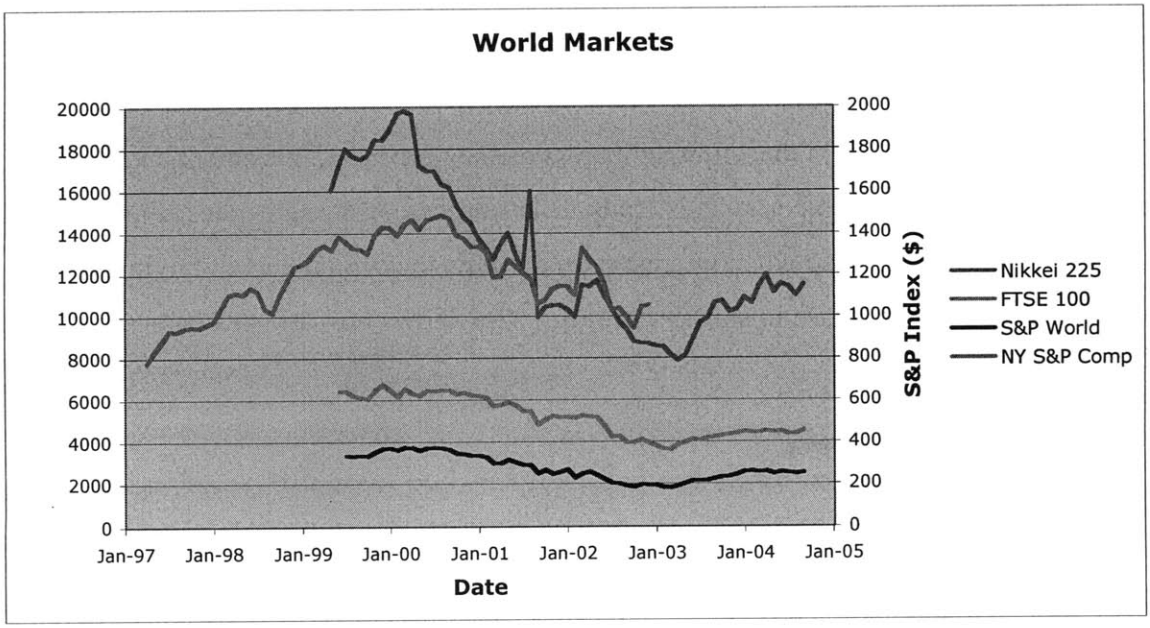


Fig. 2.2-4: The Major World Market Indices – using data from [Clarksons 2007a]

USD exchange rates affect the market in particular because shipping business is conducted (and measured) in USD. A low USD boosts the shipping market because commodities, ship chartering and ships are all cheap. The low USD is one of the reasons why the market is currently very high. Fig. 2.2-5 shows how the USD has varied against other important currencies.

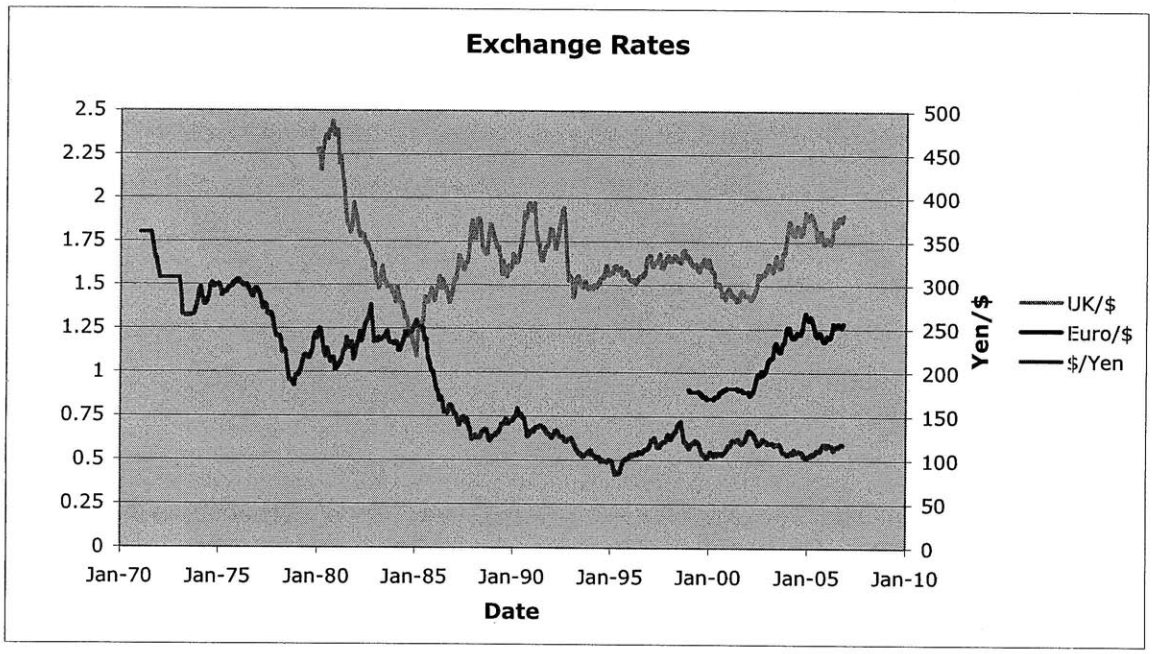


Fig. 2.2-5: Variation of the USD against the other important currencies - using data from [Clarksons 2007a]

Low interest rates help the shipping market as they promote investment and business, which creates imports and exports. This leads to an increase in freight rates. Furthermore, nearly all ships have a debt, so when interest rates are low, the capital cost of buying a ship is lower. This leads to an increase in ship prices. Fig. 2.2-6 shows how LIBOR has varied since the beginning of the 1990s.

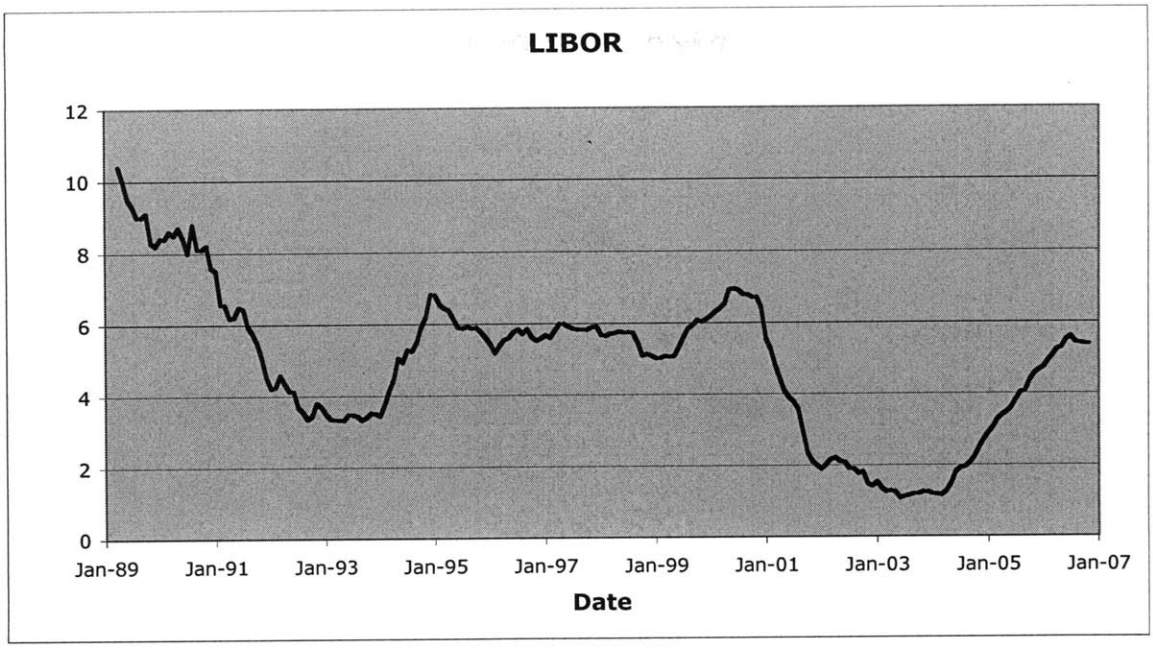


Fig. 2.2-6: LIBOR since 1989 - using data from [Clarksons 2007a]

2.2.2 Dry Bulks

Transportation of commodities such as iron ore, coal and grain typically accounts for a small percentage of total cost while profit margins on finished steel are relatively high (UNCTAD 2005). Furthermore, though there are many owners of capes and PMXs, there are no competing transportation modes. This makes demand relatively inelastic for the industry as a whole, but very elastic as perceived by each individual owner.

Due to the existence of combination carriers or Ore Bulk Oil vessels (OBOs), which constitute part of the dry fleet, the demand for oil transportation also plays a role. Demand for oil transportation is partly met by combination carriers and therefore translates to dry bulk demand. As the number of combination carriers is decreasing, their effect is becoming less significant. Fig. 2.2-7 shows this trend since the beginning of the 1980s, when there was a larger number of OBOs

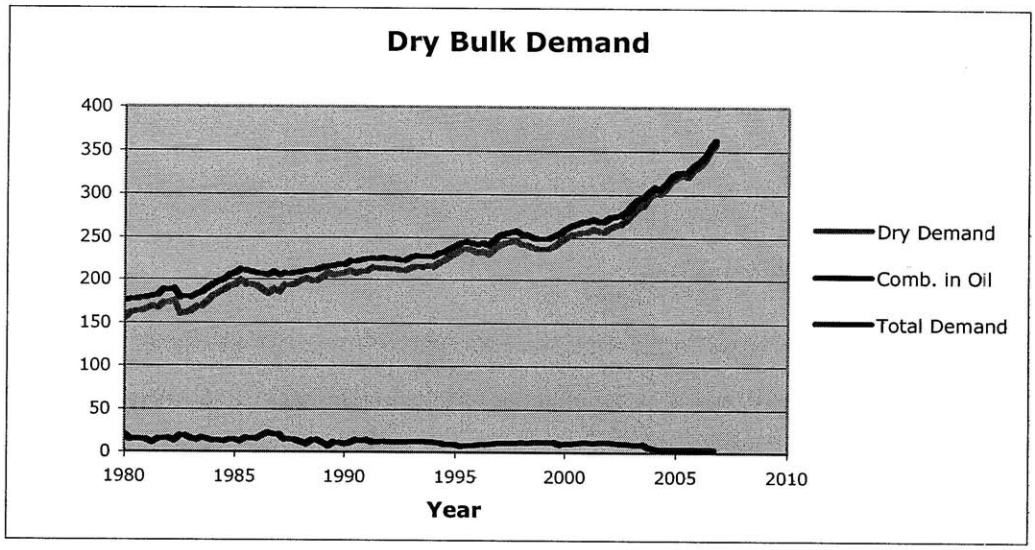


Fig. 2.2-7: The Effect of Oil Demand on Dry Bulk Demand – using data from [Marsoft 2007a]

As shown in Fig. 2.2-8, capes are used mainly in the transportation of iron ore and coal. Fig 18 shows the increase in global demand for iron ore and coal along with the total demand for dry bulk cargos since 1980.

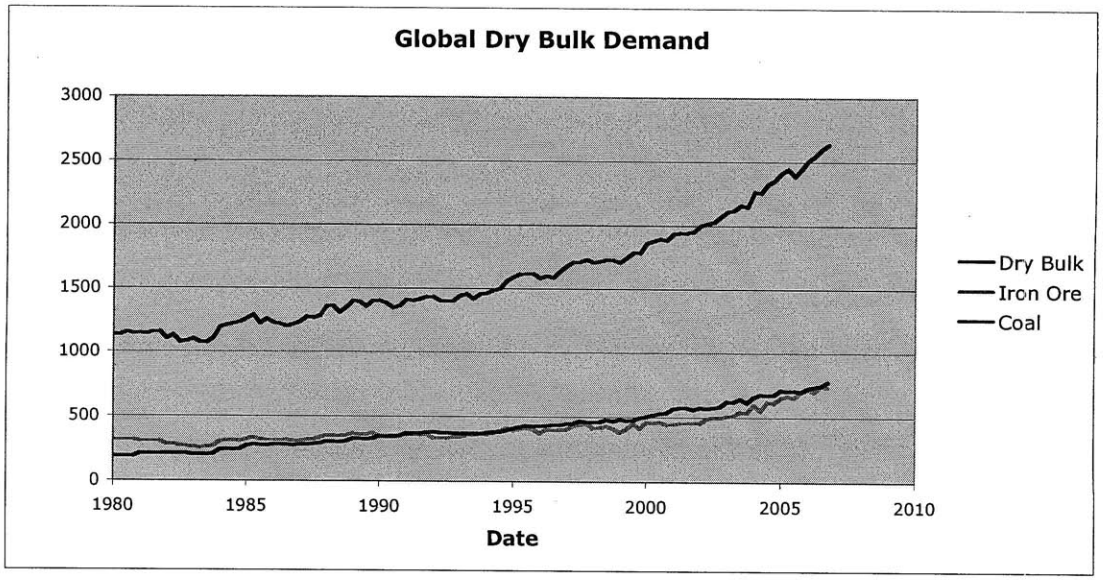


Fig. 2.2-8: Global Demand for Dry Bulk, Iron Ore and Steam Coal [Marsoft 2007a]

The coal that is transported in capes is either metallurgical or steam coal. Metallurgical coal is used with iron ore to produce steel while steam coal is used in power

plants to produce energy. A large fraction of the cargo transported in capes is therefore derived from the demand for steel. Fig. 2.2-9 shows the steel related cargos and steam coal as a percentage of total dry bulk cargo for various major countries, the world average and for capes.

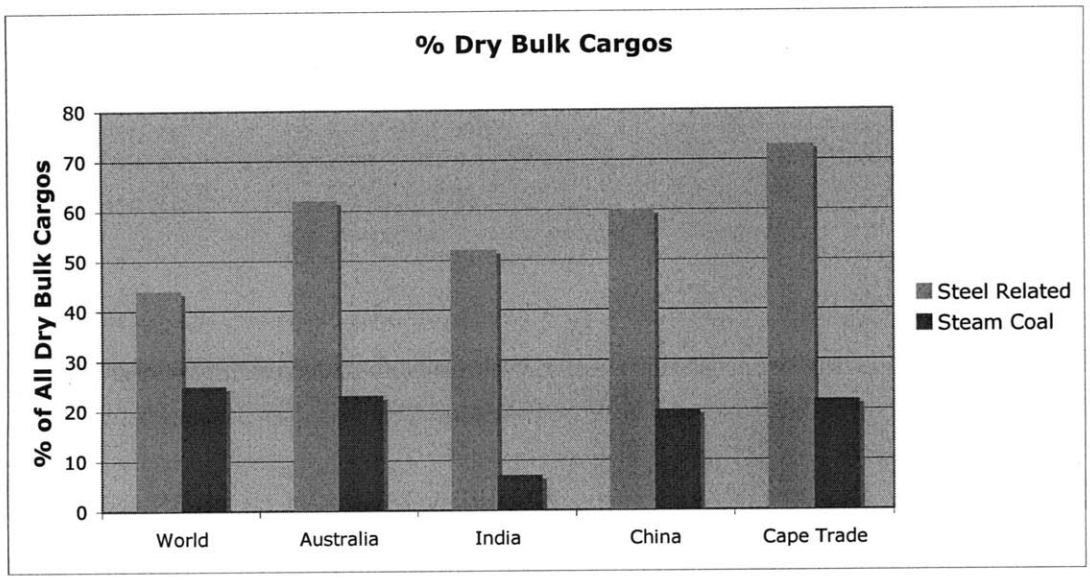


Fig. 2.2-9: Steel Related Cargos and Steam Coal as a fraction of Dry Bulk Cargos – Using data from [Braemar 2007a]

As shown in Fig. 2.2-9, steel related cargos account for a significant fraction of dry bulk trade, particularly for the major traders, while capes are heavily involved in their transportation. Demand for steel is therefore critical for capes even though steel is usually transported in handymax vessels. Capes are also used occasionally in the transportation of grain. Fig. 2.2-10 Shows the global demand for cape cargos along with the demand for steel since 1980.

As shown in Fig. 2.2-9 and Fig. 2.2-10, there has been a steady increase in demand for all cargos transported by capes, particularly steam coal and iron ore. Fig. 2.2-11 shows how the world consumption of steel and steam coal has increased since the 1990s and how it is expected to increase until 2015.

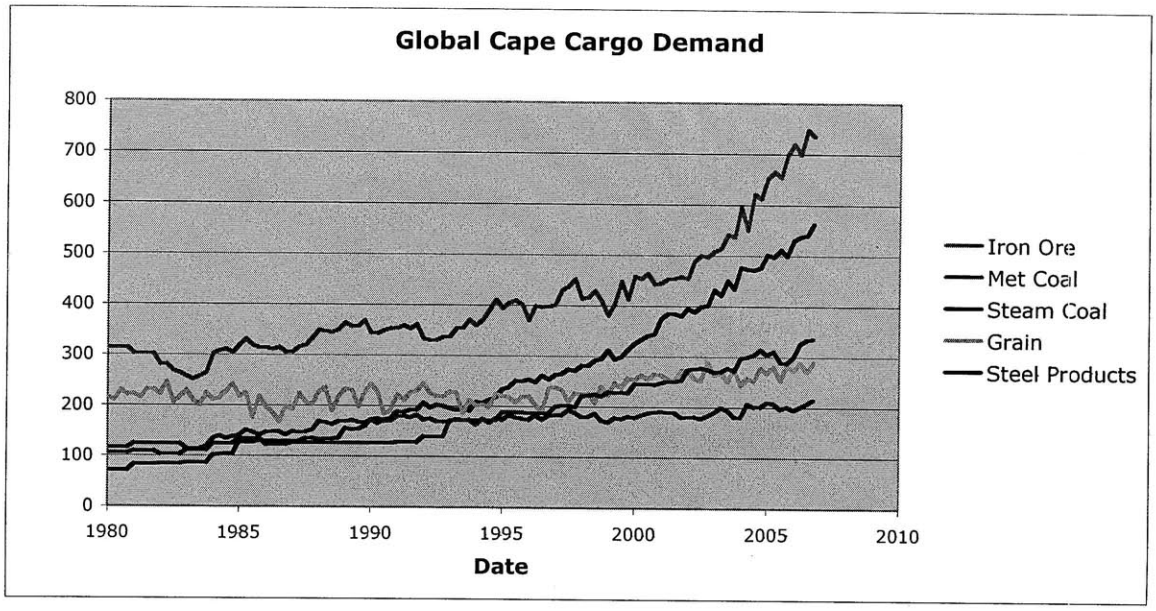


Fig. 2.2-10: Global Demand for Cape Cargos and Steel – using data from [Marsoft 2007a]

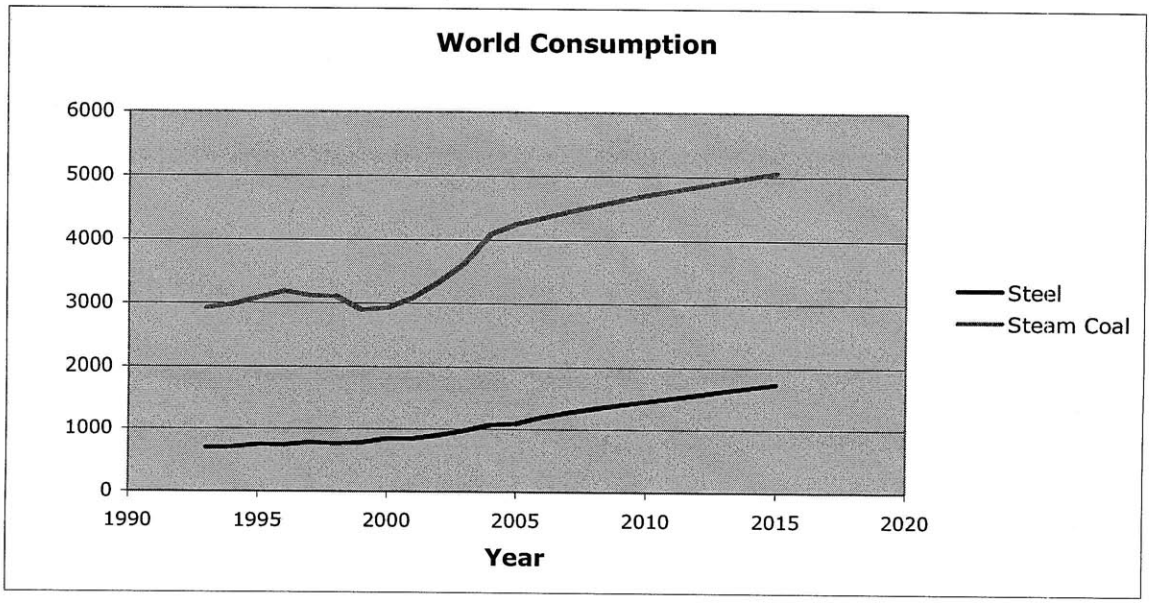


Fig. 2.2-11: World Consumption of Steel and Steam Coal using data from [Braemar 2007a]

These projections suggest a very high demand for dry bulk shipping, particularly for capes over the next ten years. According to current data, iron ore trade is expected to grow by 5% to 10% per year and dry bulk trade is expected to grow by at least 3% per year until 2015 while China and India are the biggest drivers of the market [Braemar 2007c]. China actually

accounts for about one third of global iron ore imports and over a quarter of the world's steel production [UNCTAD 2005]

2.2.3 Iron Ore

Iron ore transportation has been increasing steadily over the past 10 years and the fraction transported by sea has increased substantially since 2000 as shown in Fig. 2.2-12.

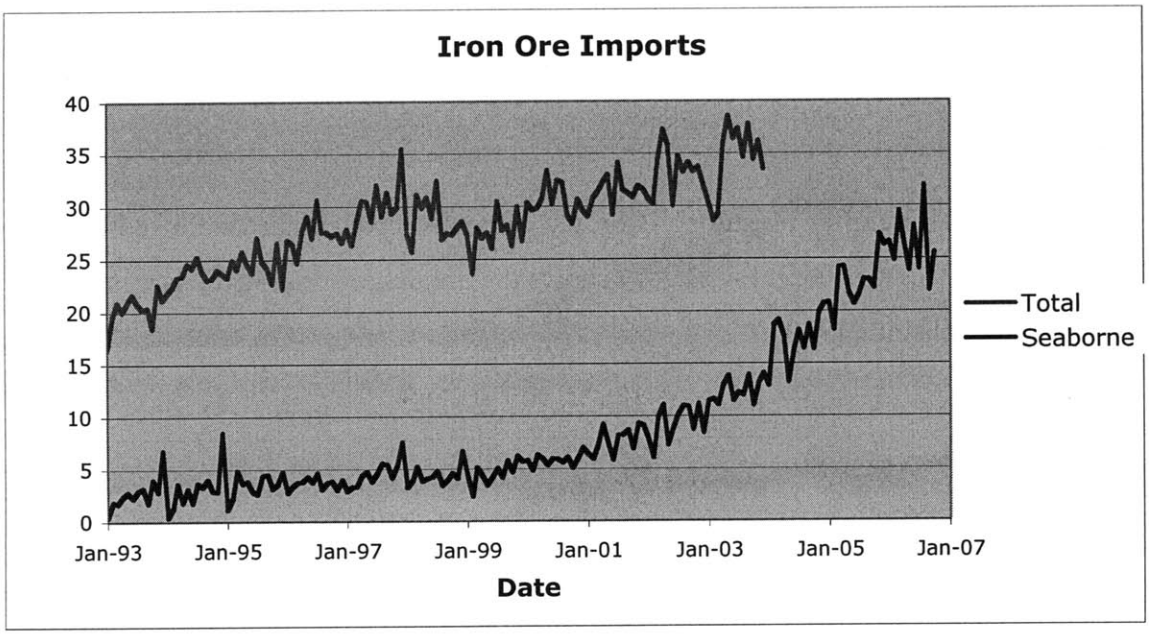


Fig. 2.2-12: Total and Seaborne transportation of Iron Ore - using data from [Clarksons 2007a]

China's expansion since the start of the century is the driving force behind the great increase in demand for seaborne iron ore that has led dry bulk freight rates to unsurpassed values over the past few years. This is clearly demonstrated in Fig. 2.2-13, which shows the annual imports by the largest importers and the world total since 1980.

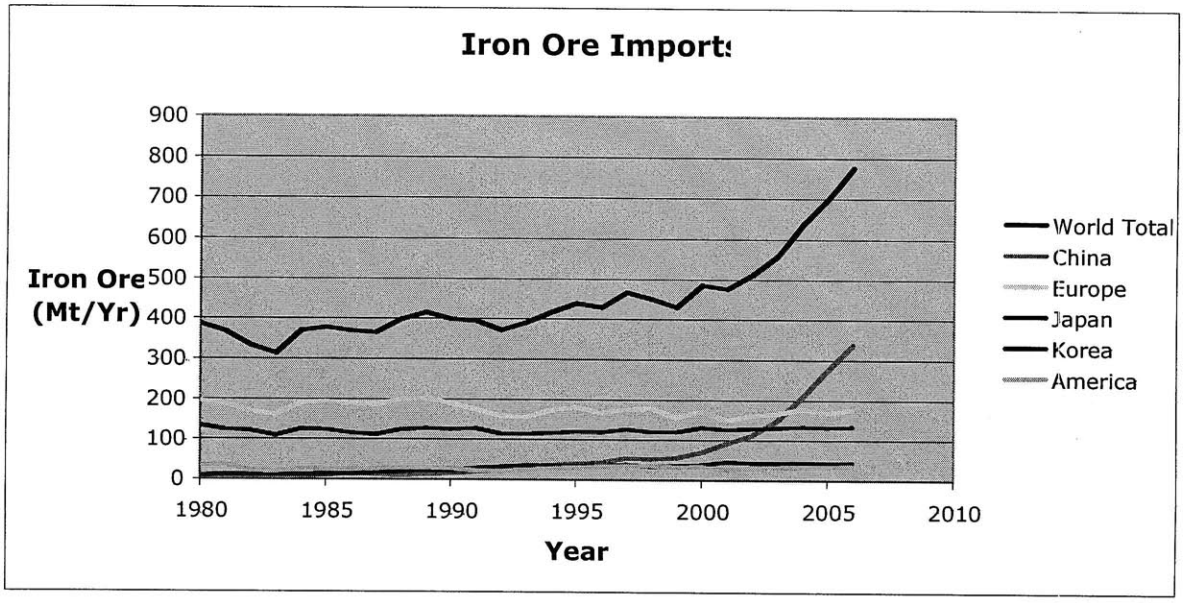


Fig. 2.2-13: Annual Iron Ore Imports of today's 5 Largest Importers and the World Total Since 1980 using data from [SSY 2006a & SSY 2006c]

The largest importer in Europe is by far Germany (Rotterdam), followed by France, Italy and the UK [SSY 2006a]. Fig. 2.2-14 shows the annual exports by the largest exporters and the world total since 1980.

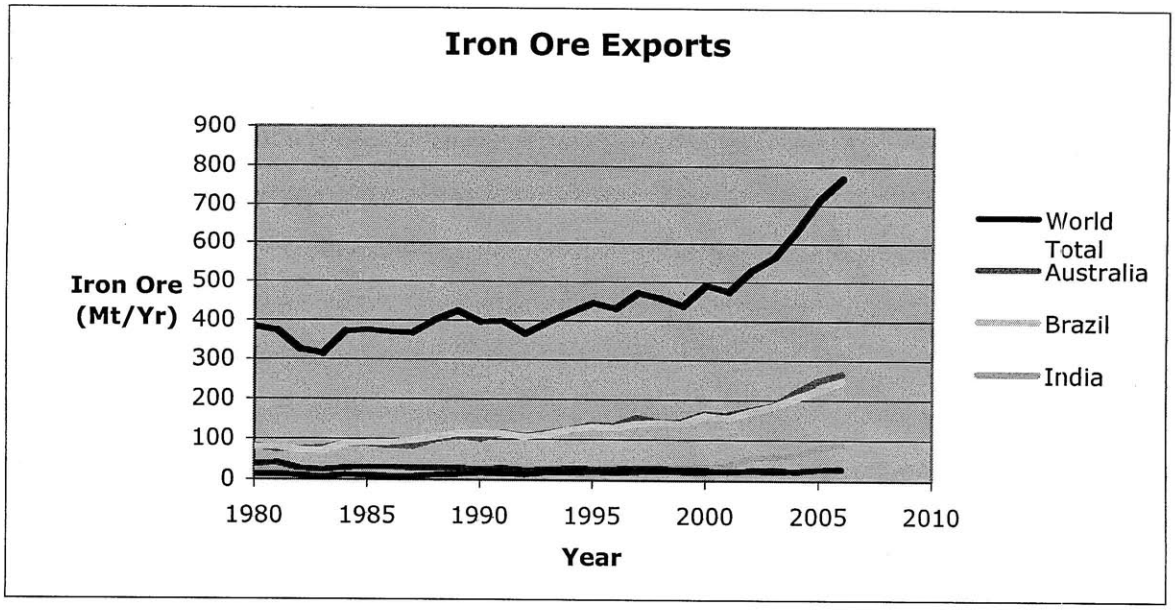


Fig. 2.2-14: Annual Iron Ore Exports of today's 5 Largest Exporters and the World Total Since 1980 - using data from [SSY 2006a & SSY 2006c]

Fig. 2.2-15 shows the monthly imports of the world's greatest importer since 2002, just before the start of the ongoing shipping boom. Fig. 2.2-16 shows China's monthly imports for each year since 2004 superimposed on the same graph.

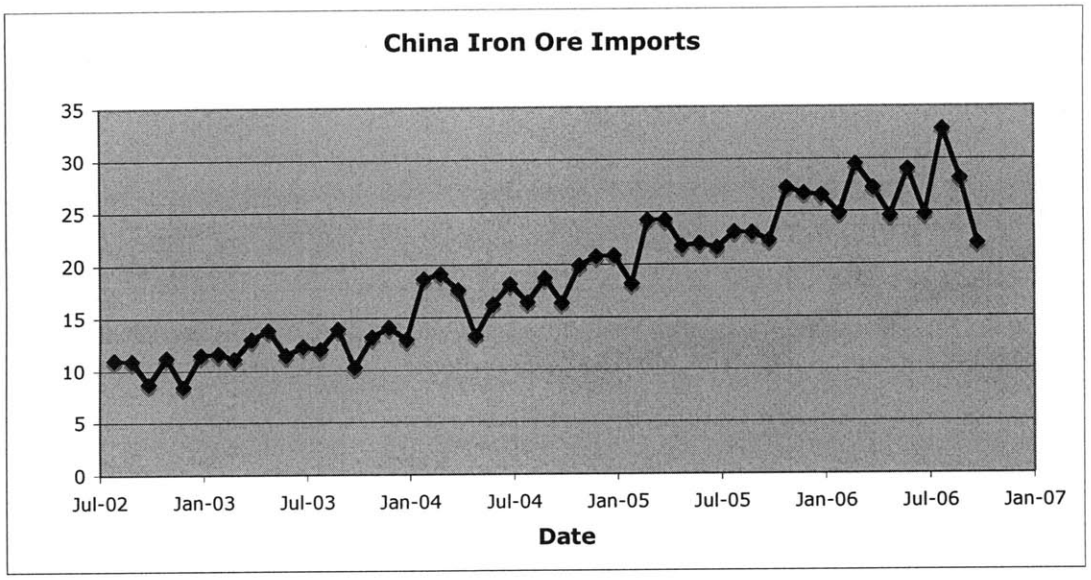


Fig. 2.2-15: Iron Ore Imports by the World's Geatest Importer since 2000 – Using data from [Doll 2006 & Braemar 2006]

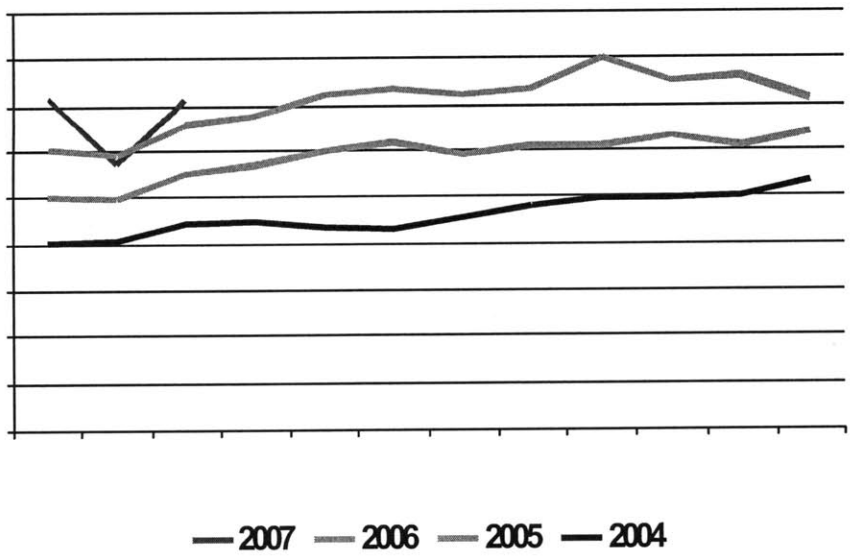


Fig. 2.2-16: China's Monthly Iron Ore Imports Each Year Since 2004 [Clarksons 2007b]

Besides importing, China's internal output of iron ore has also increased significantly to facilitate its rapid expansion. Fig. 2.2-17 shows the Chinese annual iron ore output and imports along with projections until 2010 and the equivalent number of additional capes required in the world fleet to meet the demand.

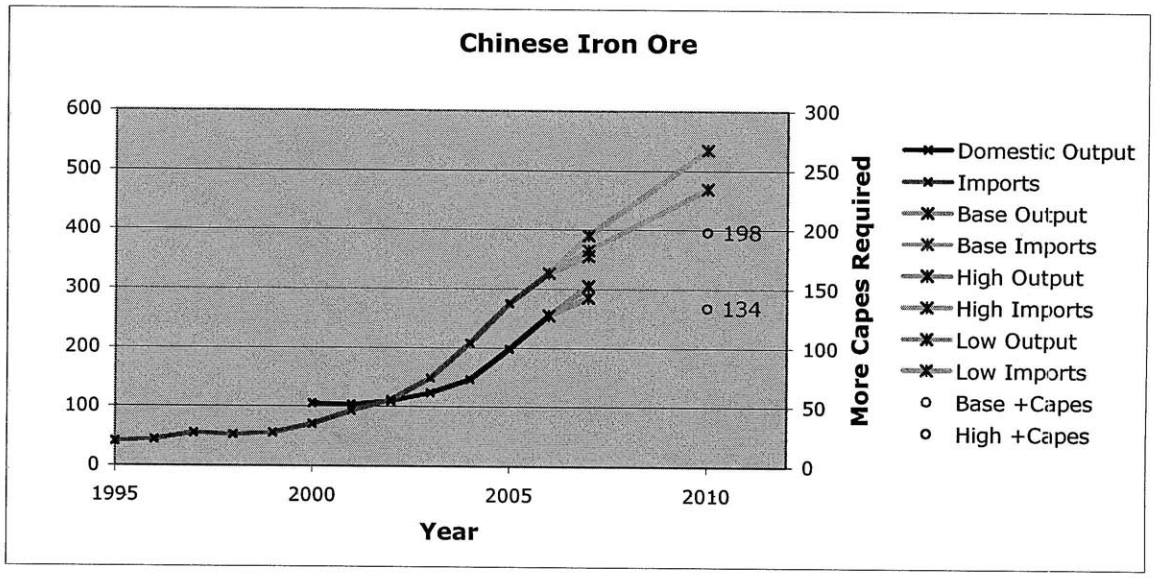


Fig. 2.2-17: Chinese Output and Imports of Iron Ore with Projections until 2010 and Estimated Additional Capes Required – using data from [SSY 2007a]

Based on simple calculations, an additional 134 to 198 capes will be required to meet the Chinese demand for iron ore imports in 2010 according to the projections. Chinese iron ore is of low Fe-content and its production costs are about 45 - 60 $/ton. This is high enough to justify the imports from Brazil and Australia who are producing at a cost of 10 - 15 $/ton [Carksons 2006b].

Domestic Chinese production is expected to peak at about 550Mt [Carksons 2006b]. Pig iron and steel production are increasing while stocks will be required for a better negotiation base for next year so imports are expected to increase substantially. Port stocks are currently 40Mt and the capacity is 60.5Mt [Clarksons 2006b]. Fig. 2.2-18 shows China's iron ore imports by country along with projections until 2015 by *Braemar Seascope Ltd.*

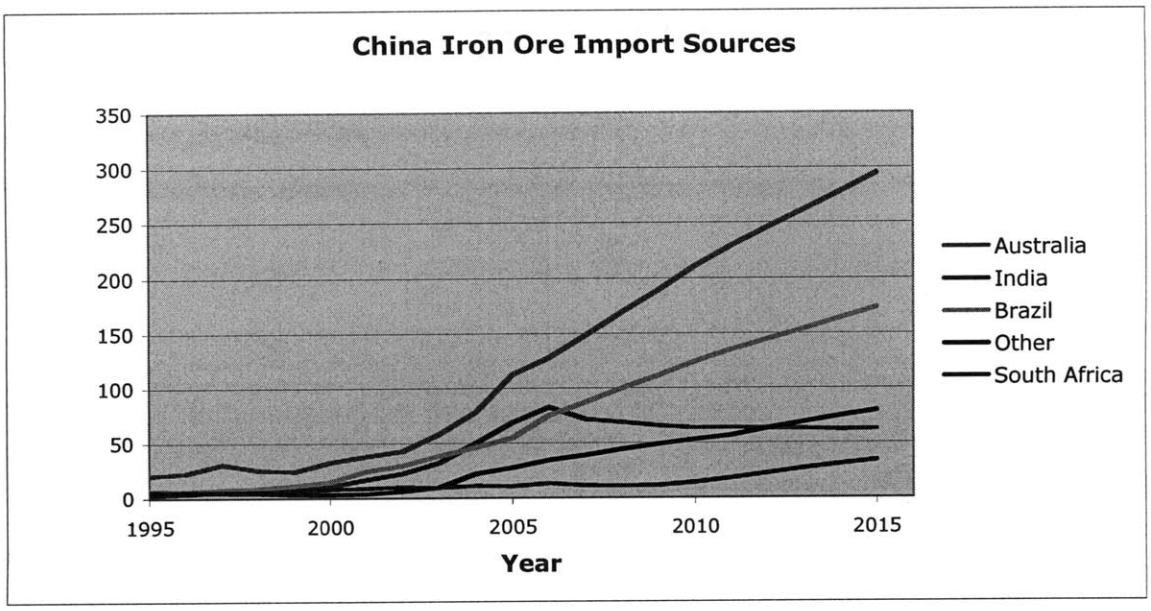


Fig. 2.2-18: Chinese Iron Ore Imports by Country – using data from [Braemar 2007a]

Brazilian Iron Ore is of a higher grade than the Australian and is therefore more desirable. The China - Brazil trade is also better for Capesize demand as the Iron Ore is imported over a longer distance. Most of Indian iron ore is on spot and fluctuates according to competitiveness with Chinese prices. It also competes with domestic needs and its exports are declining due to internal consumption. It is relatively cheaper for China to import from India than Brazil but India is finding it difficult to get this trade because of fixed contracts with Brazil.

The demand for marine transportation of iron ore is forecasted to keep increasing for a number of years as illustrated in Fig. 2.2-19. China is expected to continue expansion throughout the current decade and other countries such as India or Brazil are expected to follow and gradually become importers. Demand may therefore remain at high levels for a number of years.

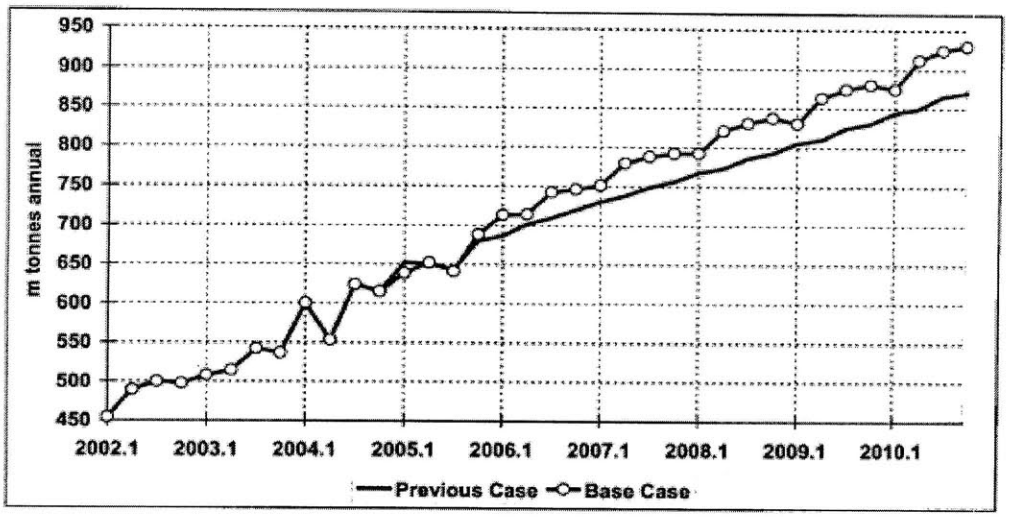


Fig. 2.2-19: Total Global Iron ore Imports for the Current Decade [Marsoft 2006]

2.2.4 Coal

Unlike iron ore, which is transported primarily in capes and the larger specialized ore carriers, coal is also transported in smaller bulkers. Fig. 2.2-20 shows the share of each bulk carrier size group in the transportation of coal.

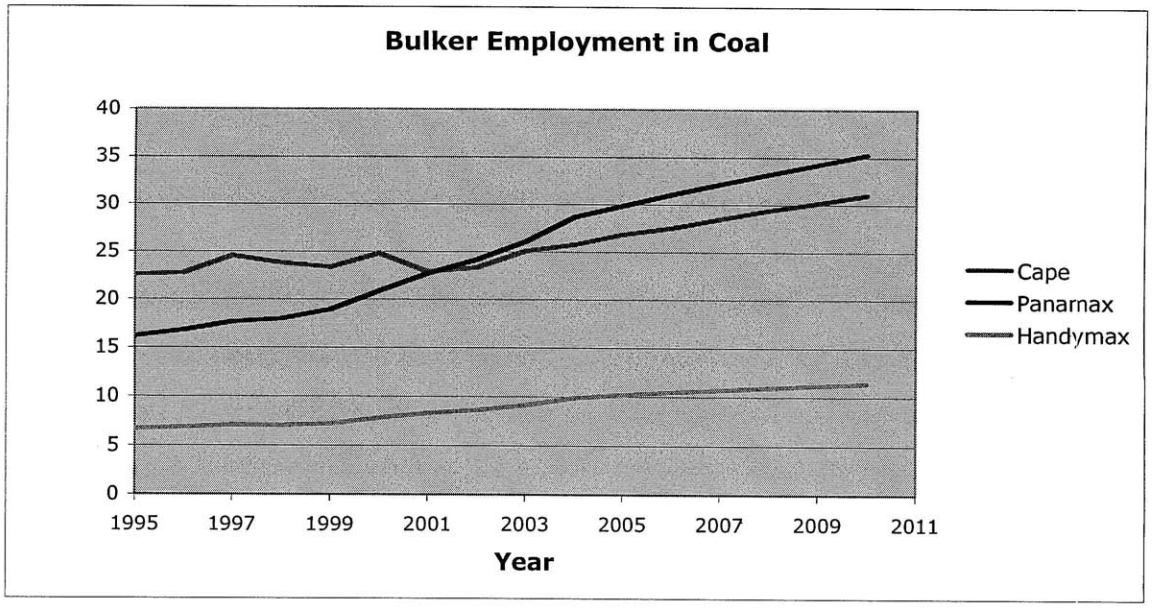


Fig. 2.2-20 Coal Transportation by Bulk Carrier Type with projections - using data from [Braemar 2007a]

The amount of coal transported is increasing steadily and this is expected to continue for all bulk carrier types. The increasing demand for steel creates demand for the transportation of metallurgical coal, which is required for its production. Meanwhile, power plants around the world are converting to coal because of the high oil prices. This creates demand for the transportation of steam coal. Fig. 2.2-21 shows the monthly imports of the major coal importers and Fig. 2.2-22 shows the monthly exports of the major exporters since the early 1990s.

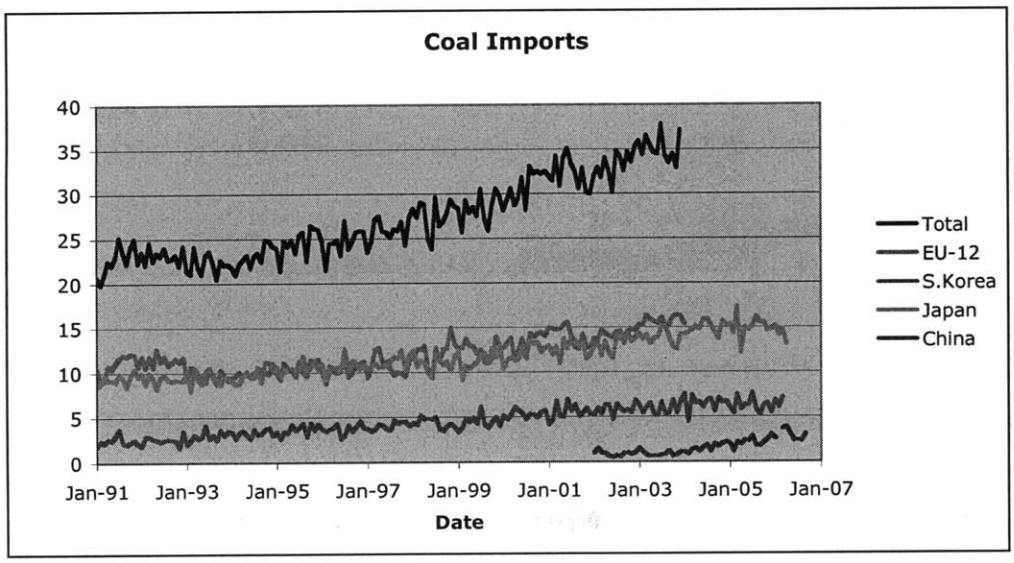


Fig. 2.2-21: Imports by the Major Coal Importers – using data from [Clarksons 2007a]

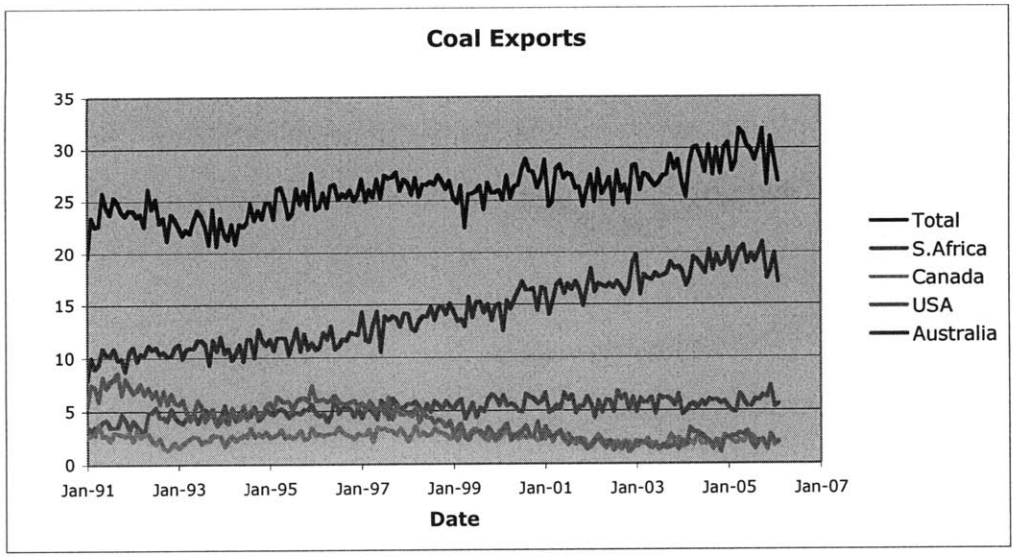


Fig. 2.2-22: Exports by the Major Coal Exporters – using data from [Clarksons 2007a]

Though China appears not to be playing a significant role in the coal trade, quite the opposite is actually happening. Its annual coal production is about 1bn tonnes and most of it is consumed internally. Chinese coal trade balances however have a big impact on the market. Fig. 2.2-23 shows China's imports and exports of coal since the start of the shipping boom in autumn 2003.

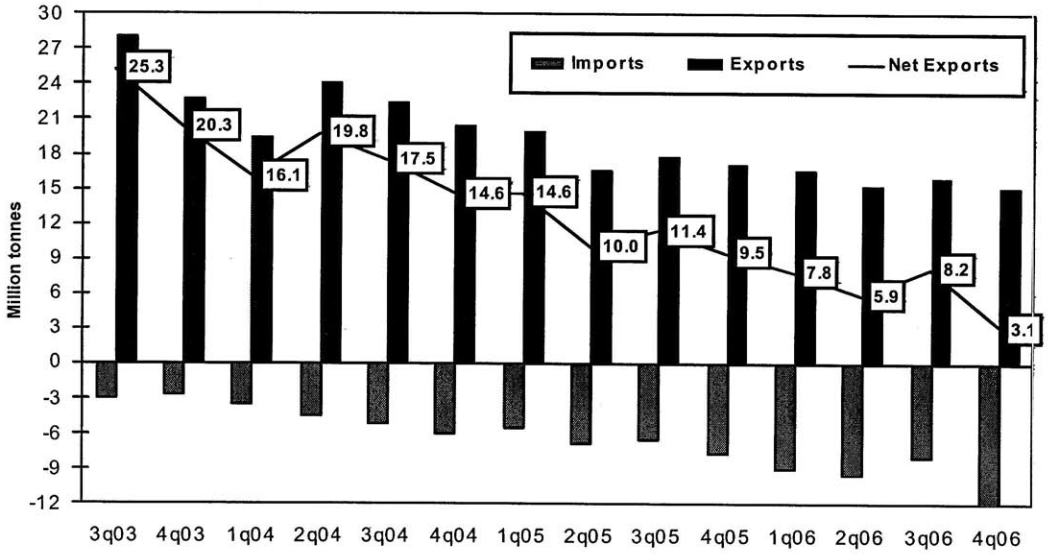


Fig. 2.2-23: China's Coal Imports and Exports since 2003Q3 [SSY 2007b]

China used to export to nearby countries but is increasingly consuming its produce and becoming an importer. This has caused other countries to go to Australia for imports leading to high congestion levels in Australian coal ports. This is currently the most important factor responsible for the very high temporary charter rates. The steady decrease in Chinese coal exports, is clear in Fig. 2.2-24, which shows the Chinese dry exports since 2002. The increase in steel exports is also evident.

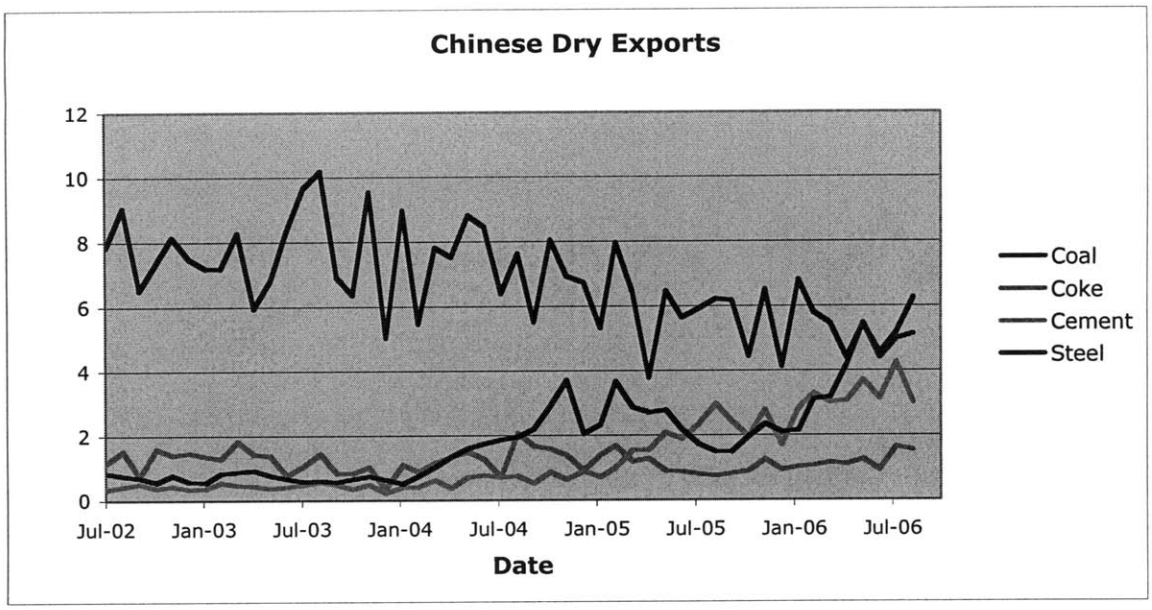


Fig. 2.2-24: Chinese Dry Exports since 2002 – using data from [Braemar 2007a]

2.2.5 Steel

Though capes do not transport steel per se, its high demand has resulted in growing trade of steel-making raw materials and this has had a big impact on the cape market. The strong increase in steel production led to increased iron ore imports in 2006 and steel is expected to continue to drive the market over the next few years. Fig. 2.2-25 shows the monthly production of the major steel producers since the early 1990s along with the steel trade weighted index.

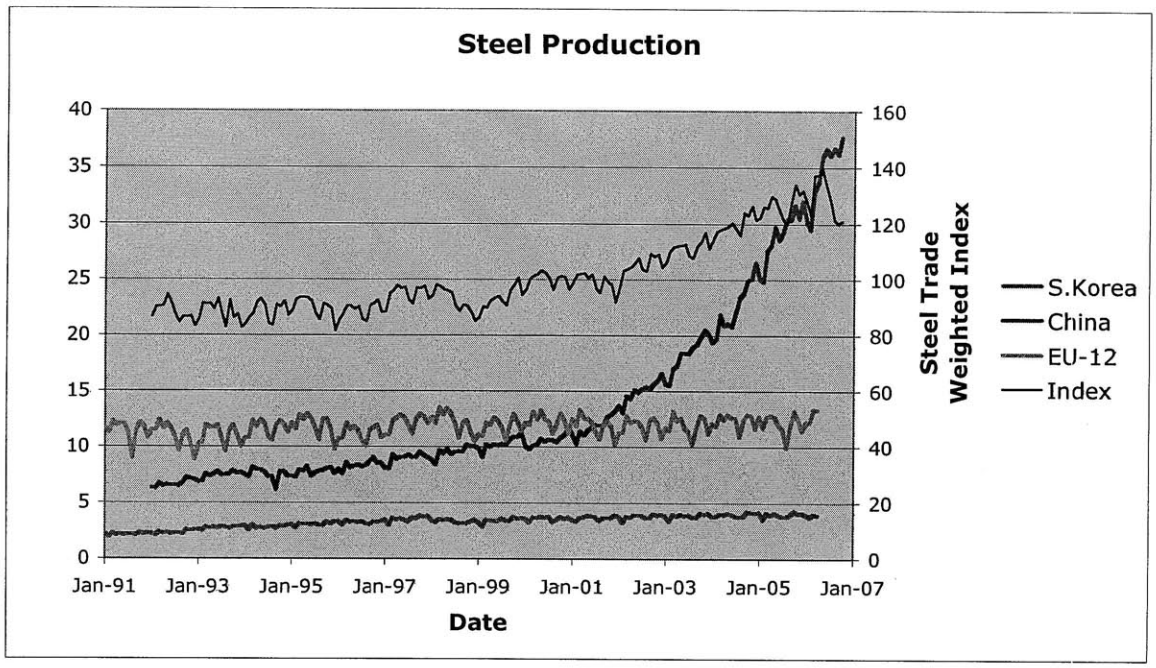


Fig. 2.2-25: Steel Production by the Major Steel Producers – using data from [Clarksons 2007a]

As shown in Fig. 2.2-26, China is responsible for the increase in global steel production since 2002 and is expected to be the driver well into the future according to current projections.

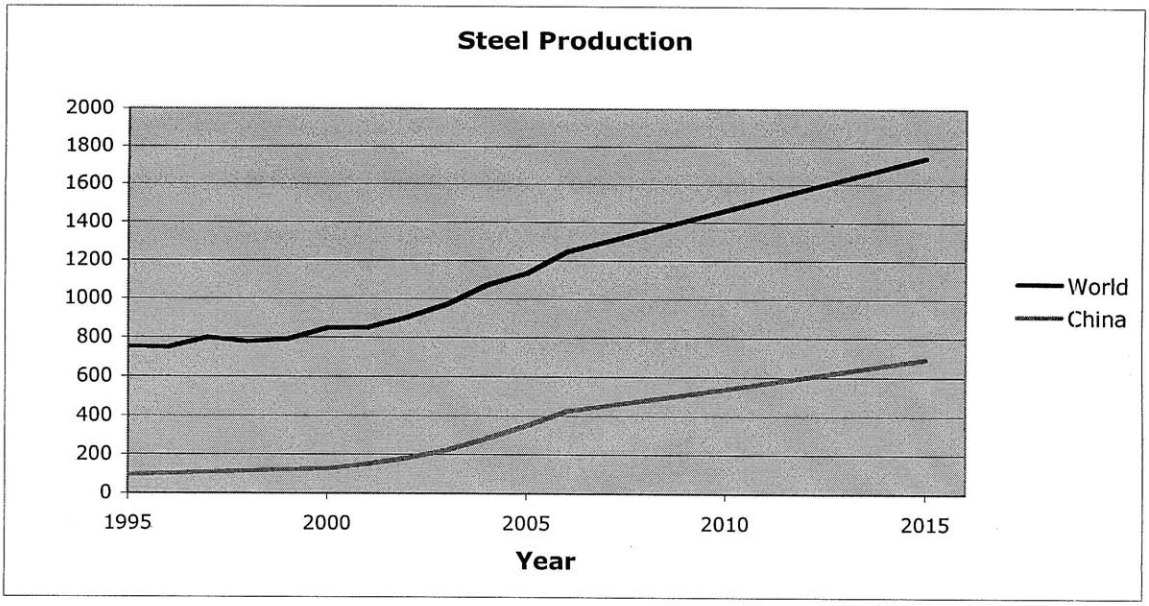


Fig. 2.2-26: Global and Chinese Steel Production – using data from [Braemar 2007a]

China currently accounts for 8.9% of steel output for the international market [Clarksons 2007b]. A large amount of its steel production is also consumed internally. Fig. 2.2-27 shows the amount of steel used domestically and that which is exported from China each year since 2001.

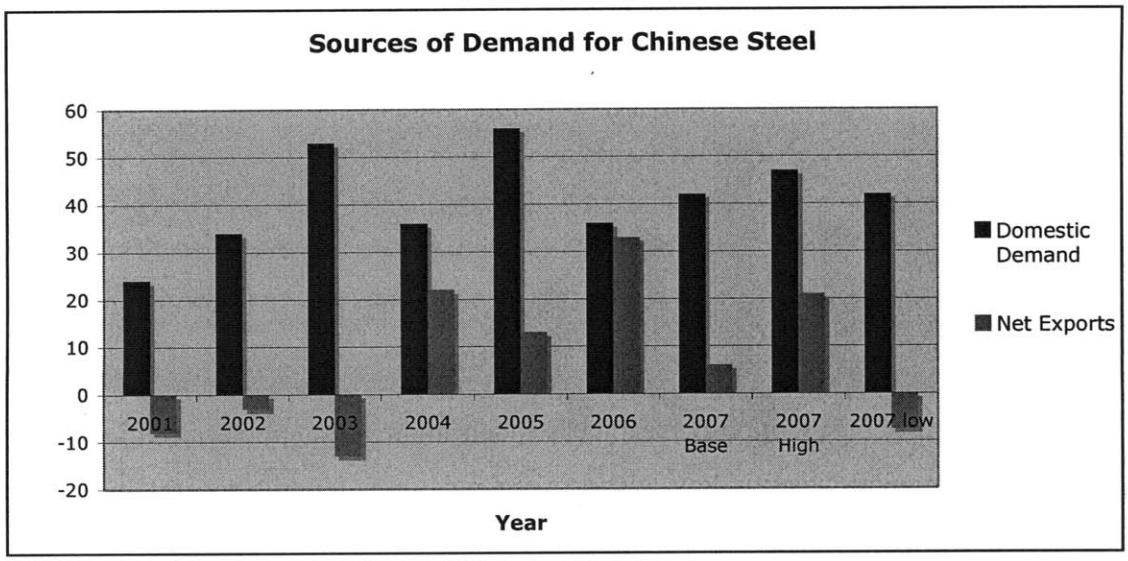


Fig. 2.2-27: Sources of Demand for Chinese Steel Production – using data from [SSY 2007a]

It is clear from Fig. 2.2-27 that Chinese steel production depends heavily on both the internal and the global markets. Fig. 2.2-28 shows the annual percentage growth in China's domestic steel demand and steel exports along with base, high and low scenario projections by *SSY Shipbrokers Ltd.*

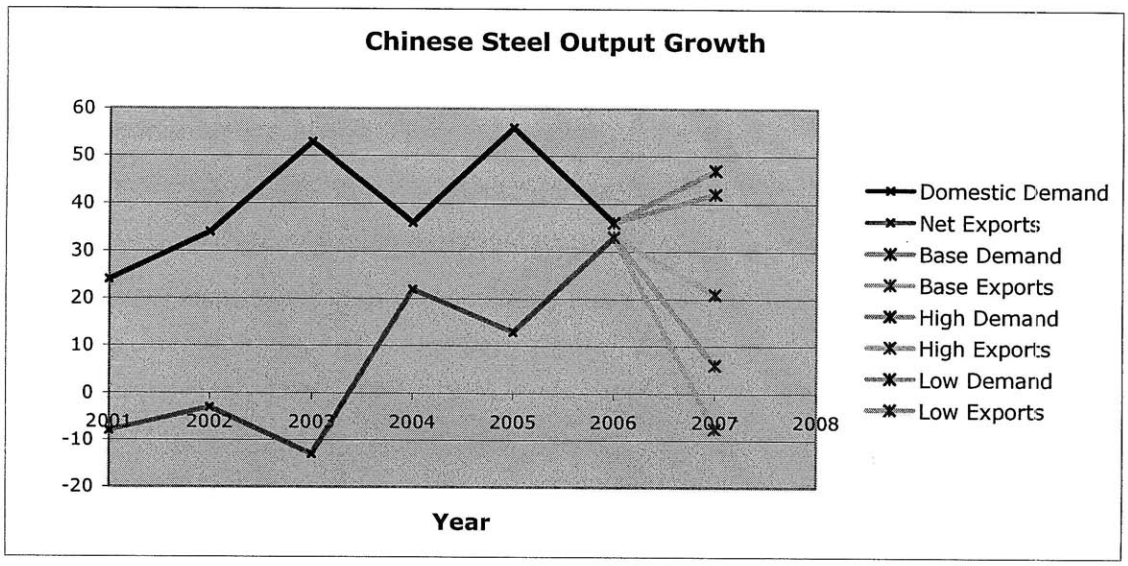


Fig. 2.2-28: Chinese Steel Demand and Export Growth – using data from [SSY 2007a]

China's steel consumption per capita is much higher in the coastal regions, but the average is 269kg/capita, which is low relative to its neighbors [Clarksons 2006b]. The same applies to India. Fig. 2.2-29 shows the consumption per capita and the population of various countries including China and India.

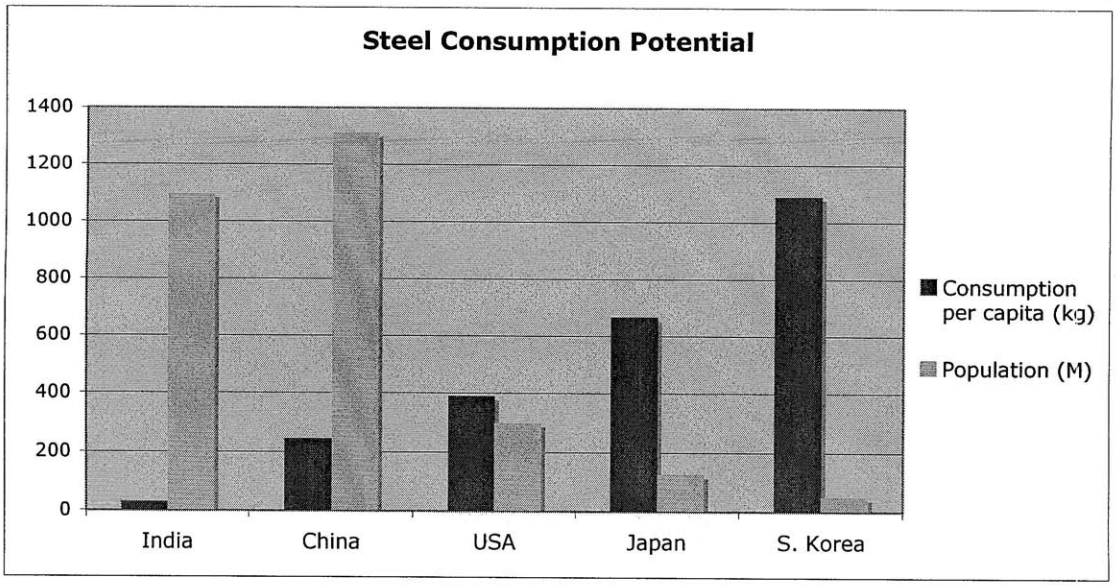


Fig. 2.2-29: Steel Consumption Potential – using data from [Braemar 2007a]

The big difference in consumption per capita of China and India with the other countries, combined with their high population indicates that there is potential for very high demand for steel as they develop and catch up (in consumption per capita). Fig. 2.2-30 shows previous trends and current projections of steel consumption per capita and population for China and India until 2015.

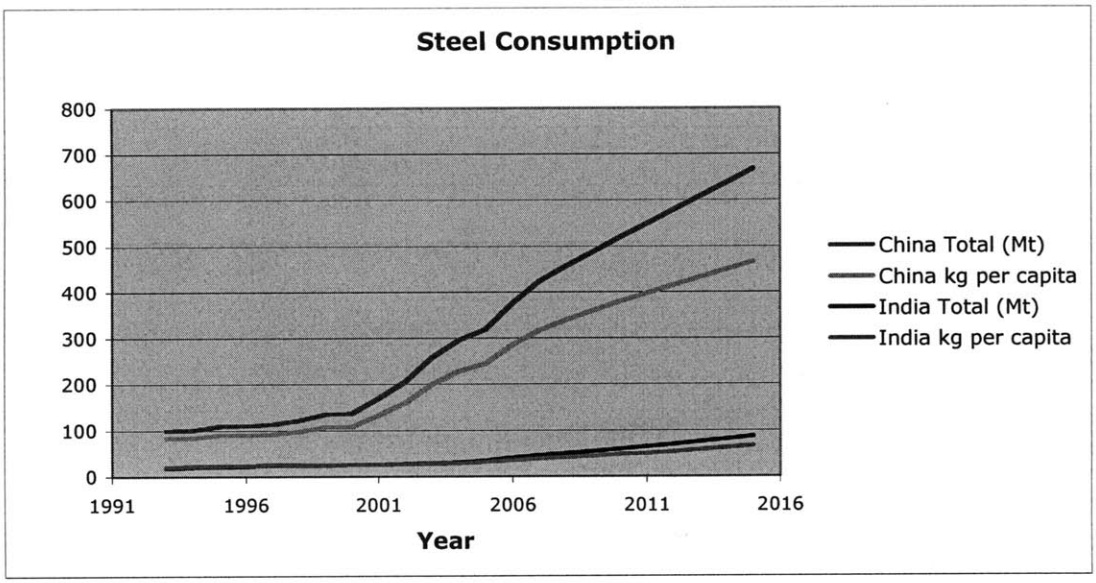


Fig. 2.2-30: Chinese and Indian Consumption per Capita and Population Trends – Using data from [Braemar 2007a]

According to the National Development and Reform Commission of China the domestic steel product consumption will increase by 10% up from last years 9.8%. Table 2.2-1 shows the steel demand for 2006 and estimates for 2007 by the International Iron and Steel Institute (IISI). A growth of 5.2% is expected, which is mainly driven by China, as it would only be 2.5% if China were excluded.

Until 2003, Japan was very steel intensive and therefore the Japan steel plate price has been a key figure for the shipping market with implications on demand and newbuilding prices. Fig. 2.2-31 shows how this has varied since the end of the 1990s.

IISI Steel Demand Estimates			
	2006	2007	Increase
China (Mt)	374	413	39
Asia – Other (Mt)	239	248	9
Europe (Mt)	204	204	0
Nafta (Mt)	152	151	-1
FSU (Mt)	47	51	4
RoW (Mt)	105	112	7
Total (Mt)	1121	1179	58
Growth (%)	8.9	5.2	
Growth ex China (%)	6.4	2.5	

Table 2.2-1: IISI steel demand estimates for 2007 [Reuters 2007]

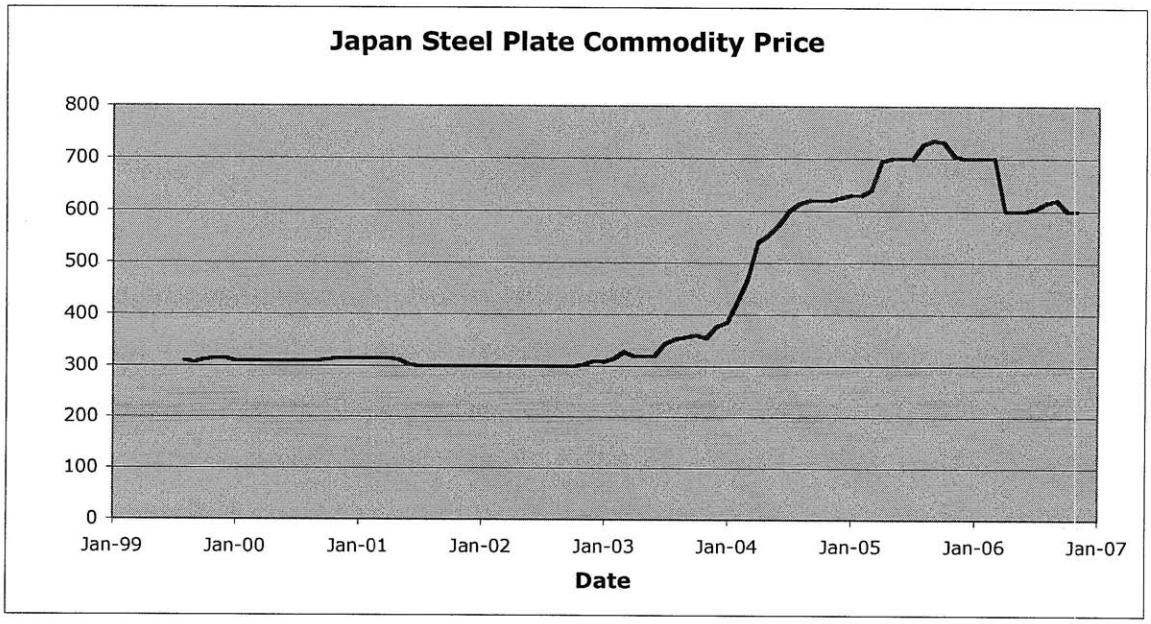


Fig. 2.2-31: Japan Steel Plate Commodity Price – using data from [Clarksons 2007a]

High steel price implies a high market for two reasons. High steel price is the result of high demand for steel, which translates to a high freight market. Furthermore, when steel is expensive, newbuildings are expensive and therefore ship values are high.

2.2.6 Conclusions

- GDP growth has a disproportionate effect on dry bulk shipping and this explains why China and India are the drivers of the current market. There is also high potential for future steel demand by both.

- The weak $ and low interest rates are helping the market to stay strong

- Chinese iron ore demand is the key indicator of the freight market

- China is gradually becoming a coal importer and its exports are decreasing while coastal coal movements were high in 2006. This led to increased demand for Australian coal with serious implications on port congestion.

- India's increasing coal/grain imports and steel/iron ore exports have a strong positive effect on the market

- World steel demand grew rapidly in 2006 creating import demand for raw materials. This led to very high freight rates. Steel production is expected to increase, supporting iron ore import growth despite further increases in supply of low-grade Chinese iron ore.

- Chinese steel production growth in 2006 was powered by domestic demand (+36 Mt) and net exports (+33 Mt). The future Chinese steel output (& iron ore imports) therefore depends on global as well as domestic markets.

- The world economy should be strong enough in 2007 to deliver healthy growth in steel and energy demand and thereby creating a strong demand for capes

2.3. Supply

2.3.1 Supply and its Elasticity

Supply is limited by the capacity of the shipyards. It takes several months to construct a newbuilding vessel, during which the ship is mainly in block stage, while the berth is occupied for just two months. The limited number of berths combined with a high and increasing demand as that of today however, can lead to high prices and delivery times ranging to a couple of years. As of 2006, the next berth is only available in 2010 / 2011. This constraint makes supply very inelastic in the short run.

Distance between the location of ships and the ports where they are needed has a similar effect. The number of ships that can arrive at a given location, or in other words supply at that location, increases with time. Unexpected accidents or events that affect supply locally can have a dramatic impact on prices, which further emphasizes the inelasticity of supply in the short run. In 2005 for example, VLCC rates exceeded $200k/day for about a week due to a Suez grounding. Ship owners on the other hand, are faced with a number of alternatives such as coal or grain trades so the quantity of ships available for trading iron ore will decrease substantially following a decrease in iron ore freight rates. This increases price elasticity of supply.

Other factors which influence the elasticity of supply in the medium term are the possibility of conversions and lay-ups. The availability of suitable ships of other types, which can switch to iron ore trading like the few existing OBOs, or ships of other types, which can be converted to capesize vessels can have a big impact. Approximately 50 tankers have been converted into bulk carriers between 2006 and 2009 [Clarksons 2009a]. The 'lay up' of ships can also impact supply in the medium term. Ships are temporarily withdrawn from the market when freight rates drop below daily operating cost and are expected to remain low for considerable time.

2.3.2 Capesize Fleet, Scrapping and Newbuildings

The supply of ships is controlled through ordering and scrapping of vessels. Following the increase in demand over the past several decades, supply has adjusted and the world fleet of capes has increased steadily since their development in the late 1960s as illustrated in Fig. 2.3-1. Deliveries, demolitions and losses per month are shown as bars whose value is read from the left axis while the resulting fleet size is shown as a line whose value is indicated on the right axis.

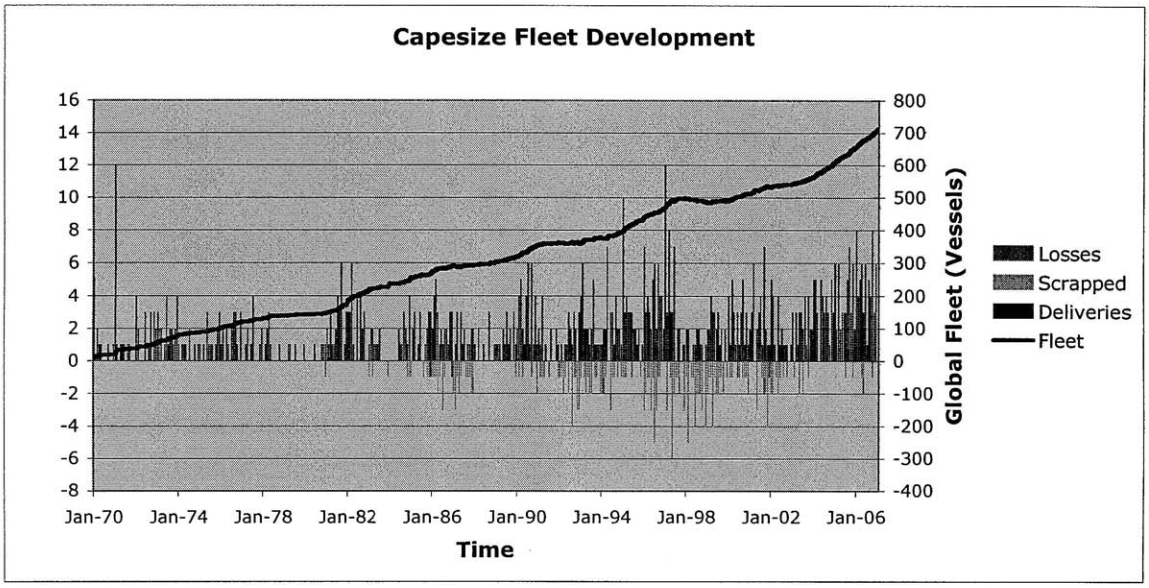


Fig. 2.3-1: The *Capesize Fleet* Development since 1970 –
using data from [Clarksons 2007a, Intercargo 2004, Lloyds 2003 & Intercargo 2002]

A similar graph in terms of total deadweight instead of number of vessels can be found in Fig. 2.3-2.

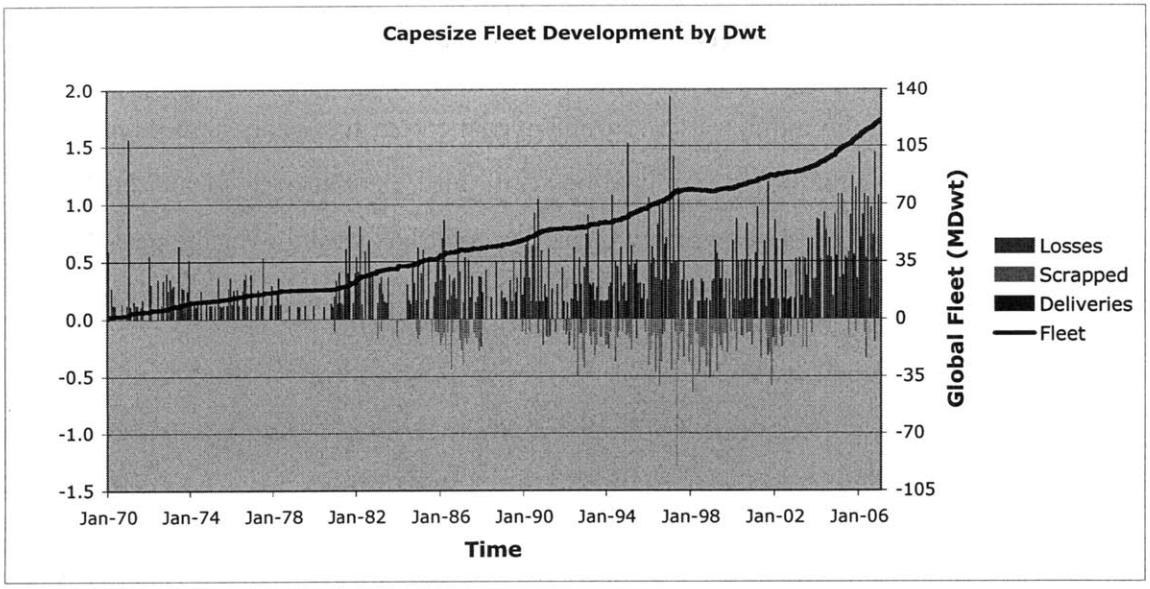


Fig. 2.3-2: Capesize Orderbook and Monthly Contracts over the past 10 years – using data from [Clarksons 2007a & Clarksons 2007c]

Scrapping was very low until the 1990s because the capesize fleet was still modern. Today, scrapping rates are again very low because of the very high freight rates since 2003. Fig. 2.3-3 shows the net change is the capesize fleet over the past 10 years along with predictions until 2008.

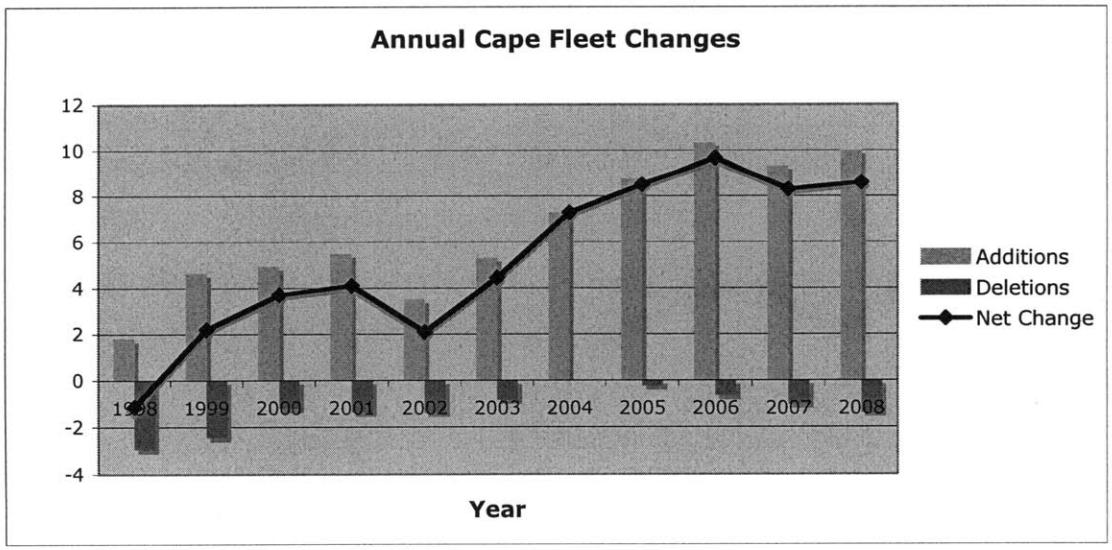


Fig. 2.3-3: Net Change in Global Capesize Fleet since 1998 and Predictions to 2008 – Using data from [SSY 2007a]

Unlike deletions, which depend on the level of the market and other uncontrollable factors such as accidents, the number of additions over the next few years is relatively easier to predict. This is because the orderbook is almost full until the end of 2011 and only minor changes are expected. Fig. 2.3-4 shows how the order book has varied over the past 10 years along with the number of contracts per month. Fig. 2.3-5 shows it in terms of deadweight in.

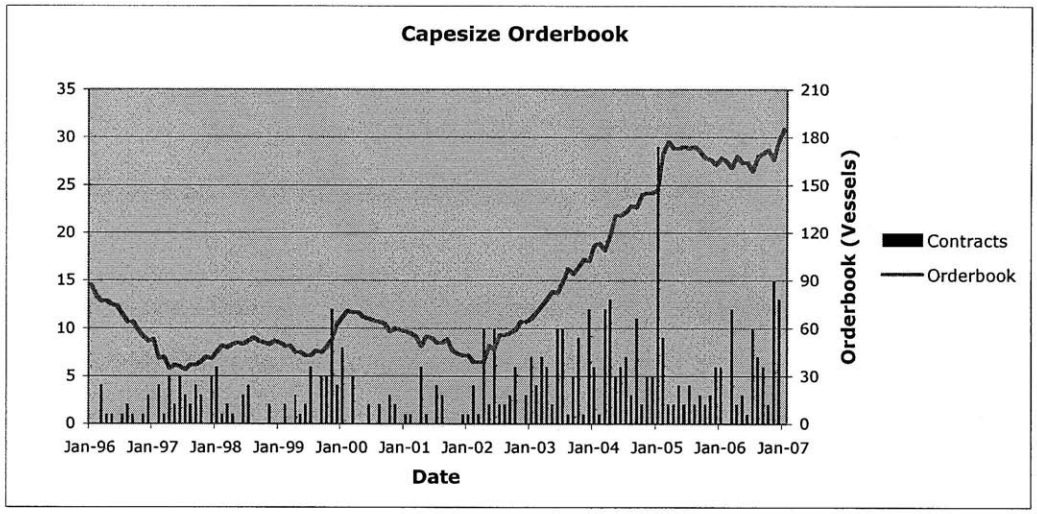


Fig. 2.3-4: Capesize Orderbook and Monthly Contracts over the past 10 years – Using data from [Clarksons 2007a & Clarksons 2007c]

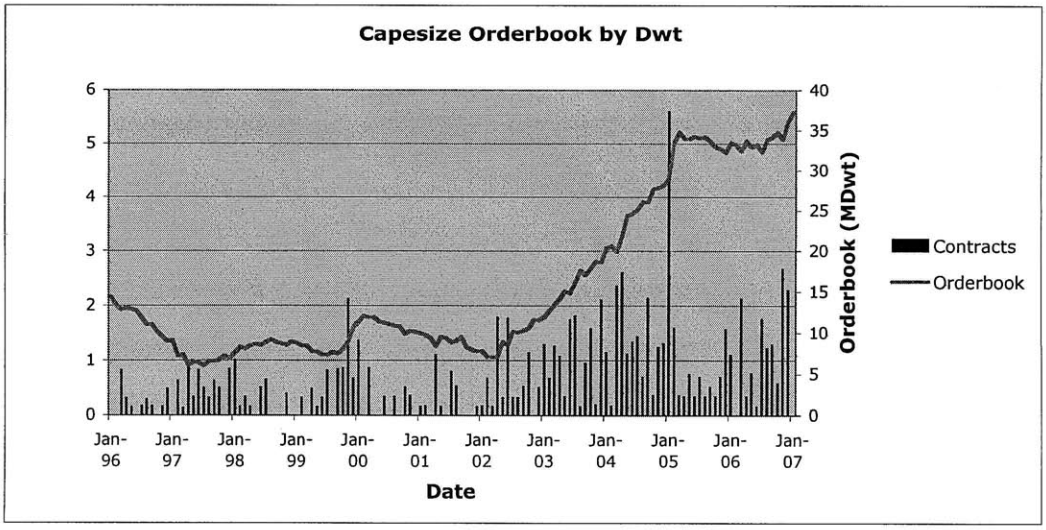


Fig. 2.3-5: Cape Sales per Month and Average Sale Prices – using data from [Braemar 2007b, Tradewinds 2007, Vafias 2007, Levene 2006, Clarksons 2006a & Clarksons 2006c]

Clearly, the orderbook is currently at very high levels historically indicating that there will be a significant increase in supply over the next several years. Table 2.3-1 shows how cape newbuilding contracting currently compares with other ship types.

Newbuilding Contracting		
Ship Type	**Contracting in 2006 (Mdwt)**	**Increase since 2005 (Mdwt)**
All 10,000+ DWT Vessels		
Tankers	76.0	+44.2
Dry Bulk Carriers	36.0	+16.0
Containers	17.6	+0.2
Gas Carriers	5.4	-0.1
TOTAL	**135**	**+60.3**
Dry Bulk Carriers		
Capesize	15.0	+7.3
Panamax	7.9	+2.5
Handymax	8.7	+5.4
Handysize	4.5	+2.2
TOTAL	**36.1**	**+17.4**

Table 2.3-1: Newbuilding Contracts of 2006 and Change from 2005 for Main Ship Types – [LR Fairplay 2007]

As shown in Table 2, contracting of tankers is far higher than that of bulk carriers but it should be noted that the majority of those vessels are replacing single hull tankers that are being phased out. Capes account for over 40% of bulk carrier and over 10% of all 10,000+dwt vessel newbuilding contracts by dwt. Cape newbuilding contracts also increased since 2005 by more than all other dry bulk carrier types. Fig. 2.3-6 shows the current orderbook compared to the existing fleet for capes of various sizes and for other dry bulk carrier types.

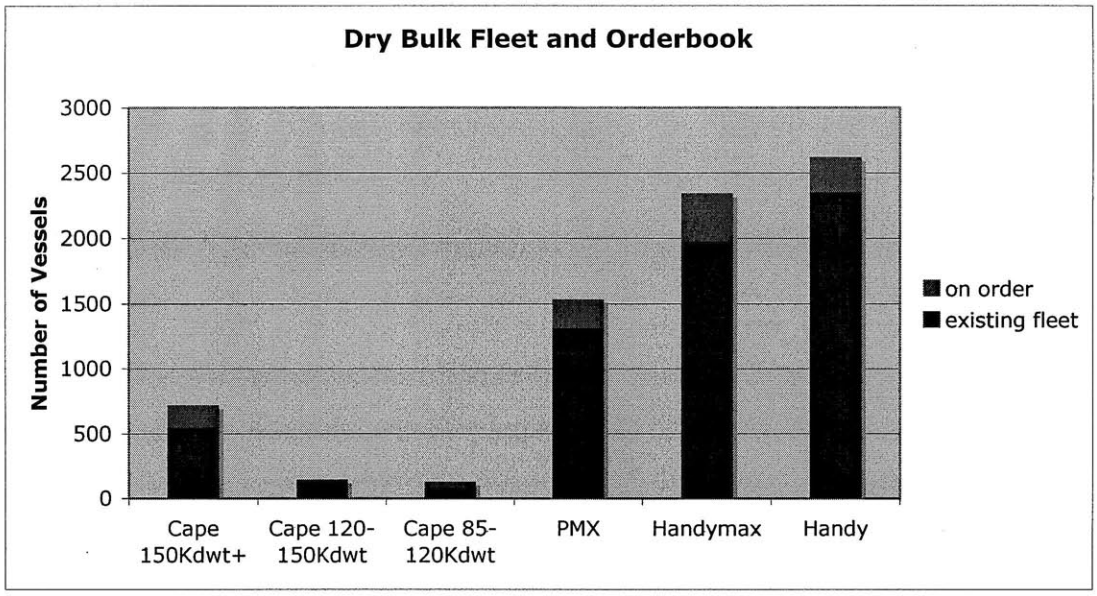


Fig. 2.3-6: Existing Fleet and the Current Orderbook for Dry Bulk Cariers – using data from [Braemar 2007a]

It is clear from Fig 45 that the cape orderbook is relatively large compared to the existing fleet. Furthermore, it consists of relatively large vessels so the anticipated supply will have a big impact. Many of the 85-120Kdwt ships were ordered in response to the decision of widening the Panama Canal in 2014 so they can also be considered as modern panamaxes. Fig. 2.3-7 shows the age distribution of the capesize fleet over 120Kdwt.

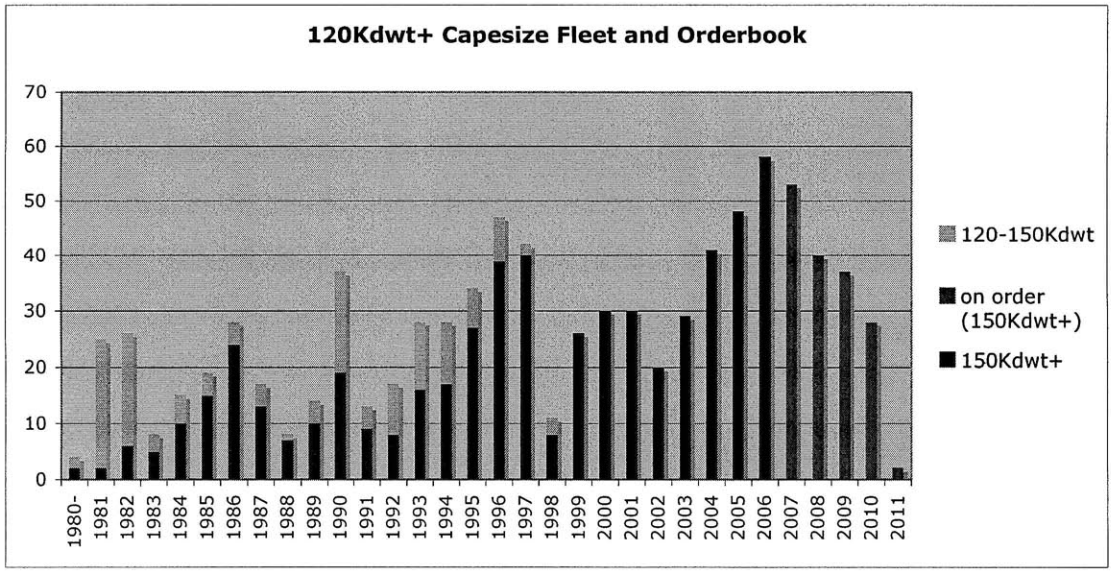


Fig. 2.3-7: Capesize Fleet Age Distribution and Oderbook – using data from [Braemar 2007a]

Unlike the handy and handymax fleets, the capesize fleet is relatively modern with a decreasing average age, which is currently less than 10 years. All orders are currently over 150Kdwt with the typical size being about 180Kdwt. The modernity of the cape fleet compared to other dry bulk carriers is clear in Fig. 2.3-8, which shows the orderbook and 20 and 25-year scrapping pool for the dry bulk carrier groups.

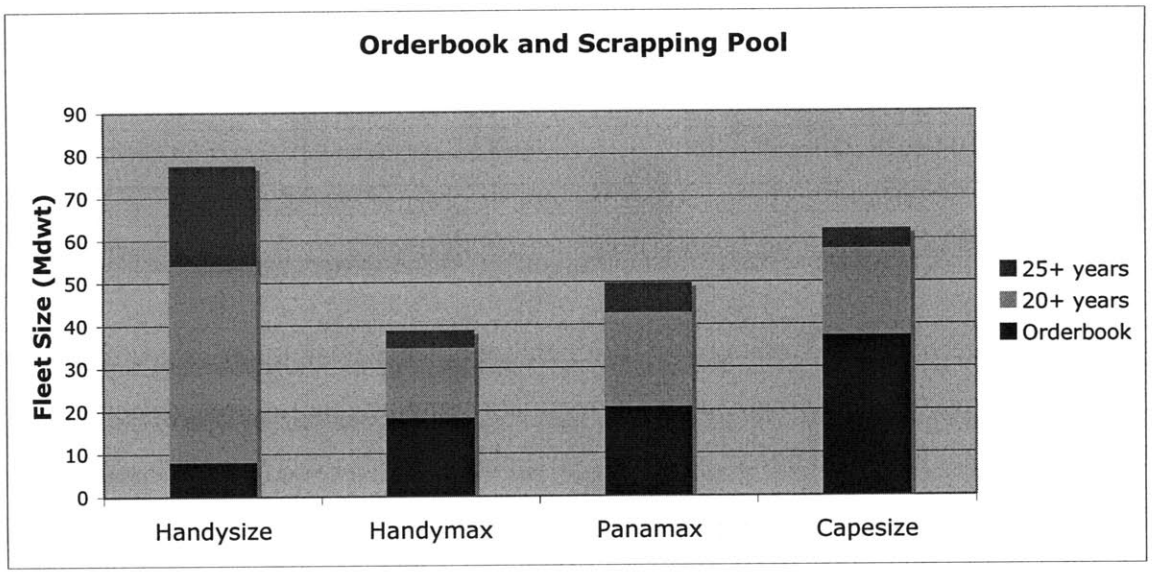


Fig. 2.3-8: Orderbook along with 20 & 25-year Scrapping Pool for Bulk Carrier Groups – Using data from [SSY 2007a]

There are currently between 700 and 800 capes in the world fleet and approximately one cape per week is going to be delivered on average in 2007. Furthermore, the number of orders per month since the beginning of 2007 has been increasing along with the market and has been much higher than 2006 meaning that the orderbook is increasing. Table 2.3-2 shows the number of contracts per month for the various bulk carrier groups since January 2007.

2007 Newbuilding Contracts								
Month	**CAPE**		**PMX**		**HANDYMAX**		**DRY BULK**	
	No.	**KDwt**	**No.**	**KDwt**	**No.**	**KDwt**	**No.**	**KDwt**
Jan	10	1,673	18	443	27	3,830	64	6,494
Feb	20	3,732	21	579	46	1,248	93	5,679
Mar	41	7,293	7	1,768	22	2,614	74	11,875
Apr	33	6,084	5	1,404	67	1,475	125	9,239
Total	**104**	**18,718**	**51**	**4,194**	**162**	**9,167**	**356**	**33,286**

Table 2.3-2: Dry Bulk Carrier Newbuilding Contracts Since Jan-2007 – Using data from [SSY 2007a, Clarksons 2007a, Clarksons 2007c, Braemar 2007a]

There were only 2 demolitions in 2005 and another 2 demolitions and 2 losses in 2006. High demand for steel combined with minimal scrapping due to the high opportunity cost of the good market has led to record-high scrapping prices. A record-high price was set in October by a Bergen product tanker that was sold for $481/ltd [Lillestolen et al 2006]. Fig. 2.3-9 shows the demolition prices in India and Bangladesh, where the vast majority of cape scrapping takes place, along with the average scrapping value of capesize bulk carriers.

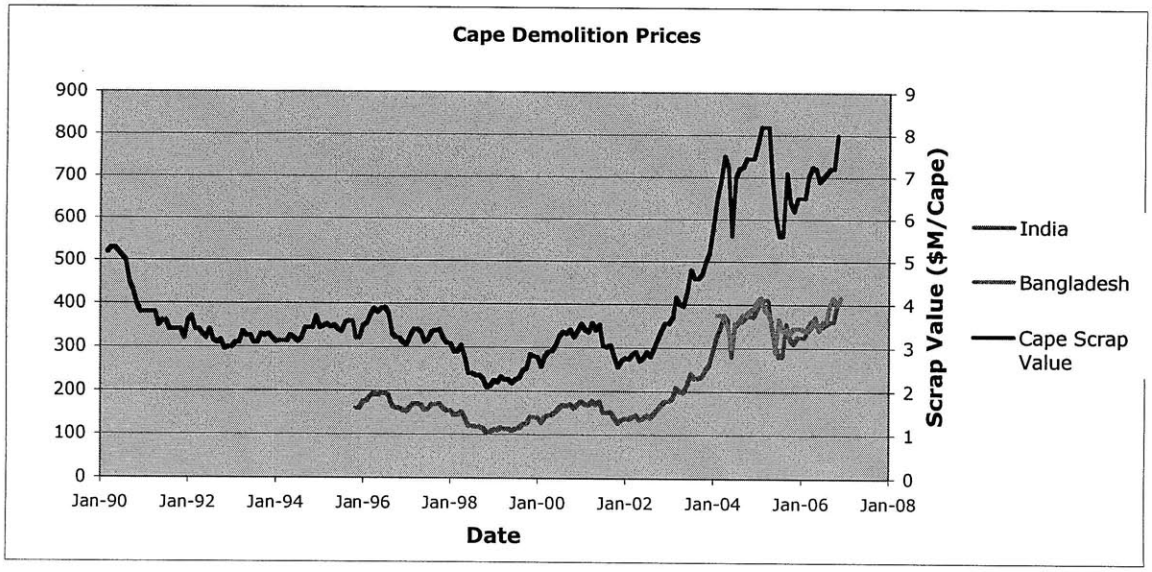


Fig. 2.3-9: Demolition Prices and Average Cape Scrap Values – using data from [Clarksons 2007a]

Minimal scrapping due to high earnings along with the optimistic market outlook indicates that the scrapping pool is going to increase. Fig. 2.3-10 shows projections of the scrapping pool for the various bulk carrier groups based on the current age distribution and the market outlook. A 23-year scrapping pool is chosen because that has been the average scrapping age over the past 30 years.

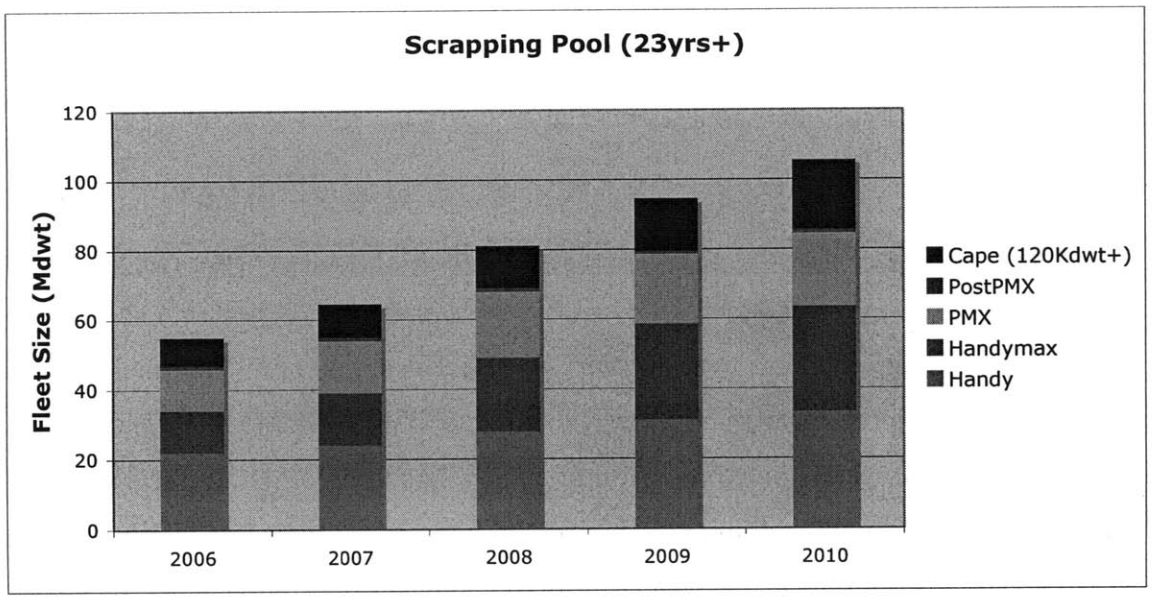


Fig. 2.3-10: 23-year Scrapping Pool Projections for the Various Bulk Carriers – using data from [Braemar 2007a]

The scrapping pool is expected to increase substantially as long as the market remains firm. This is true for all bulk carriers but for the handymax fleet in particular as it is relatively old. A high scrapping pool means that if earnings decrease, old vessels will be scrapped which will help prevent a market crisis.

Historically, owners in the dry bulk industry order more ships as earnings increase and fewer when earnings are decreasing. As a result, the annual change in deliveries with time has been almost out of phase with the change in earnings as illustrated in Fig. 2.3-11.

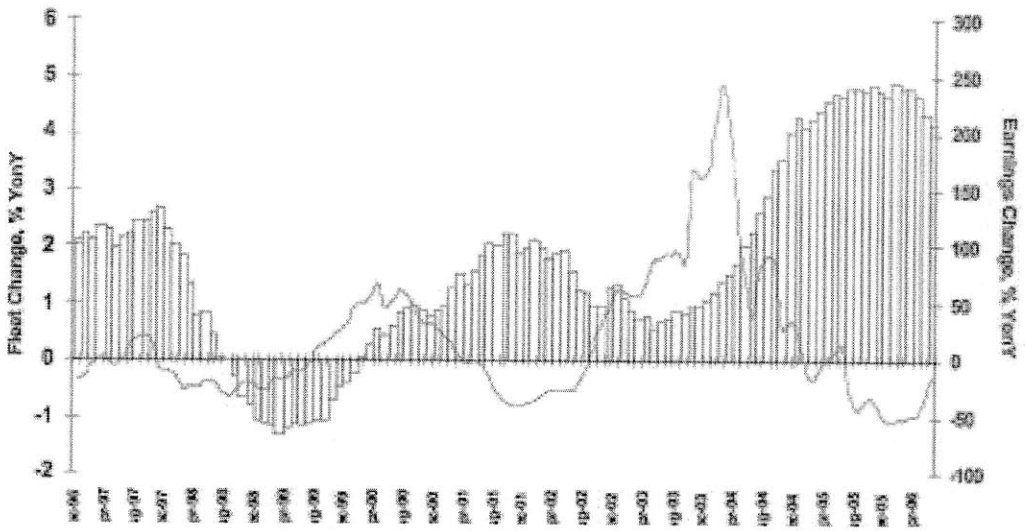


Fig. 2.3-11: Out of Phase Annual Change in Fleet and Annual Change in Earnings [Clarksons 2006b]

By comparing Fig. 2.3-4 with Fig. 2.1-9, it is also observed that the capesize orderbook has been approximately in phase with the dry bulk market, which leads to the same conclusion. These results due to the rush of shipowners to order new vessels when the market is high combined with the limited capacity of shipyards that makes supply inelastic in the short-run. The rush is similar for buyers in the secondhand market as shown in Fig 51, which indicates that cape sales volume is higher when ship prices are high.

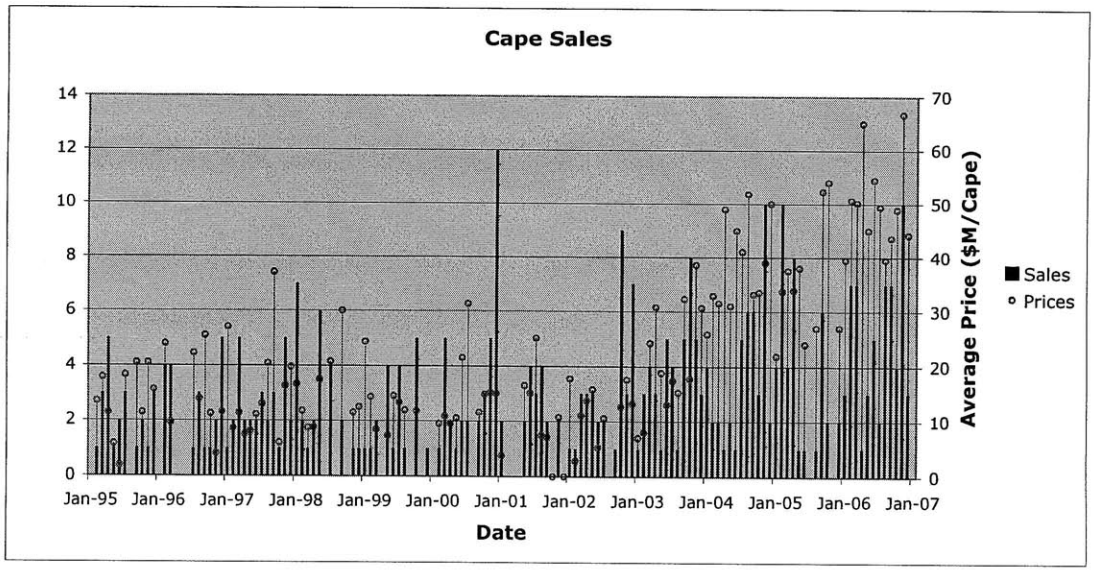


Fig. 2.3-12: Cape Sales per Month and Average Sale Prices – using data from [Braemar 2007b, Tradewinds 2007, Vafias 2007, Levene 2006, Clarksons 2006a & Clarksons 2006c]

A similar graph with sales in terms of volume is shown in Fig. 2.3-13.

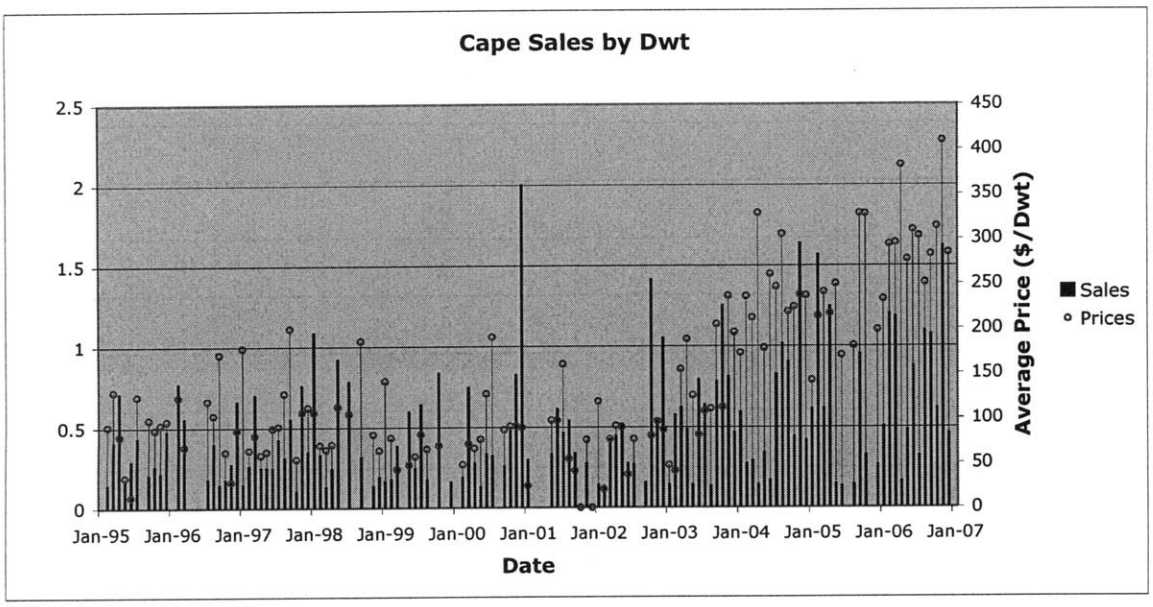


Fig. 2.3-13: Cape Sales per Month and Average Sale Prices – using data from [Braemar 2007b, Tradewinds 2007, Vafias 2007, Levene 2006, Clarksons 2006a & Clarksons 2006c]

2.3.3 Shipyards

The vast majority of capes have been built in the Far East. Japan has always been the major supplier with numerous relatively small shipyards. Korea has had a strong presence for many years with few relatively large shipyards. Taiwan has also built a significant number of capes and China is currently emerging with shipyards of a wide range of experience and quality. Table 2.3-3 provides a summary of the number of shipyards of the existing capesize fleet and of the fleet on order for each country.

Capesize Fleet and Orders by Shipyard Country		
Country	**Number of Shipyards of Existing Capesize Fleet**	**Number of Shipyards with Capesize Orders**
Japan	22	7
Korea	6	3
China	3	5
Taiwan	2	1
Other	16	0
TOTAL	**49**	**16**

Table 2.3-3: Cape Shipyards of Each Country – using data from [LR 2007, Braemar 2007a, SSY 2007a, Clarksons 2007c]

As of the end of 2006, the existing fleet consisted of 711 capes and 185 capes on order. Fig. 2.3-14 shows the distribution of the 711 existing capes amongst the 49 shipyards that built them.

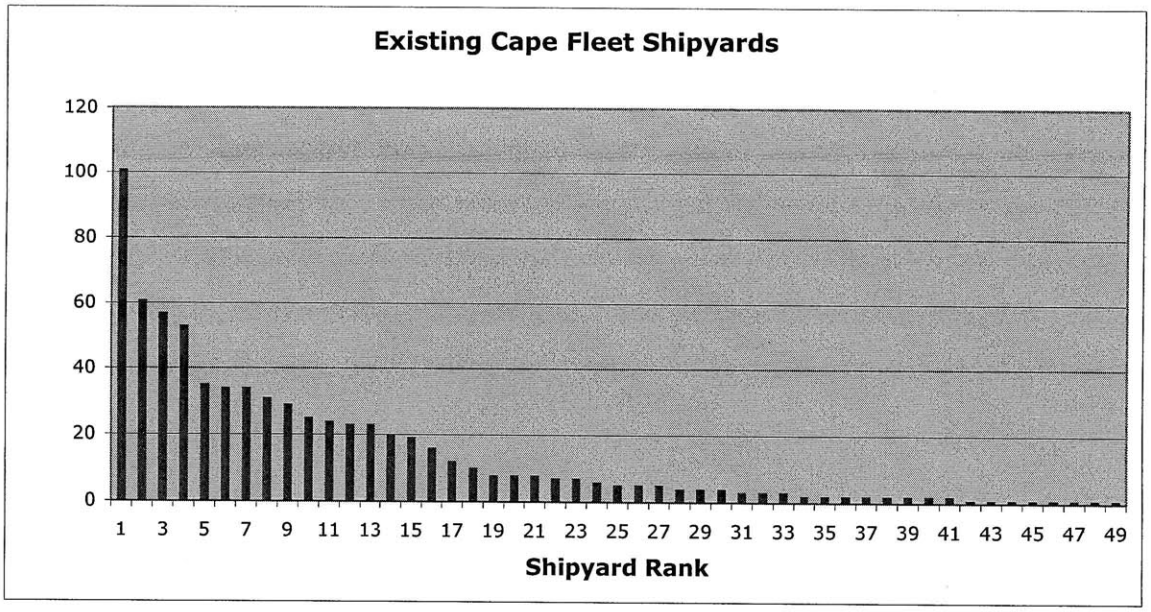


Fig. 2.3-14: Capesize Fleet Distribution Amongst Shipyards – using data from [LR 2007, SSY 2007a, Clarksons 2007a]

Korea-Ulsan based Hyundai Heavy Industries (H.H.I.), which is the largest shipyard in the world, has built 101 of the 711 capes. As shown in Fig. 2.3-14, it is significantly larger than any other shipyard in its share of the existing capesize fleet. Fig. 2.3-15 shows the number of capes of the existing fleet by shipbuilding country.

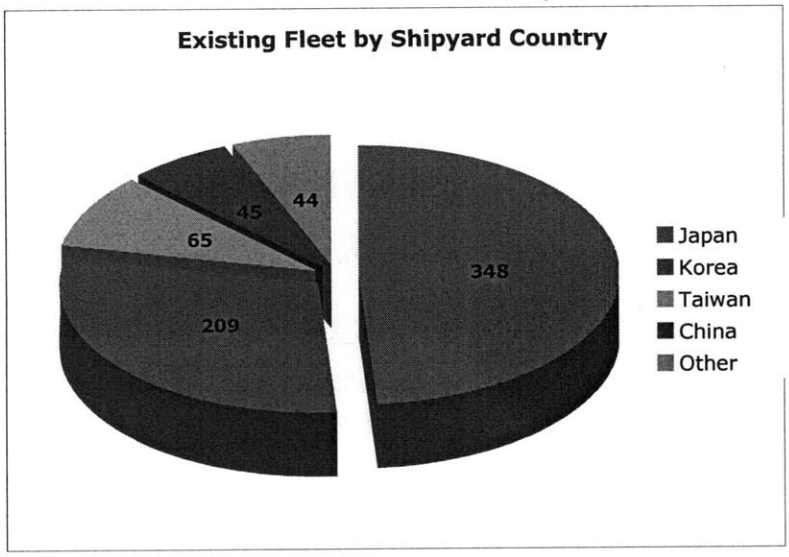


Fig. 2.3-15: Capesize Fleet Distribution Amongst Countries – using data from [LR 2007, SSY 2007a, Clarksons 2007a]

Fig. 2.3-15 shows the dominance of Japanese and Korean capes in the existing fleet while only 44 vessels have been built in 16 yards in 10 other countries that are not in the Far East. The next largest country in its share of the existing capesize fleet after China is Italy with a total of 8 capes, followed by Rumania and Brazil with 7 each. Fig. 2.3-16 shows the distribution of the 185 capes on order amongst their 16 shipyards.

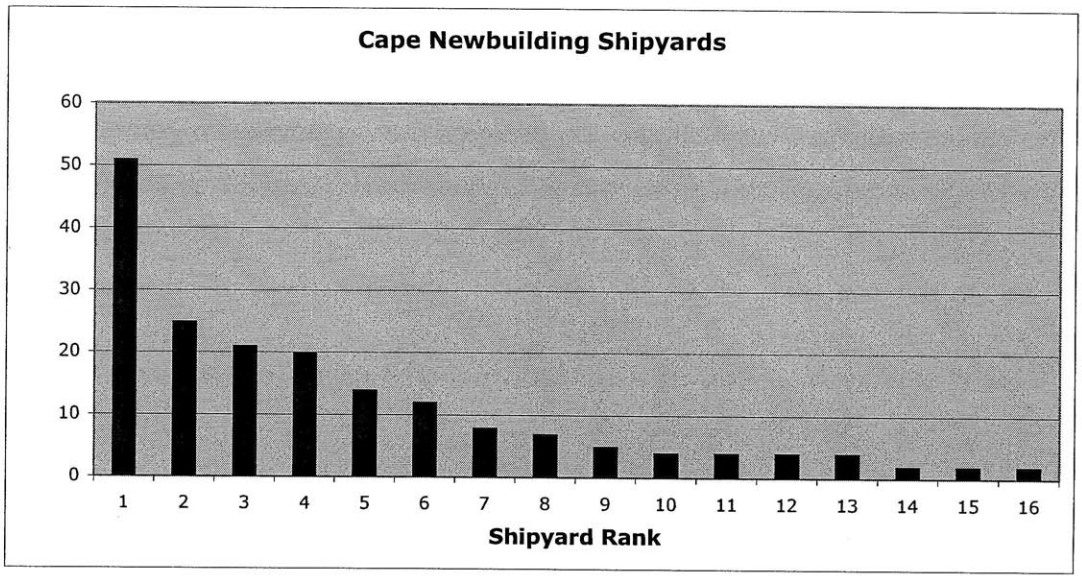


Fig. 2.3-16: Capesize Orderbook Distribution Amongst Shipyards – using data from [Braemar 2007a, SSY 2007a, Clarksons 2007c]

China-Shanghai based Waigaoqiao S/Y (SWS) is by far the largest shipyard in the world in terms of current capesize orders with an orderbook of 51 capes out of the 185. Being the most experienced, it is also generally the most preferred shipyard out of the ones in China and is relatively more expensive. Fig. 2.3-17 shows the number of capes on order by shipbuilding country.

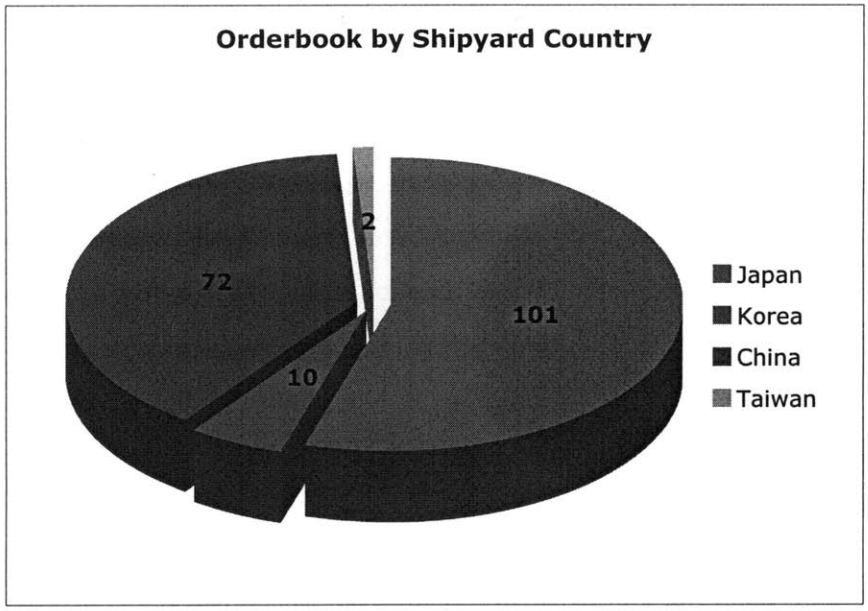


Fig. 2.3-17: Capesize Orderbook Distribution Amongst Countries – using data from [Braemar 2007a, SSY 2007a, Clarksons 2007c]

It is evident by comparing Fig. 2.3-15 and Fig. 2.3-17 that China is becoming a major player in capesize newbuilding while Korea's share has decreased substantially. Japan remains strong and there are zero orders in countries out of the Far East.

2.3.4 Port Congestion

Port capacity is another constraint that makes supply inelastic in the short-run. The inability to cope efficiently with demand has resulted in high congestion of ships at both iron ore and coal terminals particularly in Australia. Delays measured in weeks are not uncommon while average charter rates are currently in excess of $100K daily.

According to a study performed by [Clarksons 2006b], congestion in capesize iron ore terminals corresponds to a decrease in supply by about 28% for ships discharging in China. Congestion may be affected by several factors such as the Chinese New Year or bad weather. Fig. 2.3-18 shows the average mid-month delays at iron-ore terminals in Australia until Sept 2006.

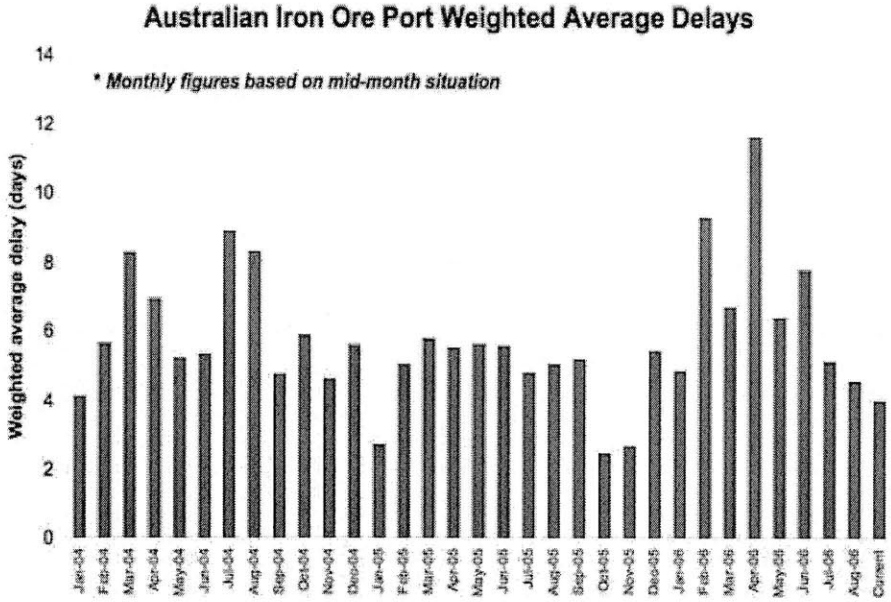


Fig. 2.3-18: Australian Iron Ore Port Congestion Indices [SSY 2006b]

Fig. 2.3-19 shows the average delays and the queue length at Australian iron ore ports between January-22 and April-30 2007.

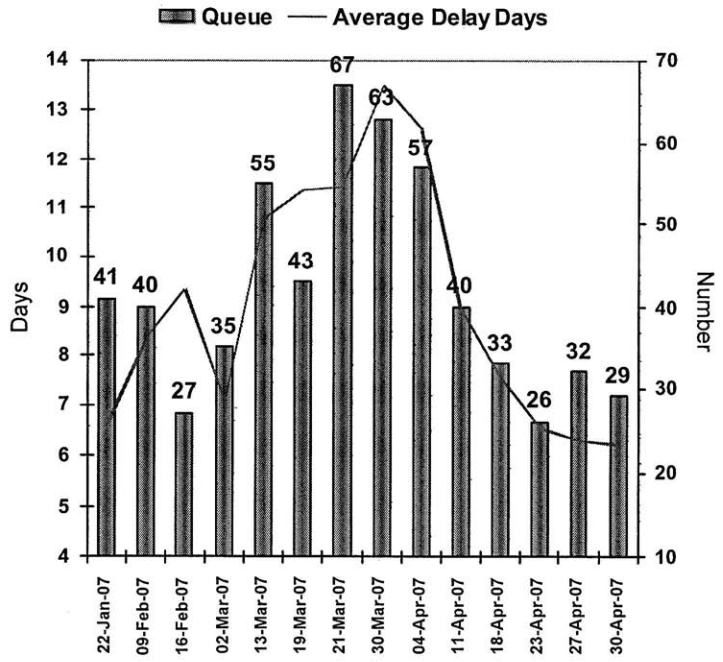


Fig. 2.3-19: Australian Iron Ore Port Congestion and Queue Length [Clarksons 2007b]

Increasing iron ore loading rates can reduce congestion, but this is dangerous particularly for older vessels that have a lower deballasting capacity. Loading rates depend on the loading abilities of existing vessels and are mainly limited by their deballasting capacity. Peak loading rates of up to 16,000–18,000t/hr have been achieved in Ponta de Madeira (Brazil) while some ports are aiming in the future to go up to 32,000t/hr [Ferguson et al 1993]. Though average rates are usually close to 50% of peak values, high loading rates are known to be the cause of serious failures and ship losses [Corbett 2006a, Isbester 1998, Intercargo 1998, IACS 1997, MER 1997].

Improving loading rates at already fast ports will only further compromise safety. Doing so in other parts of the world however by investing in more efficient conveyor belt systems may be effective as equipment in most ports is rather old. Congestion can also be effectively improved by newer ships with high deballasting rates; larger ships that will reduce the number of berthing/unberthing delays; more loaders, loading terminals and berths that will increase turnover; higher storage capacity at terminals that will buffer against inland accidents, bad weather etc.; aligned improvement of inland transportation, loading and discharging ports to avoid bottlenecks etc.

Both Ponta de Madeira in Brazil and the port of Dampier are adding one terminal each this year. Improving tracks, boogies and locomotives that operate between mines and ports can also be effective. "Breakthrough teams" working for Hamersley achieved a great increase in rail system capacity by reducing the time spent by trains unloading at Dampier port before returning to the mine from 90 to 30 min. [Renwick 2002].

It is important to understand however that these solutions may be effective in the short-run, but they involve heavy investment and will be a huge loss in the long run if Chinese demand drops or the world economy goes into recession.

An allocating system was implemented last year in Australia and was very effective in reducing congestion. There has been criticism however that it favored some shippers over others and that has delayed its re-implementation this year.

Besides iron ore port congestion, coal port congestion increased substantially during the final quarter of 2006 and this had a big impact on freight rates. As discussed earlier, the

main reason for this is that China is becoming a net importer and the countries to which it previously exported have now turned to Australia.

Waiting time at the Australian port of Newcastle reached 20 days at the end of 2006 with queues of up to 55 vessels waiting to load [Clarksons 2007d]. Congestion has further increased since then causing charter rates to reach record high levels. Fig. 2.3-20 shows the Australian coal port congestion index until January 2006 and Fig. 2.3-21 shows the average delays along with the queue length since then.

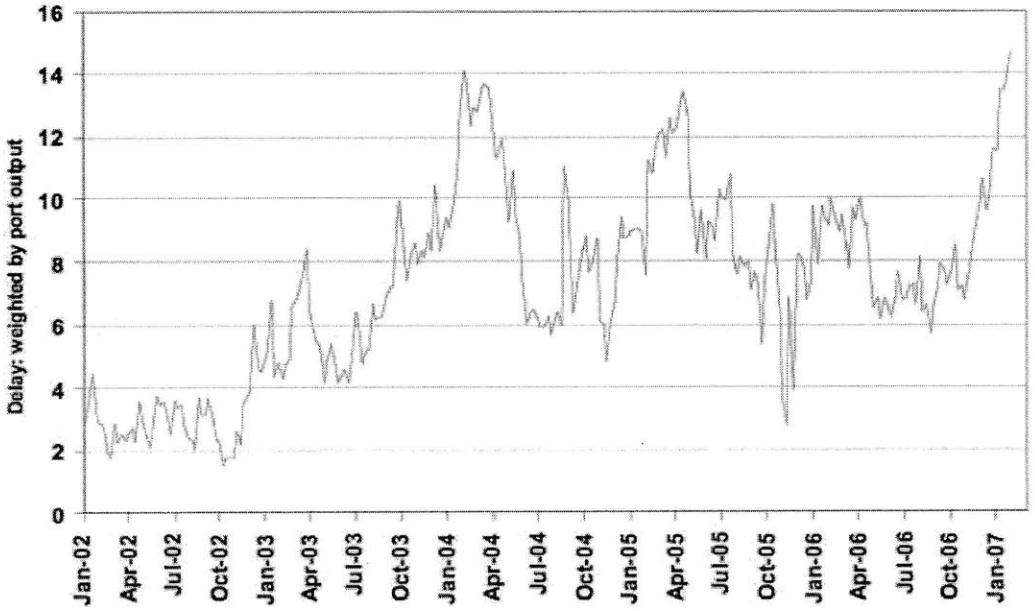


Fig. 2.3-20: Australian Coal Port Congestion Index [SSY 2007b]

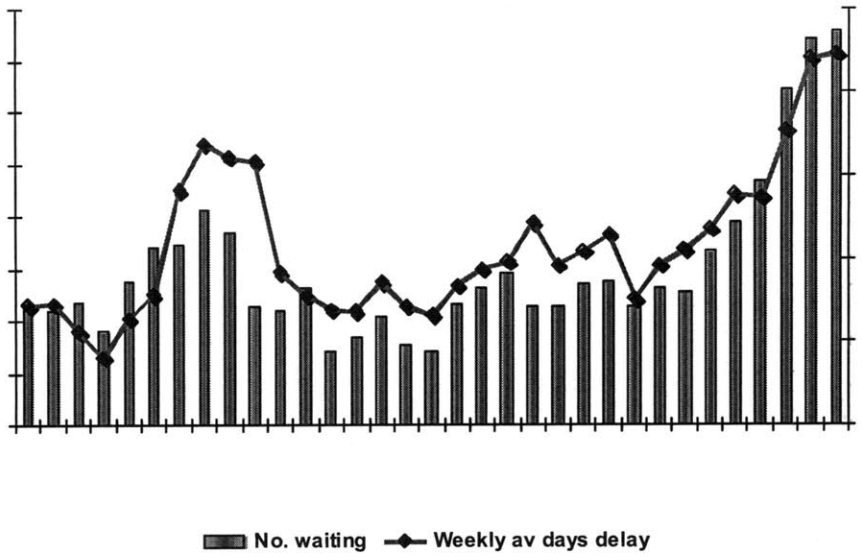


Fig. 2.3-21: Australian Coal Port Congestion and Queue Length [Clarksons 2007b]

Fig. 2.3-22 shows the transpacific capesize daily earnings along with average coal port delays until January 2007.

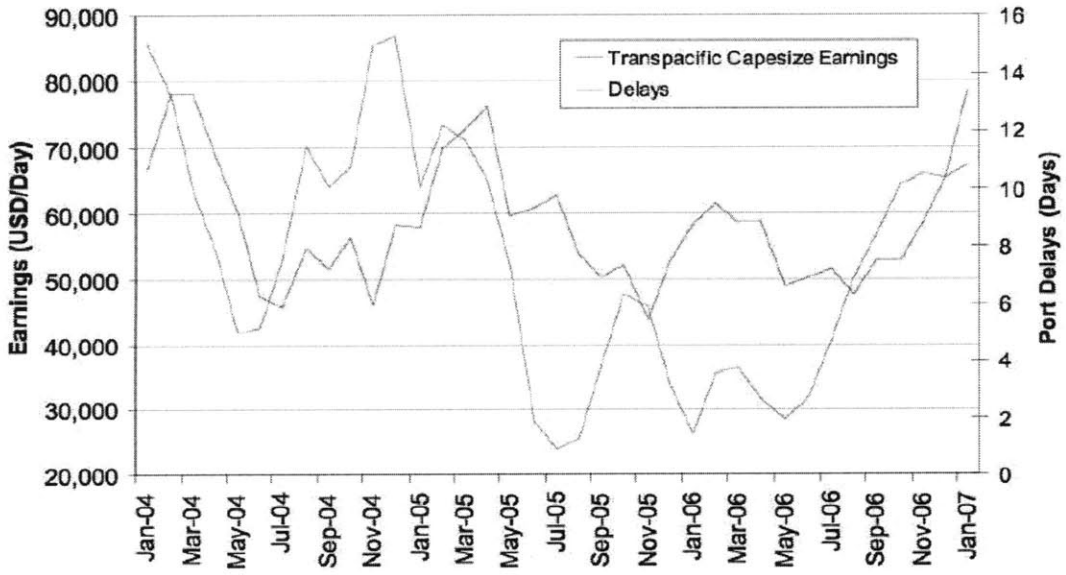


Fig. 2.3-22: Transpacific Capesize Earnings and Delays [SSY 2007b]

It is clear from Fig. 2.3-22 that there is a close correlation between freight rates and congestion. According to [SSY 2007b], congestion corresponds to a decrease in supply of the order of about 50% and this is what has caused freight rates to be so high. One can treat

congestion as a reduction in supply because it corresponds to a number of vessels being idle. On the other hand, congestion can be interpreted as a decrease in overall productivity of the fleet. This leads to an increase in demand, as more ships of a lower productivity are required to transport the same amount of cargo. The latter approach is the one adopted by Marsoft in their estimates of fleet utilization to predict freight rates.

2.3.5 Oil Prices and Operating Costs

The increasing price of crude oil translates to an increase in bunkering costs for shipowners. It therefore shifts the supply curve to the left and increases price (freight rates). This has the opposite effect of improvements in naval architecture, materials, technology and automation, which increase efficiency and reduce operating and construction costs, shifting the supply curve to the right. Fig. 2.3-23 shows marine diesel oil prices in Rotterdam and Singapore, the two major bunkering ports for capes.

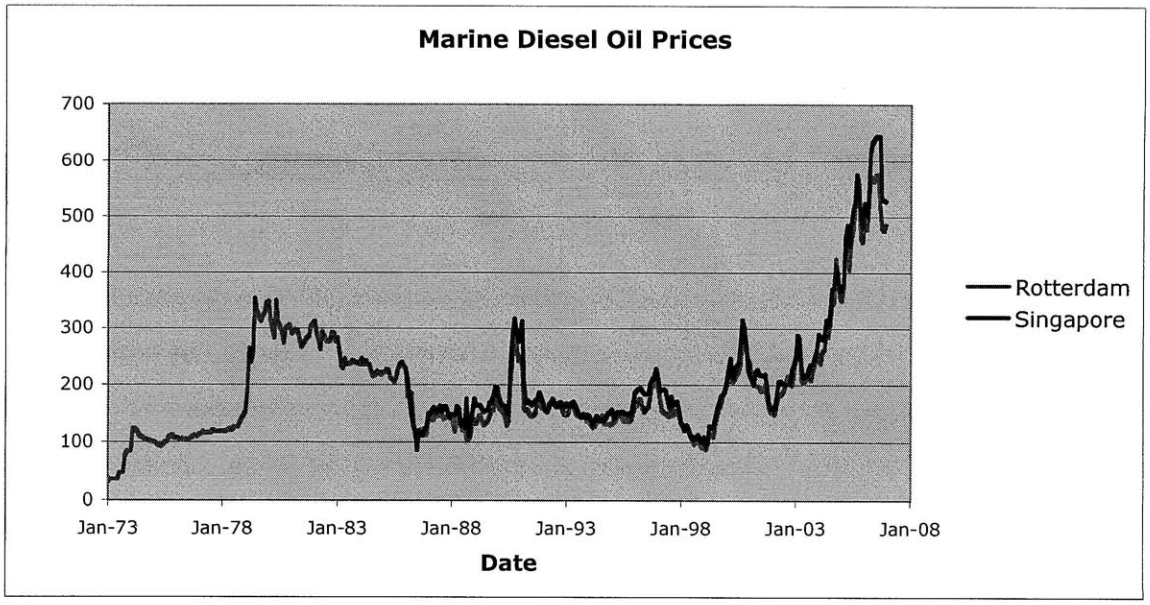


Fig. 2.3-23: MDO Prices in Rotterdam and Singapore - using data from [Clarksons 2007a]

The increase in operating costs alone would reduce output and revenues if demand were elastic. This however has been greatly offset by the increase in demand for transportation. The demand for steam coal transportation increases significantly with oil prices as many factories and power plants around the world switch to coal. This has a positive effect on dry bulk freight rates. Fig. 2.3-24 shows crude oil prices (in red) along with the Baltic Dry Index (in blue).

Fig. 2.3-24: Baltic Dry Index (blue) and Crude Oil (red) [Investment Tools 2006]

2.3.6 25-Year Age Limit on Ore-Trading Capes

High-density cargos like iron ore have been the cause of several dramatic casualties in the past with not enough reaction time to even send a distress signal. Examples include the capes *Alexandre P., Pasithea* and *Algarrobo,* all of which disappeared virtually without trace in 1990 while loaded with iron ore [LR, Peckham, Ferguson 1991] and the *Mineral Diamond* in 1991 again loaded with iron ore.

Most recently, only 7 out of the crew of 33 were rescued after the rapid failure and sinking of *Alexandros T.* in May off the coast of Port Alfred in South Africa. The ship was transporting iron ore from Brazil to China – a very common route. Naturally, this has attracted public attention and has been of great concern to many involved in the shipping industry.

Cargo owners and charterers have recently responded by introducing a 25-year age limit on vessels that are allowed to transport iron ore. This will force the older vessels out leading to a reduction in supply that will counteract the effect of deliveries and perhaps push the rates up over the coming years.

2.3.7 Conclusions

- Port and shipyard capacity constraints as well as the distance between the location and demand of ships, make supply inelastic in the short-run

- Substitutability between capesize trades make supply price elastic causing freight rates along the various routes to move in parallel

- Minimal scrapping due to high rates and excessive ordering has led to a record high net fleet growth and newbuilding orderbook

- The inability of shipyards to cope with demand has led to record high prices and delivery times

- Fleet annual cargo carrying capacity will increase substantially and the supply increase is expected to have a big impact on shipping

- China is quickly becoming a major player in the cape newbuilding industry while capturing a great portion of Korea's share of the market

- Bulk carriers are likely to become a key target for shipbuilders this year

- Newbuilding ordering is in phase with earnings causing deliveries to be approximately out of phase with the cyclical market

- The sharp increase in Australian coal port congestion during the final quarter of 2006 led to record-high freight rates that are ongoing

- Solutions to improve congestion are available but they include drawbacks such as safety, investment risk and criticism of favoring certain shippers
- The soft spot in the market will be dictated by the resolution of the Australian port congestion problem and pacific rates will be the first to drop

- The increasing scrapping pool as a result of low scrapping creates a buffer because a decline in rates will induce scrapping, leading to a market recovery

- The 25-year age limit imposed on iron ore transporting capes effectively leads to a decrease in supply

- Congestion effectively decreases supply, though it can also be treated as a decrease in the fleet productivity and therefore an increase in demand

- Increasing oil prices effectively decrease supply as they imply higher operating costs. This however is more than offset by the corresponding increase in demand for steam coal transportation as factories switch to coal

- The availability of suitable ships of other types, which can switch to iron ore trading like the few existing OBOs, or ships of other types, which can be converted to capesize vessels, affect the elasticity of the short term supply curve

- The long term supply curve is governed by the shipbuilding capacity (i.e. the number and size of shipyards)

- The 'lay up' of ships can also impact supply in the medium term. This happens when freight rates drop below daily operating cost and are expected to remain low for considerable time.

- The Capesize market follows the dry bulk market due to the knock-on effect between the various bulk carrier size groups. The current shipping boom however has had a bigger impact on capes

- The market is very volatile with huge percentage changes in freight rates over relatively short periods of time, particularly for capes

- TC-Equivalent voyage earnings and TC earnings along various routes move in parallel, as they constitute substitutes. Substitutability however is limited by the need to ballast from one port to another

- Coal and iron ore freight rates along the same routes are very close substitutes and therefore yield similar earnings

- China's demand for iron ore has resulted in flow irregularities resulting in much higher front haul than back haul rates. This however is counteracted by America's increasing demand

- Time charter rates are less volatile for longer time charter periods meaning that shorter period rates are higher in a strong market and lower in a weak market

- Time charter rates are less volatile and on average lower than spot rates

- The time lag between TC rates and spot rates and between TC rates of various lengths, is dependent on the TC period length and independent of ship size

2.4 Market Equilibrium and Ship Earnings

2.4.1 Equilibration of Supply and Demand

Shipping is a cyclical market and the large number of factors that affect it renders it almost impossible to make future predictions. The fact that it is cyclical however implies that it is not totally random. As for any good or service, the market price for a voyage or a period charter is determined by supply and demand at any given location and time. In practice, equilibrium may never be achieved due to the high dynamics of the market but average prices and trends will always be governed by supply and demand. Fig. 2.4-1 shows the supply and demand for capes since 1995 with extrapolations until 2010.

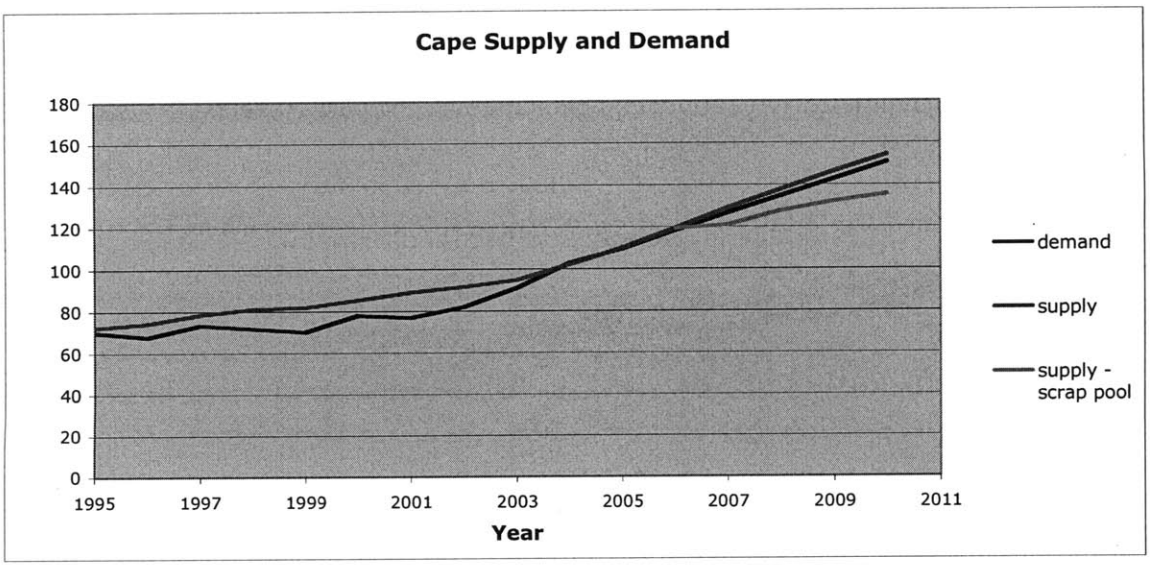


Fig. 2.4-1: Supply and Demand of Capes along with a 23-year scrapping scenario – using data from [Braemar 2006 & Braemar 2007a]

The demand projection (in million tonnes transported per year) is based on WTO (World Trade Organization) predictions about the industries related to capesize trades (iron ore, coal and grain). The summation of the estimated demand for capesize deadweight

capacity along the various trade routes gives the total demand curve shown. Estimates of GDP growth in major players such as China have also been incorporated, using historical correlations between GDP growth and the bulk carrier market.

The supply projection is based on the existing fleet and the capesize orderbook, which is known until the end of 2010. The red projection assumes that there will be no capesize scrapping while the green projection assumes that all capes above 23 years old will be scrapped. 23 years is the 30-year average scrapping age but a 30-year scrapping age or no scrapping at all is more likely in today's market. The red and green curves therefore provide a useful upper and lower bound for supply until 2010.

A tight balance between supply and demand is therefore expected for capes until 2010 but supply has the potential of decreasing significantly if demand drops. This means that old vessels will be scrapped following a decline in rates so a market crisis is unlikely.

It is reasonable to assume that demand for transportation is price inelastic because prices of the final products are relatively high and they usually have high profit margins. Freight rates are therefore driven by annual changes in demand and supply while the volume transported is to a large extent unaffected by freight rates. Fig. 2.4-2 shows the annual percentage change in bulk carrier supply and demand over the past 10 years.

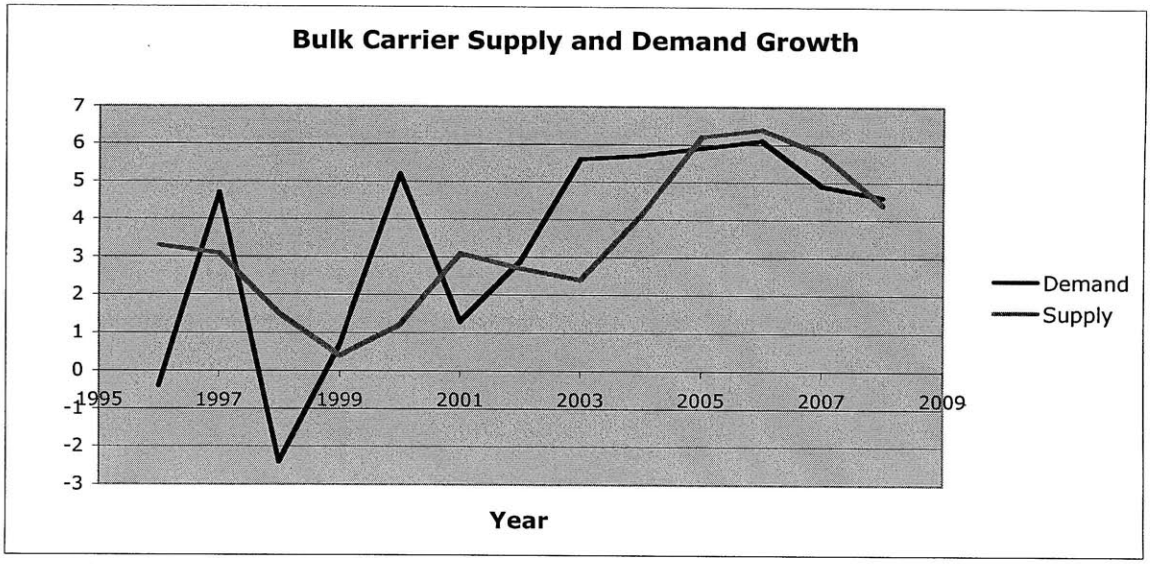


Fig. 2.4-2 Annual Percentage Change in Supply and Demand for Bulk Carriers – using data from [SSY 2007a]

When the demand is rising faster than supply, meaning that the blue line is above the red line in Fig. 2.4-2, freight rates increase and vice versa.

Marsoft base their predictions of the market on their estimates of fleet utilization. Utilization is defined as the percentage ratio of demand to supply. The forecast of demand in tonne-miles is based on extensive data of countries' trade predictions and geographical distances. Tonne-miles are then converted to deadweight (MDwt) using the estimated fleet productivity, which incorporates port congestion, average sailing speed and other parameters. Supply is based on the anticipated scrapping and newbuilding deliveries.

The Idle fleet is simply the difference between supply and demand while fleet utilization is the percentage ratio and is used as an indicator of the market. Note that supply, demand and the idle fleet can be measured in deadweight, deadweight per year, tonne-miles or tonne-miles/year. Fig. 2.4-3 shows the fleet size, demand and the idle fleet in MDwt along with fleet utilization as a percentage since 1980.

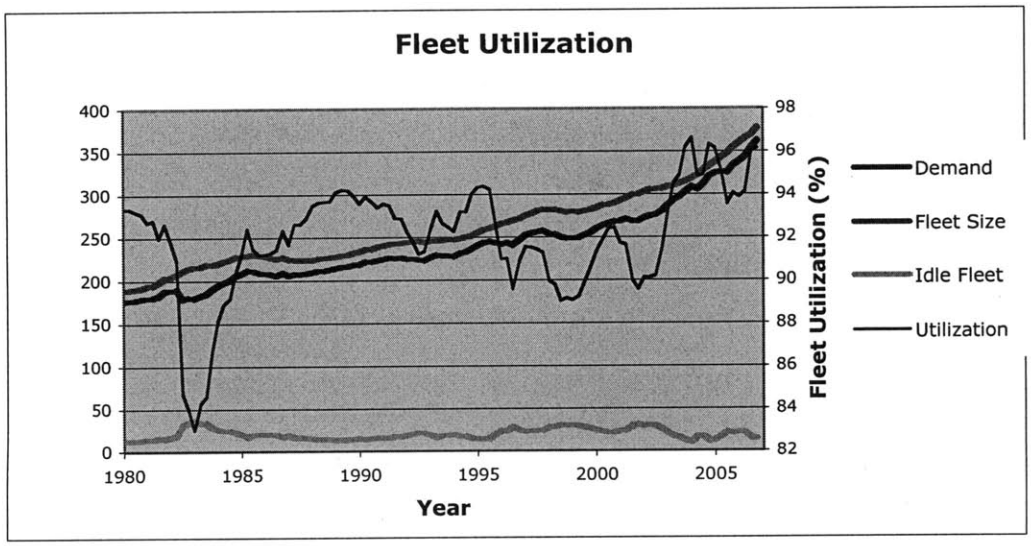


Fig. 2.4-3: Fleet Utilization and its Components since 1980 - using data from [Marsoft 2007a]

Note that Fig 65 shows only actual historical data without predictions. We are now experiencing record-high utilization rates while there is a very tight balance between supply and demand and this explains the record-high market. By comparing Fig. 2.4-3 with Fig. 2.1-9, it can be seen that the peaks in utilization rate coincide with the peaks of the dry bulk market (1980, 1985, 1989, 1995, 2001 and now) and so do the bottoms (1983, 1986, 1993,

1999 and 2002). The utilization rate therefore is a good market indicator though it is hard to predict.

The above fleet utilization is for dry bulk carriers. A cape-specific pseudo-utilization rate is derived using cape specific data of supply and demand and then incorporated. Its effect however is not very significant, as the cape market tends to follow the dry bulk market closely. Historical correlation between freight rates and (100 - fleet utilization) is used to predict the market because fleet utilization is usually close to 100 and small percentage changes are common.

2.4.2 Dry Bulk Earnings

The Baltic Index for capes has closely followed the dry bulk market over time. The current boom over the last few years however is more intense for capes than for other bulk carriers. That is because it is driven by China and iron ore imports while the majority of iron ore is transported in Capes. Fig. 2.4-4 shows the daily earnings of capes and other bulk carriers since 2001.

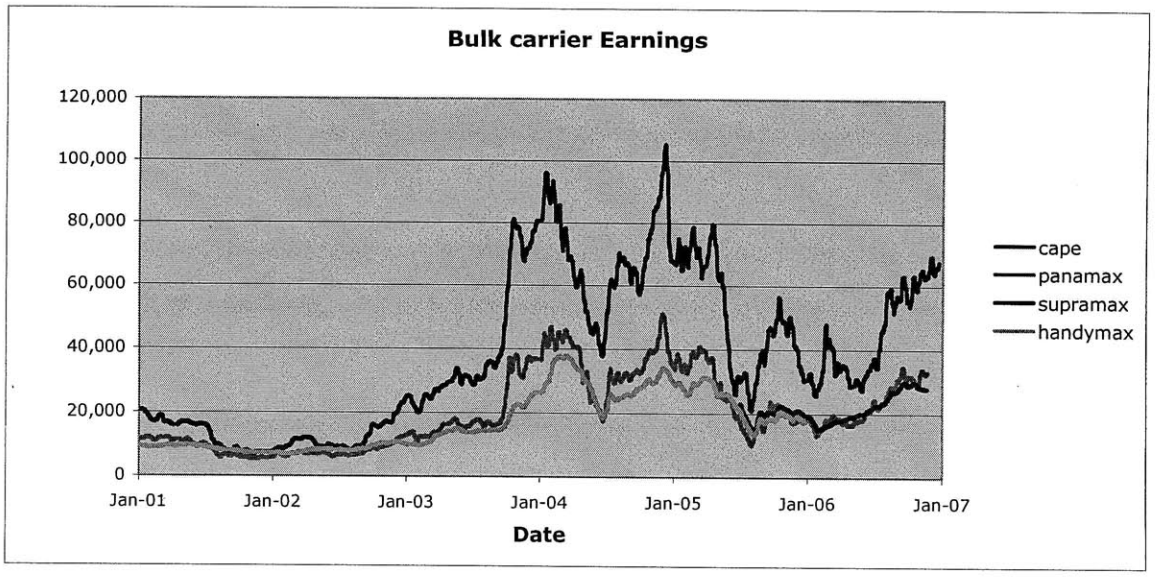


Fig. 2.4-4: Dry Bulk Carrier Average Earnings [Baltic Exchange 2007]

The similarity between the trends of the cape market and the other dry bulk markets explain why the effect of the cape specific factor not very significant in the fleet utilization. The reason for this similarity is the knock-on effect between the dry bulk markets as discussed in Section 1. The relatively higher percentage increase in cape earnings compared to other bulk carrier groups in the current boom is shown in Table 2.4-1.

Increase in Bulk Carrier Earnings Between Sept-2001 and Dec-2004			
Average Rates	**Cape**	**PMX**	**HMX**
Sept-10, 2001	$6,140/day	$6,306/day	$8,070/day
Dec-7, 2004	$105,520/day	$49,518/day	$33,945/day
Increase	**1,619%**	**685%**	**321%**

Table 2.4-1: Increase in Average Rates from Sep-2001 to Dec-2004 – using data from [Baltic Exchange 2007]

It should be noted that a similar increase occurred by January 15th 2004 when average cape earnings reached $96K/day and today the market is even higher with average cape earnings of about $115K/day and further increasing.

2.4.3 Freight Rates and Earnings

The main cargos transported by capes are coal and iron ore and the main destinations are China and Rotterdam. Iron ore freight rates along the main routes to Rotterdam and China by capesize bulk carriers are shown in Fig. 2.4-5 and Fig. 2.4-6 respectively.

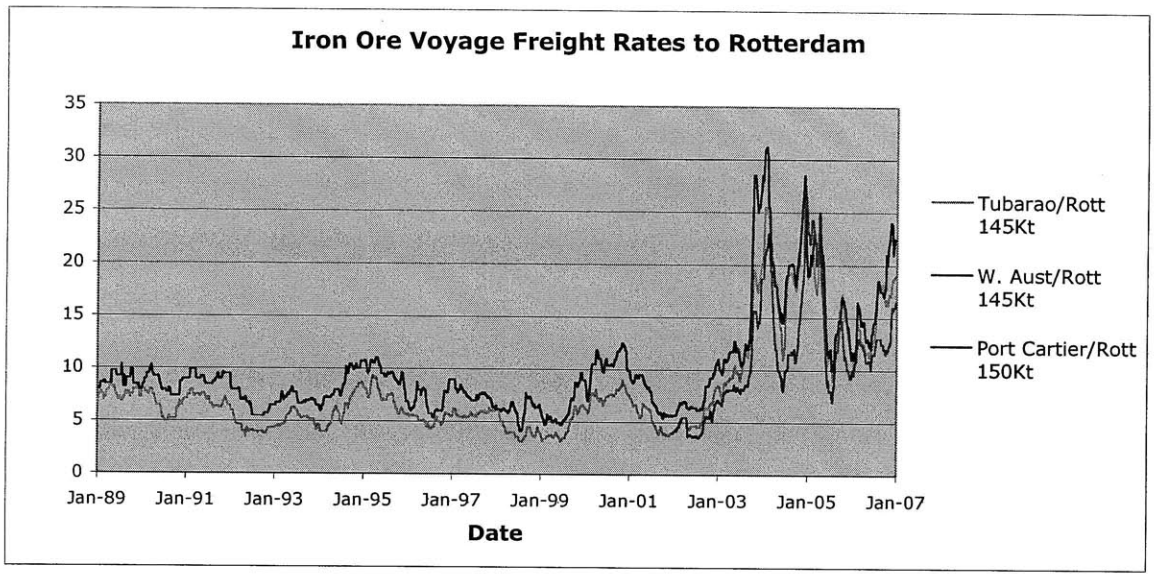


Fig. 2.4-5: Iron Ore Freight Rates along the Main Routes to Rotterdam [Clarksons 2007a]

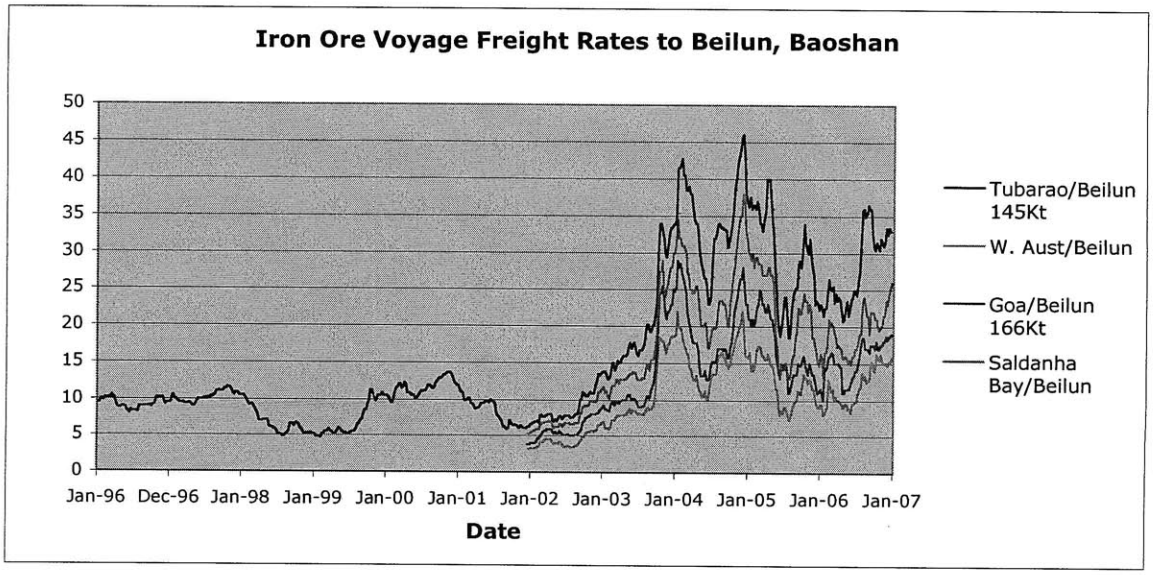


Fig. 2.4-6: Iron Ore Freight Rates along the Main Routes to China - Beilun [Clarksons 2007a]

The highest iron ore freight rates appear to be from Brazil (Tubarao) to China and the cheapest route is from Australia to China. One however should consider the fact that a shorter distance corresponds to higher ship earnings per day (time charter equivalent) which is the effective price seen by suppliers (shipowners). This ought to be more balanced across the various routes.

The Baltic Exchange keeps track of the average freight rates (average of coal and iron ore) along the main routes to China and Rotterdam for capesize bulk carriers. These are shown in Fig. 2.4-7.

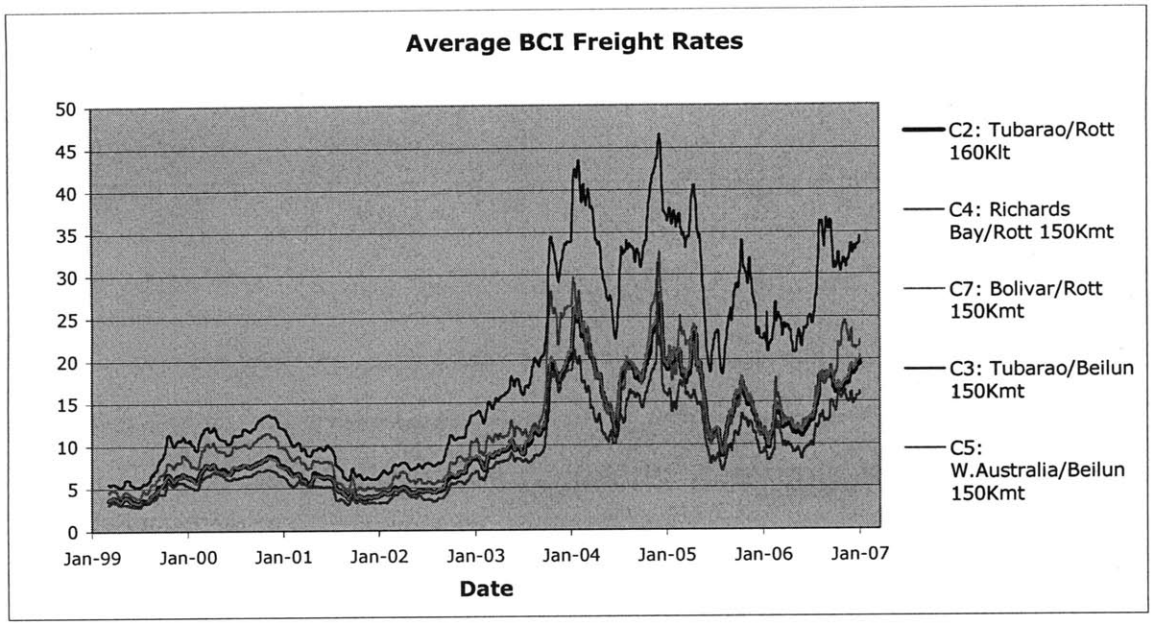


Fig. 2.4-7: Average Baltic Cape Index Freight Rates Along the main Routes – using data from [Baltic Exchange 2007]

It can be seen that these are not very different than the iron ore freight rates along the corresponding routes. That is because the iron ore and coal are close substitutes for the shipowner and both are usually available on these routes.

The typical ways in which a vessel is employed are on voyage charter, time charter, which can be for a single voyage or up to 10 years, and bareboat charter, which is typically for longer term and may conclude with delivery of the vessel to the charterer (bareboat lease). Besides period length, the main difference between those is in the costs paid by the charterer and the shipowner.

Crudely speaking, costs can be divided into CAPEX (Capital costs/expenses including asset cost and repairs), OPEX (operating expenses including manning, insurance, maintenance, stores and equipment etc.) and VOYAGE costs (fuel, port expenses, canal fees etc.). CAPEX are fixed costs, OPEX are only time dependent and VOYAGE costs are route dependent. In a bareboat charter, the shipowner only pays CAPEX. In time charter, the owner

also pays OPEX and in voyage charters (spot charter), the owner incurs all costs including VOYAGE.

Since there is high variation in the costs incurred by the shipowner, the time-charter equivalent is calculated for each employment option in order to enable direct comparisons. Fig. 2.4-8 shows the freight rate, the voyage costs and the resulting daily earnings for a typical cape along the Brazil/Rotterdam route and how these have varied since 1980.

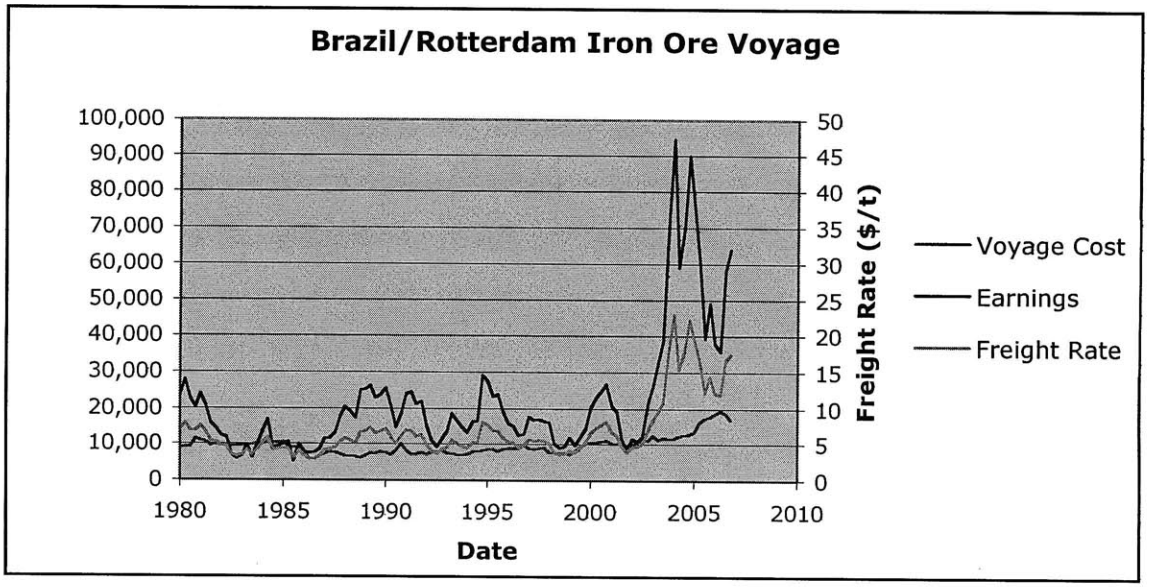


Fig. 2.4-8: Freight Rates, Voyage Costs and Resulting Cape Earnings – using data from [Marsoft 2007a]

Fig. 2.4-9 shows how the resulting daily earnings along that route compare with average earnings and 1-year time charter rates.

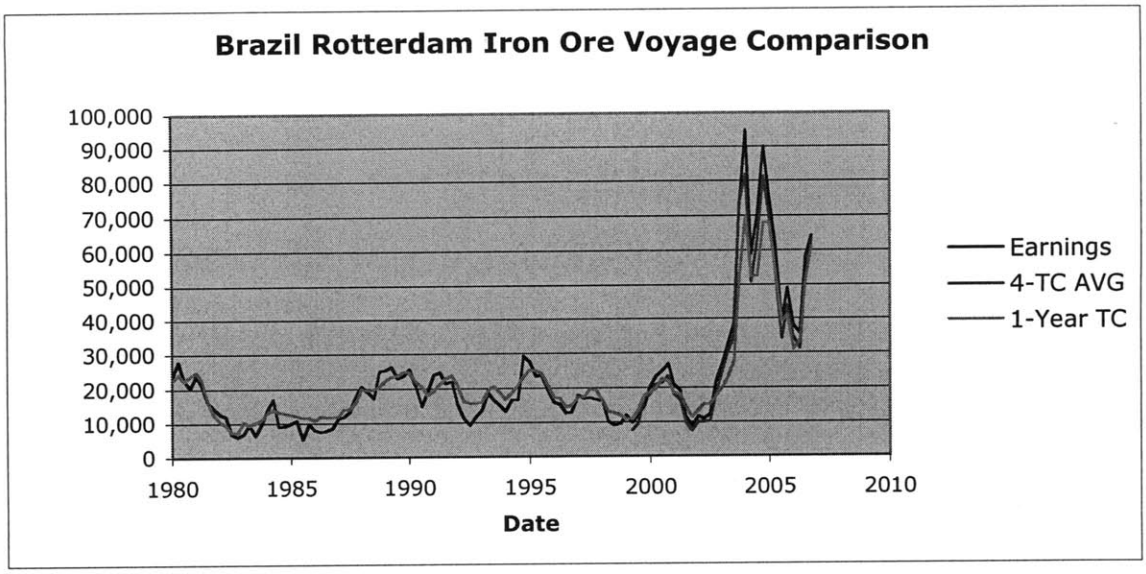


Fig. 2.4-9: TC Equivalent Earnings Compared with 1-Year TC Earnings – using data from [Marsoft 2007a]

It is clear from the graph how the equivalent earnings from a voyage charter are aligned with the earnings from time charters.

The daily cape earnings on the main coal voyages to Rotterdam and China are shown in Fig. 2.4-10 and Fig. 2.4-11.

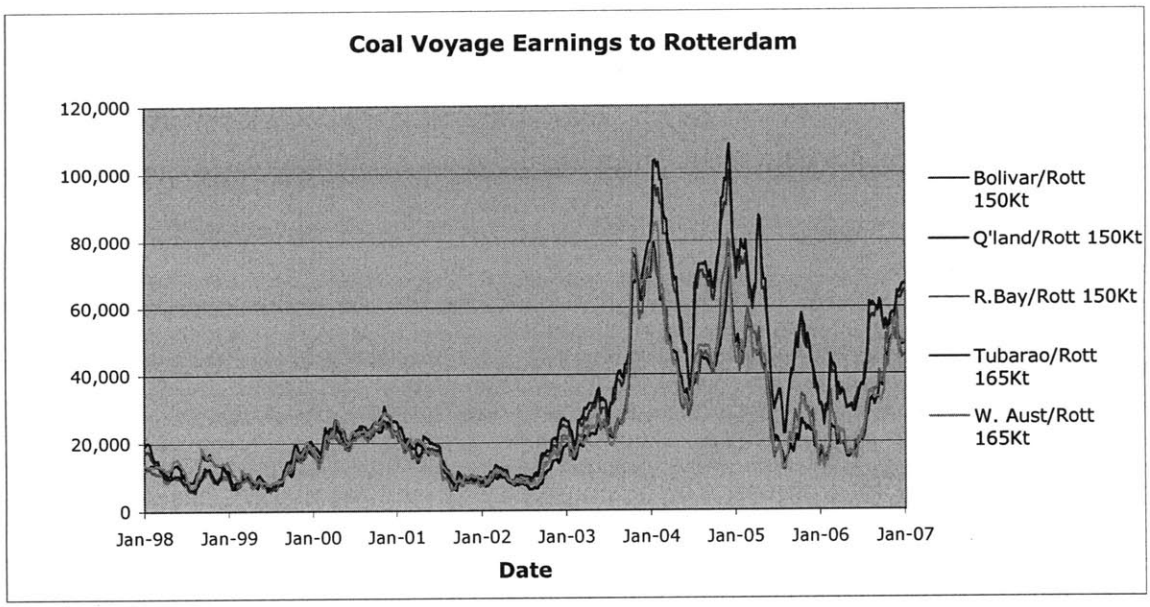


Fig. 2.4-10: Coal Freight Rates along the Main Routes to Rotterdam [Clarksons 2007a]

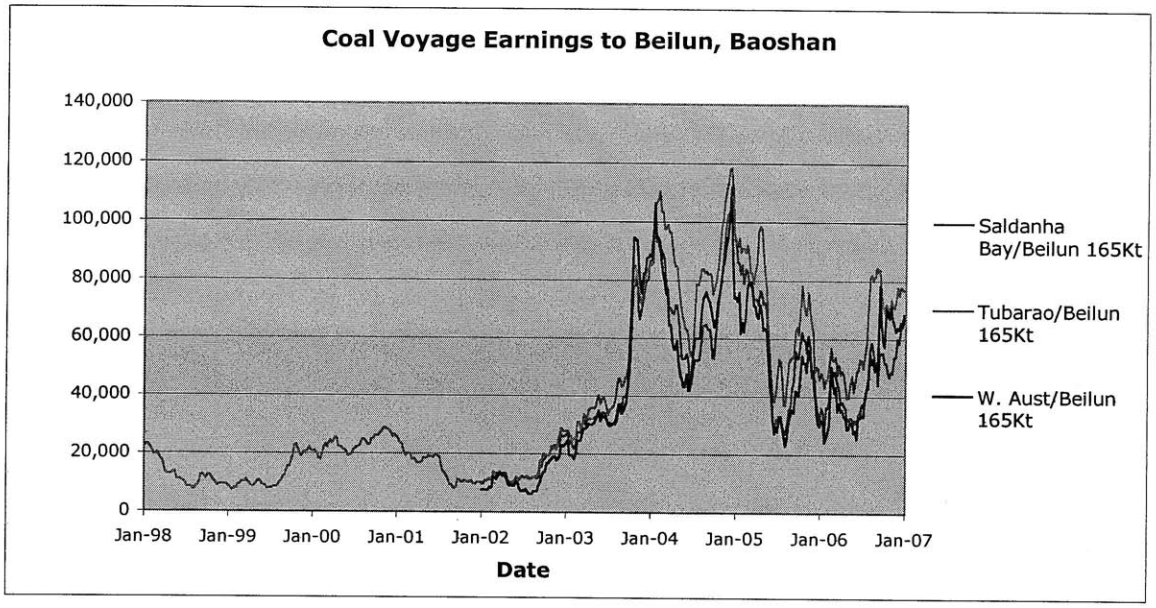


Fig. 2.4-11: Iron Ore Freight Rates along the Main Routes to China - Beilun [Clarksons 2007a]

As can be observed, the freight rates along the various routes are closely related and run parallel to each other. This is because they constitute very close substitutes (for shipowners). An increase in freight rates along a particular route leads to a corresponding increase in quantity along that route and a decrease in supply along the remaining options. This forces freight rates along other routes to follow the trend. Differences in rates exist because substitutability between routes is limited by the need to ballast from one region to another. Iron ore and coal cargos along the same route however constitute closer substitutes and therefore rate differences between them are small.

2.4.4 Spot Charter Rates

China's demand for iron ore, which is currently driving the market, has created flow irregularities. Capesize earnings are therefore significantly higher along front hauls (Atlantic to Pacific) compared to backhauls (Pacific to Atlantic). The gap between them however has narrowed lately as a result of America's increasing demand. This is demonstrated in Fig. 2.4-

12, which shows the daily earnings for transatlantic and transpacific rounds and front-haul and backhaul voyages.

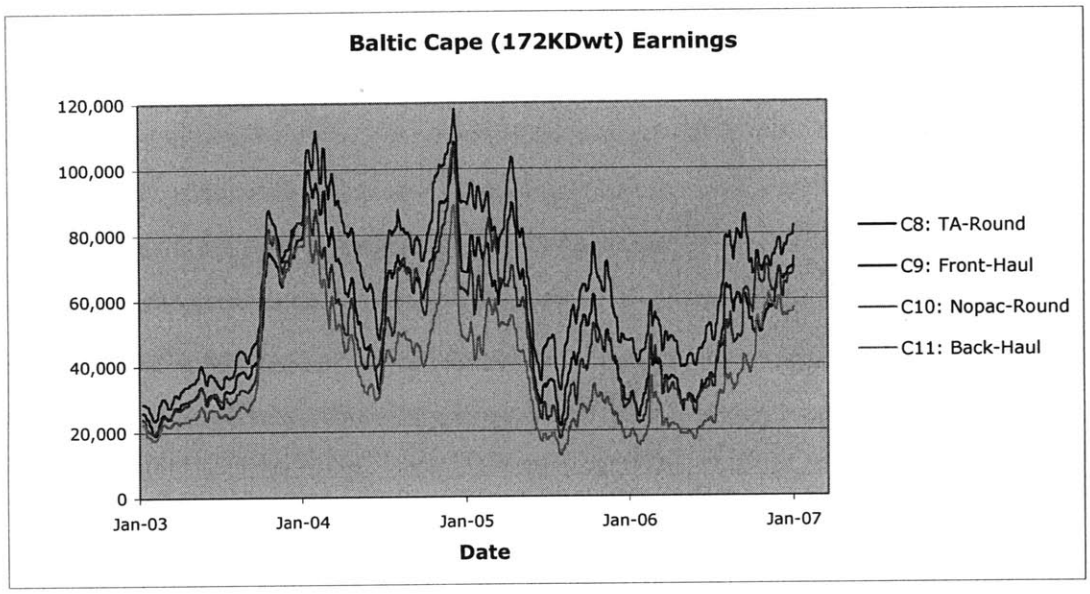


Fig. 2.4-12: Earnings along the 4 TC Routes – using data from [Baltic Exchange 2007 & Clarksons 2007a]

Besides the Baltic Dry Index (BDI), today the Baltic Exchange also produces indices for the various size groups of bulk carriers such as the Baltic Cape Index (BCI) and the BPI (Baltic Panamax Index). These are composed daily using the input of several panelists and they reflect the daily freight market. Fig. 2.4-13 shows the BCI since its introduction in 1999 along with the BCI and average earnings. "Average earnings" is simply the average of the 4 TC routes shown in Fig. 2.4-12.

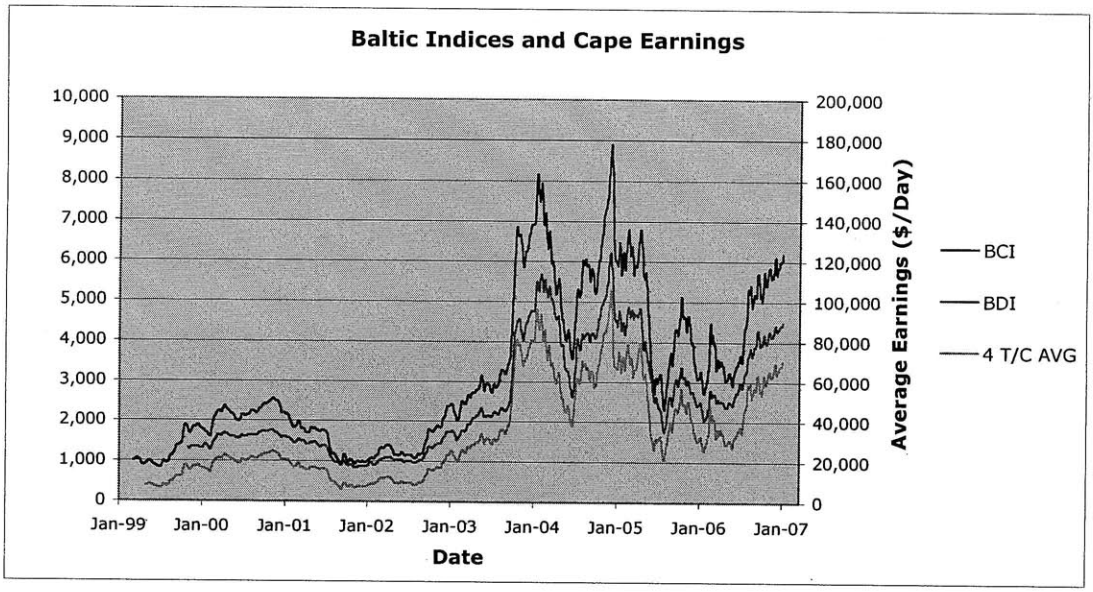


Fig. 2.4-13: BCI, BDI and Average of the 4 TC Routes 2001 - using data from [Baltic Exchange 2007 & Clarksons 2007a]

The close alignment of BCI with the average earnings of the 4 TC routes shows that it is an accurate measure of the market. Again comparing BCI with BDI shows how cape earnings have followed the dry bulk market while being affected slightly more by the current boom since 2003.

2.4.5 Period Charter Rates

Period charter rates tend to be slightly less volatile than spot rates depending on the period length. In other words, 1-year charter rate peaks are lower than those of spot rates and higher than those of 3-year charters. The highest 1-year fixture ever reported was that of the 2004-built *"Cyclades"* earlier this month at $92,500/day [Lewis 2007c]. The highest spot charter ever fixed was last week (May 2007) at $145,000/day. Average spot earnings are currently about $15,000/day higher than this value and on an upward trend. This conclusion is also clear in Fig. 2.4-14, which shows 170Kdwt cape spot and time charter earnings for various period lengths.

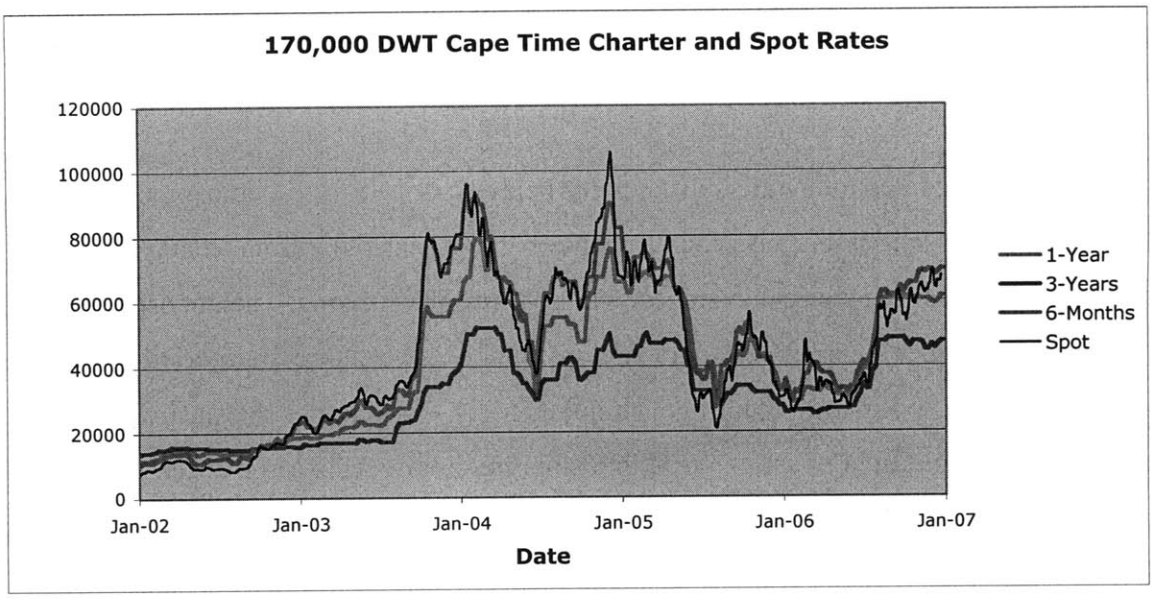


Fig. 2.4-14: Spot and Time Charter Earninigs for 170KDwt Capes – using data from [Baltic Exchange 2007, Braemar 2007a & Clarksons 2007a]

The reason is that one would be more likely to charter at a rate closer to the average spot market when chartering for a longer time. Fluctuations about an average value are therefore smaller for longer period charters. It should be noted that the "average" is not necessarily a historical average. It is what the people in the current market believe to be an average market and this can change significantly after a big crisis as in 1986 or after a big boom as in 2003. 10-year charter rates today for example are about $40,000/day, which is remarkably high compared not only to the 15 or 20-year average but also to the pre-2003 record high spot market rates.

It can also be seen in Fig. 2.4-14 that average time charter rates are lower than those of the spot market and decrease with t/c length. This is because they provide a steady, long term and secure income, which is valued by many owners, particularly IPOs. Note that the 6-month time charter is almost equivalent to spot chartering since a typical voyage charter lasts for a few months.

For a given charter period length in a given market, the rate depends on the reliability of the charterer and the number and quality of assets that they own. When chartering a vessel on period in a high market, one relies on the fact that the charterer will continue to pay the

agreed rate if the market goes down. The risk of having to renegotiate varies depending on the integrity of the charterer and the probability of the market declining. Each individual owner may also interpret it differently. More importantly, time charter rates depend on market expectations.

Time charter rates today are substantially below spot rates and decrease significantly with period length. This is because many people believe that the current market, which is very strong compared to historical averages, will not last for very long. The opposite was true in the 1983 crisis when people were very optimistic about the future and period rates were thus higher than the spot market. During a shipping crisis, time charter rates usually increase with period length and the opposite is true in a shipping boom. This can be seen in Fig. 2.4-15 and Fig. 2.4-16, which show historical 6-month, 1-year and 3-year charter rates for 150Kdwt and 127.5Kdwt capes respectively.

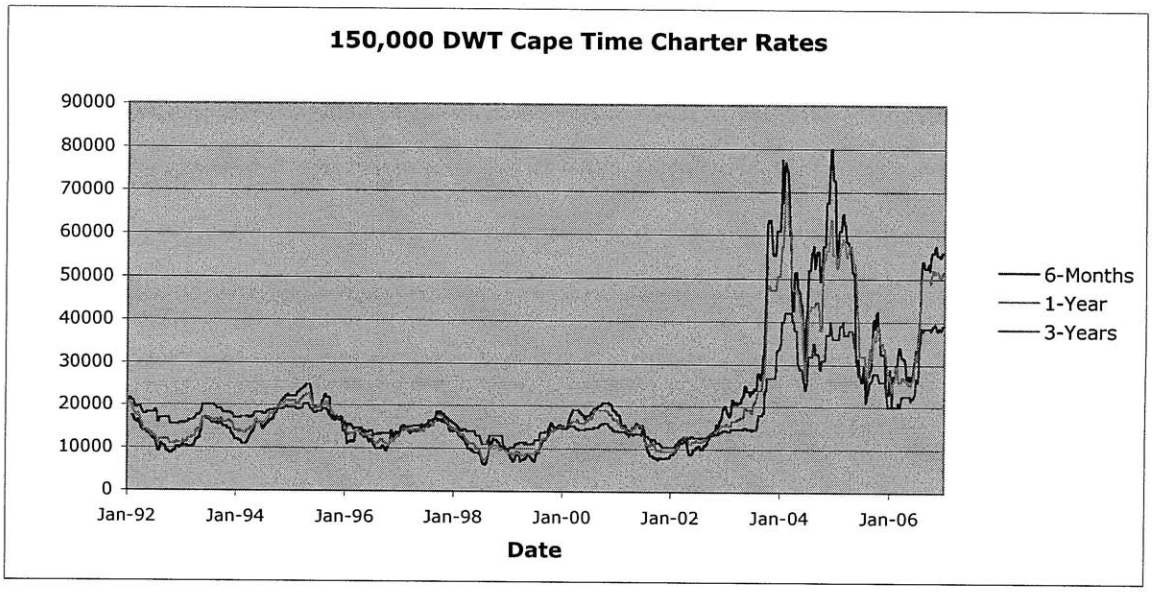


Fig. 2.4-15: Spot and Time Charter Earninigs for 150KDwt Capes – using data from [Baltic Exchange 2007 & Clarksons 2007a]

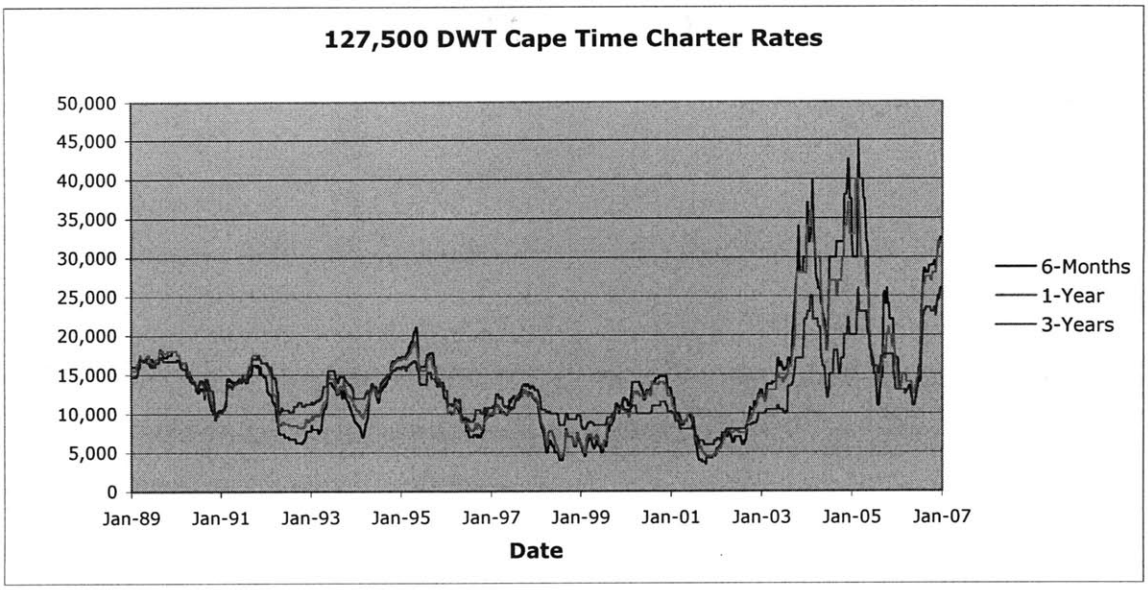


Fig. 2.4-16: Spot and Time Charter Earninigs for 127.5KDwt Capes – using data from [Baltic Exchange 2007 & Clarksons 2007a]

One can also see that there is a time lag or a phase difference between the charter rates of various lengths. 3-year charter rates for example increase and decline later than 1-year charter rates. The 3-year charter rate curve therefore appears to be slightly shifted to the right (forward in time) compared to the 1-year time charter rate curve.

The time lag is analogous to the period length. This is because the period length corresponds to the level of commitment involved in chartering. After a market change, new rates are often perceived as temporary. People therefore often wait until the new market level is somewhat established before chartering for a long period, as this takes a more sophisticated decision than a short charter.

It is also observed by comparing Fig. 2.4-14, Fig. 2.4-15 and Fig. 2.4-16 that charter rates for similar periods are significantly higher for larger vessels. This is clearer in Fig. 2.4-17, which shows 1-year and 3-year time charter rates for 170Kdwt and 150Kdwt capes.

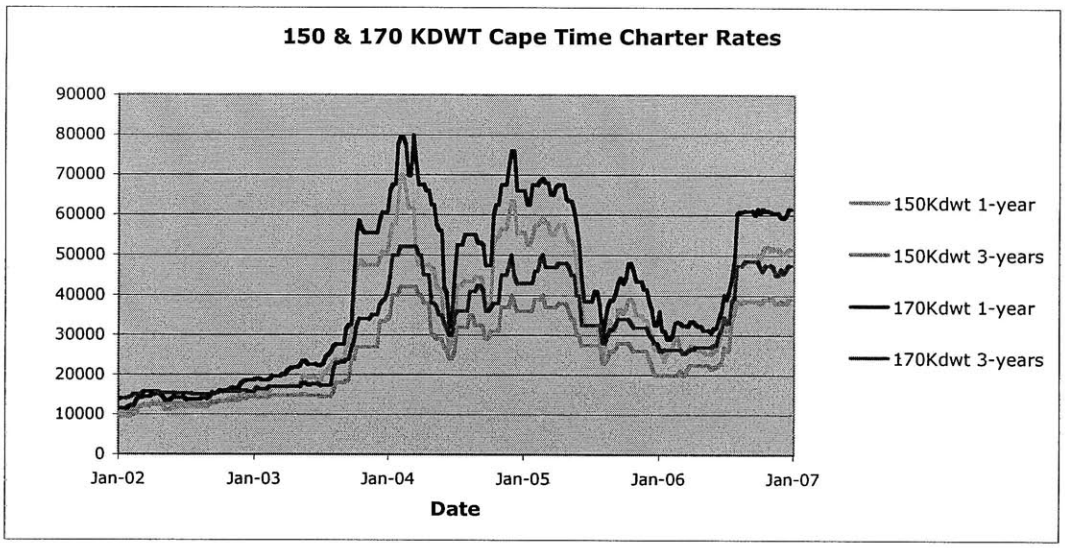


Fig. 2.4-17: 1-year and 3-year Time Charter Rates for 170KDwt a nd 150KDwt Capes – using data from [Baltic Exchange 2007, Braemar 2007a & Clarksons 2007a]

Fig. 2.4-17 clearly shows the decrease in rates with period length and the decrease in rates with ship size. It is also clearly shown that the time lag is consistently dependent on period length for the two ship sizes, and independent of ship size.

2.4.6 Conclusions

- Freight rates depend on the fleet utilization and their direction is driven by changes in global supply and demand

- There will be a tight balance between supply and demand until 2010 but the increasing scrapping pool will allow supply to decrease if demand drops and this will prevent freight rates from dropping significantly

2.5 Ship Values and the S&P Market

2.5.1 Introduction

Ship values are dictated by their earning capacity, their age, the newbuilding price and the scrap value. The drastic changes that have taken place since the fall of 2003 however, has had a big impact on the Sale and Purchase (S&P) market, and has made ship valuations a complicated task. Some remarkable phenomena have been observed making this a very interesting topic to explore. As commented by Mr. Sydney Levine for example, the ratio of prices between a 20-year-old and a 5-year-old vessel increased steeply in 2003 after being steady for decades. Furthermore, the newbuilding has not only become cheaper than the secondhand, but is now also cheaper than the 10-year old vessel.

2.5.2 Database

Mr. Sydney Levine provided a large database of capesize S&P transactions that have taken place between December 1987 and December 2006 [Levine 2006]. This S&P database was completed by adding data that was collected from reports by Harry Vafias [Vafias 2007], Braemar Seascope Ltd. [Braemar 2007b], and transactions reported in Tradewinds [Tradewinds 2007]. The complete S&P database consists of 285 secondhand dry bulk cape transactions between December 1987 and March 2007. This does not include newbuilding orders and newbuilding resales, which were kept separately. The details of the S&P database are summarized in Table 2.5-1.

DATABASE DETAILS	
Period	Dec'87 – Mar'07
Number of Ships	285
Average Size	163,373 dwt
Average Price	$30.9 m
Average Age	11.3 years

Table 2.5-1: S&P Database Information

2.5.3 Time Distribution of S&P Transactions

While bearing in mind that year 1987 only includes December and year 2007 only includes the first quarter, it is safe to assume that the S&P database is fairly complete meaning that it includes most reported deals. Fig. 2.5-1 shows how the 285 capesize vessel transactions that took place in the investigated period, were distributed over time.

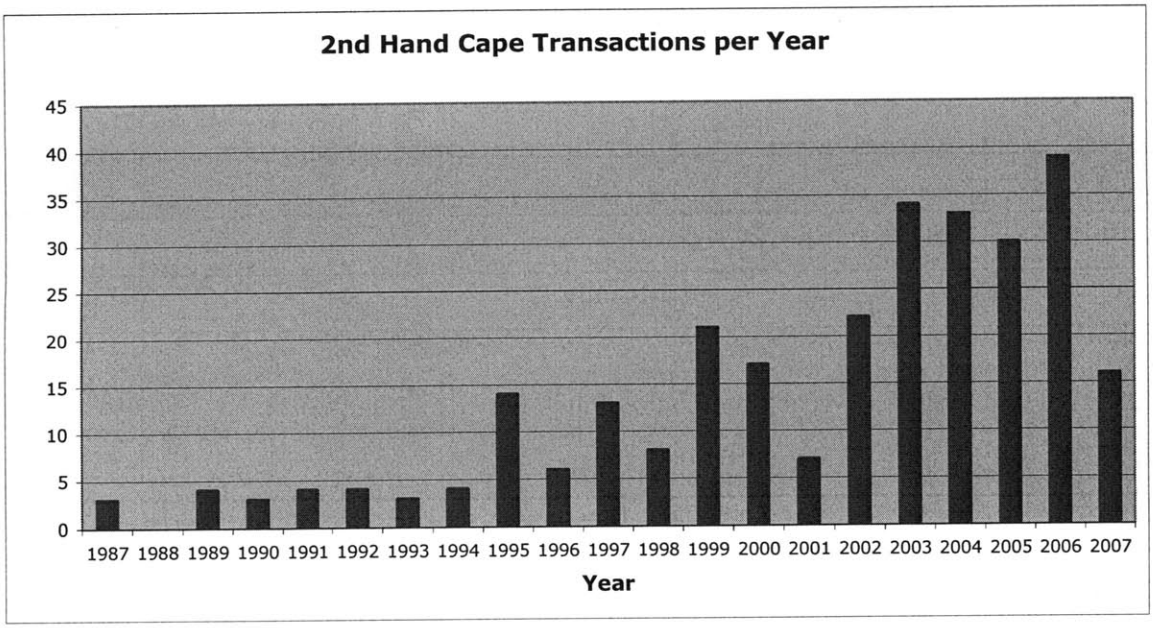


Fig. 2.5-1: Number of Transactions Recorded from the Database for Each Year

Interestingly, it is observed that the frequency of transactions was higher during the years when the market was high (e.g. 1995 and 2003 until today). Fig. 2.5-2 shows the number of transactions per quarter along with the 1-year time charter rates for a 150Kdwt cape to illustrate this. The historical values of time charter rates were obtained from [Clarksons 2006a] and completed by considering relevant fixtures in the charter market.

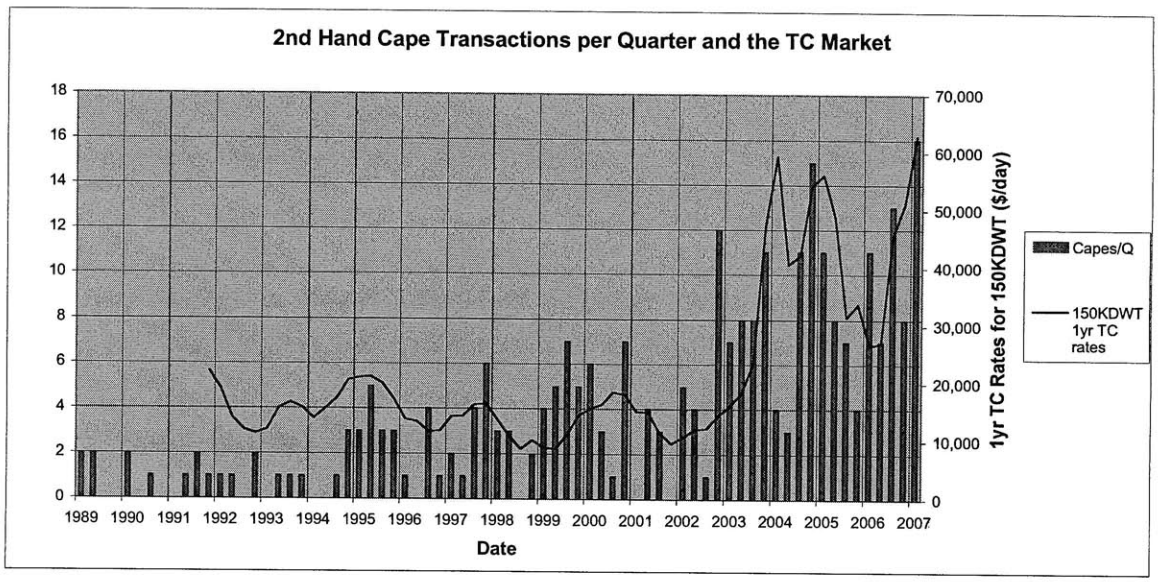


Fig. 2.5-2: Number of S&P Transactions per Quarter along with 1-year TC Rates

How to Read Fig. 2.5-2		
Consider 2007 Q1 (far right)		
Legend	Meaning	Value
Capes/Q	Number of cape deals between 1-Jan-07 and 31-Mar-07	16
150KDWT 1yr TC rates	Average 1-year time charter rates between 1-Jan-07 and 31-Mar-07 for a 150,000dwt cape	$62,900/day

Table 2.5-2: How to read Fig. 2.5-2

Clearly, activity in the S&P market is closely correlated to freight rates. Since earnings affect prices, the same can be also said about activity in the S&P market and prices.

Fig. 2.5-3 shows the frequency of transactions along with the price of a 10-year-old typical cape.

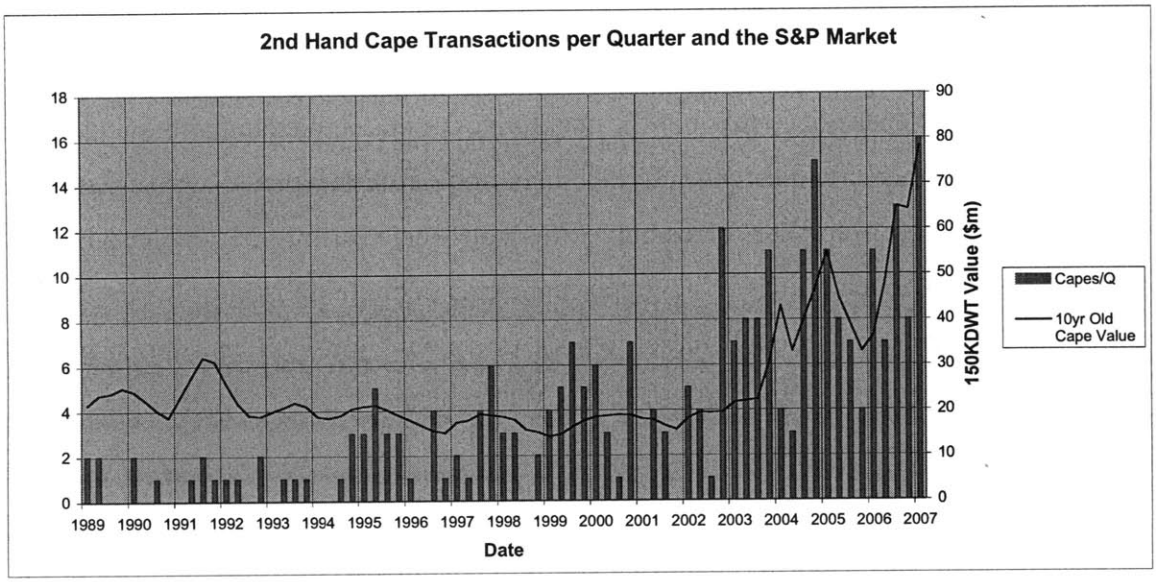


Fig. 2.5-3 Number of Transactions per Quarter and Typical Cape Prices

How to Read Fig. 2.5-3		
Consider 2007 Q1 (far right)		
Legend	Meaning	Value
Capes/Q	Number of cape deals between 1-Jan-07 and 31-Mar-07	16
10yr Old Cape Value	Average value of a 10-year old cape between 1-Jan-07 and 31-Mar-07	$78.2m

Table 2.5-3: How to read Fig. 2.5-3

As shown on the diagram, it appears that when the S&P market is strong, meaning that prices are high, there is more activity going on which is obviously to the benefit of the sellers.

2.5.4 Determinants of Ship Values (Size, Age, Capacity & Time)

The data was analyzed in order to examine the factors that determine ship values. Due to the size of the database, it is feasible for qualitative purposes to examine the independent effect of each parameter while ignoring all others and assuming that they average out. A graph of price against ship size for example was constructed using the whole database as shown in Fig. 2.5-4. Each point on the graph represents a single transaction while the black line is a linear regression through these points. As shown by its gradient, price generally increases with size but the low value of R^2 (0.011) indicates that other factors have a big impact.

The model indicates that on average, one would pay an extra $30,000 for each additional 1,000dwt on size. This is significantly lower than the real value for the size range that we are concerned with. The price difference between a 150Kdwt and a 175Kdwt vessel for example is usually higher than $750,000, perhaps by an order of magnitude. It is a small number of large and old (cheap) ore carriers in the 200Kdwt+ range that can be identified at the right end of the graph, leading to this result.

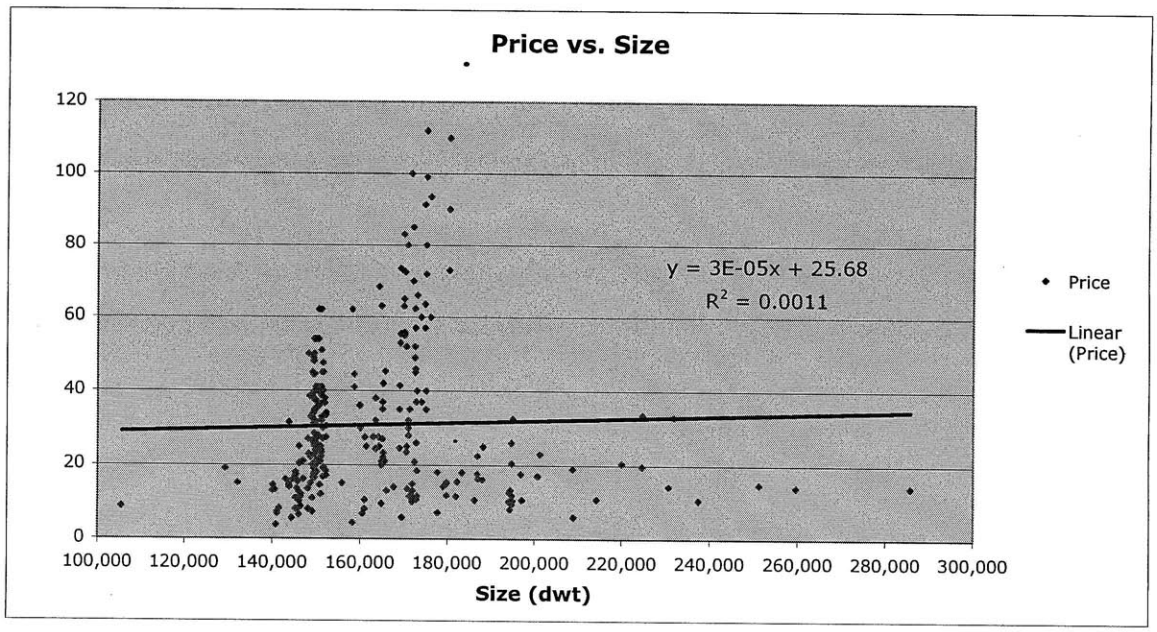


Fig. 2.5-4: Impact of Size on Ship Value

How to Read Fig. 2.5-4		
Consider 259,587dwt		
Legend	Meaning	Value
Price	The price of a transaction involving a ship of 259,587dwt	$14m
Linear (Price)	Linear Regression model prediction for the price of an average 259,587dwt vessel	$33.5m

Table 2.5-4: How to read Fig. 2.5-4

A similar graph was produced to evaluate the effect of age on vessel price. This is presented in Fig. 2.5-5. Again a linear regression model has been used representing a straight-line depreciation.

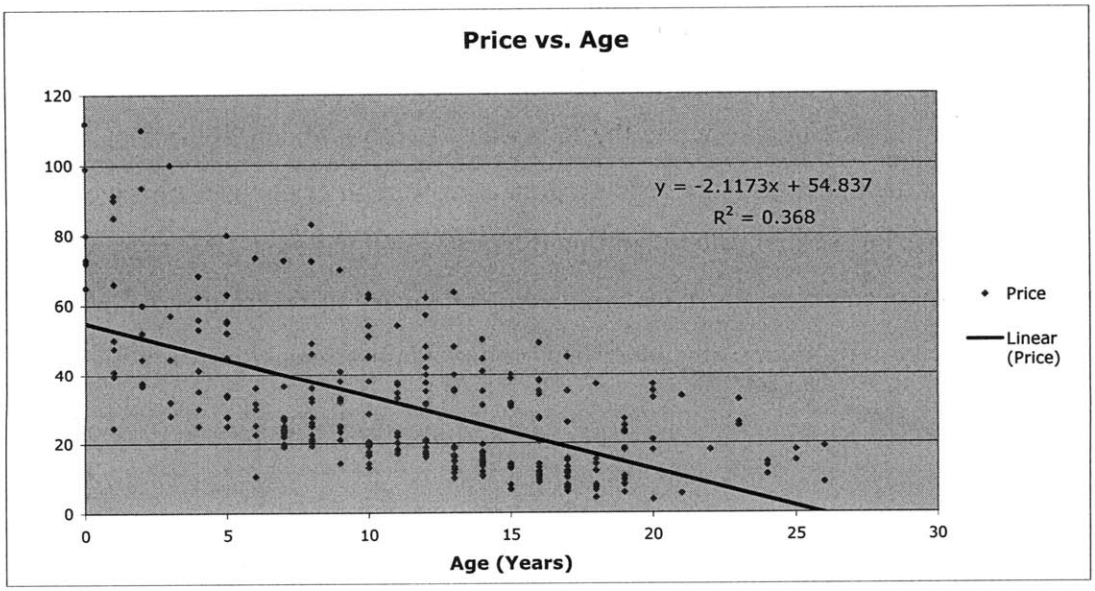


Fig. 2.5-5 Impact of Age on Ship Value

How to Read Fig. 2.5-5		
Consider 22 years of Age		
Legend	Meaning	Value
Price	The price of a transaction involving a 22-year old vessel	$18m
Linear (Price)	Linear Regression model prediction for the price of an average 22-year old vessel	$8.3m

Table 2.5-5: How to read Fig. 2.5-5

The y-intercept of the regression model is $55m while the gradient is -$2m/year. This means that based on the collected data, the model values a new ship at about $55m, and the vessel is depreciated by an average of $2m per year. One can see on the y-axis of the graph (x=0), that all the points lie above the y-intercept. The reason for this is that all new vessel transactions took place in the period between 2004 and today, during which prices were significantly above average.

The x-intercept of the graph is 26 years meaning that model predicts the value of an average ship to drop to 0 at that age. If one however assumes an average scrap value of $5m, the model predicts the scrapping age at 23.5 years, which is about right. The values predicted by this model are all reasonable while the R^2 value (0.368) is much higher than that of the previous model. This indicates that age has a greater impact on price than ship size.

Since it has been established that price increases with size and decreases with age, an attempt is made to combine the two parameters on one graph. Price was therefore first divided by capacity to produce $/dwt, and then plotted against age as shown in Fig. 2.5-6.

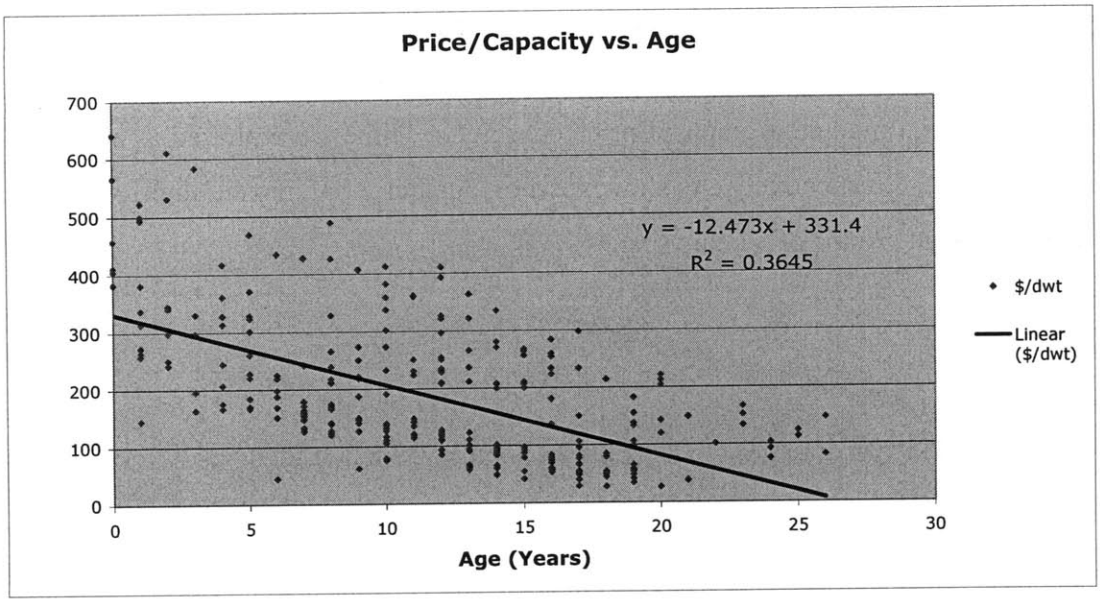


Fig. 2.5-6: Impact of Age on Ship Price/dwt

How to Read Fig. 2.5-6		
Consider 22 years of Age		
Legend	Meaning	Value
$/dwt	The price/capacity of a transaction involving a 22-year old vessel	101$/dwt
Linear ($/dwt)	Linear Regression model prediction for the price/capacity of an average 22-year old vessel	57$/dwt

Table 2.5-6: How to read Fig. 2.5-6

Fig 2.5-6 looks like Fig. 2.5-5 with a similar level of scatter. The regression model of this graph values a new 175,000dwt at $58m and predicts its rate of depreciation at $2.2m per year. If one assumes a scrapping price of $6m, the scrapping age is predicted to be 23.8 years, which again is about right. The value of R^2 (0.365) is about the same and shows no increase from that of Fig. 2.5-5 (0.368). This shows that dividing price by capacity (to account for the effect of size) does not improve the scatter or accuracy of the model.

The above analysis provides an insight on the effect of the examined parameters on price. The data however was very scattered and the accuracy of the regression models was low with R^2 always less than 0.4. This is because the most important parameter has been

ignored. That is the market, or in other words, time. Ship values are very closely related to ship earnings so when the market is high, prices are up and vice versa. To account for this, a graph of price vs. time and a graph of price/capacity vs. time were plotted as shown in Fig. 2.5-7 and Fig. 2.5-8 respectively. As shown earlier, age has a big impact on prices so the data was divided in age groups of 5 years span.

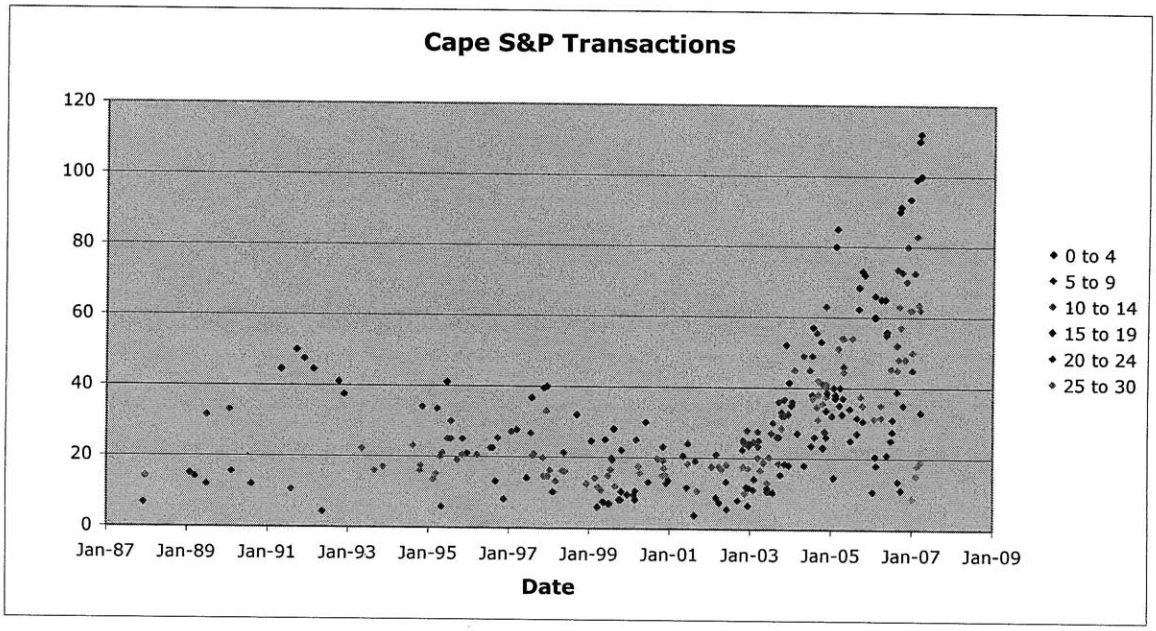


Fig. 2.5-7: Price vs. Time for the various Age Groups

How to Read Fig. 2.5-7		
Consider March 2007		
Legend	Meaning	Value
0 to 4	Price of a 0-4 year old cape deal on 03/12/07	$112m
10 to 14	Price of a 10-14 year old cape deal on 03/20/07	$62m
20 to 24	Price of a 20-24 year old cape deal on 03/24/07	$33m
25 to 30	Price of a 25-30 year old cape deal on 03/24/07	$19m

Table 2.5-7: How to read Fig. 2.5-7

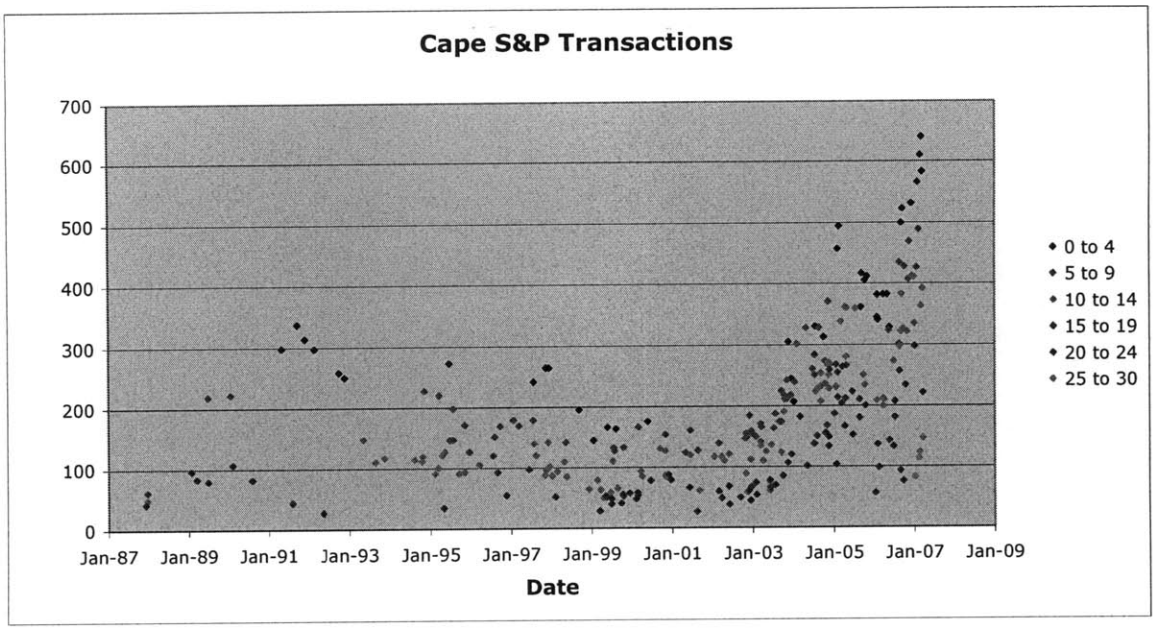


Fig. 2.5-8: Price/Capacity vs. Time for the various Age Groups

How to Read Fig. 2.5-8		
Consider March 2007		
Legend	Meaning	Value
0 to 4	Price/Capacity of a 0-4 year old cape deal on 03/12/07	640$/dwt
10 to 14	Price/Capacity of a 10-14 year old cape deal on 03/20/07	392$/dwt
20 to 24	Price/Capacity of a 20-24 year old cape deal on 03/24/07	222$/dwt
25 to 30	Price/Capacity of a 25-30 year old cape deal on 03/24/07	147$/dwt

Table 2.5-8: How to read Fig. 2.5-8

As shown on the graphs, dividing into age groups greatly reduced the data scatter. Prices or prices per capacity of the age groups move parallel to each other along with the fluctuating market. The market affects all age groups while the newest ones are higher. There are some exceptions to this because of data scatter, which is explained by the age range of the groups. To overcome this, another graph was produced, shown in Fig. 2.5-9, which shows price vs. time for vessels of 0, 5, 10, 15, 20 and 25 years old.

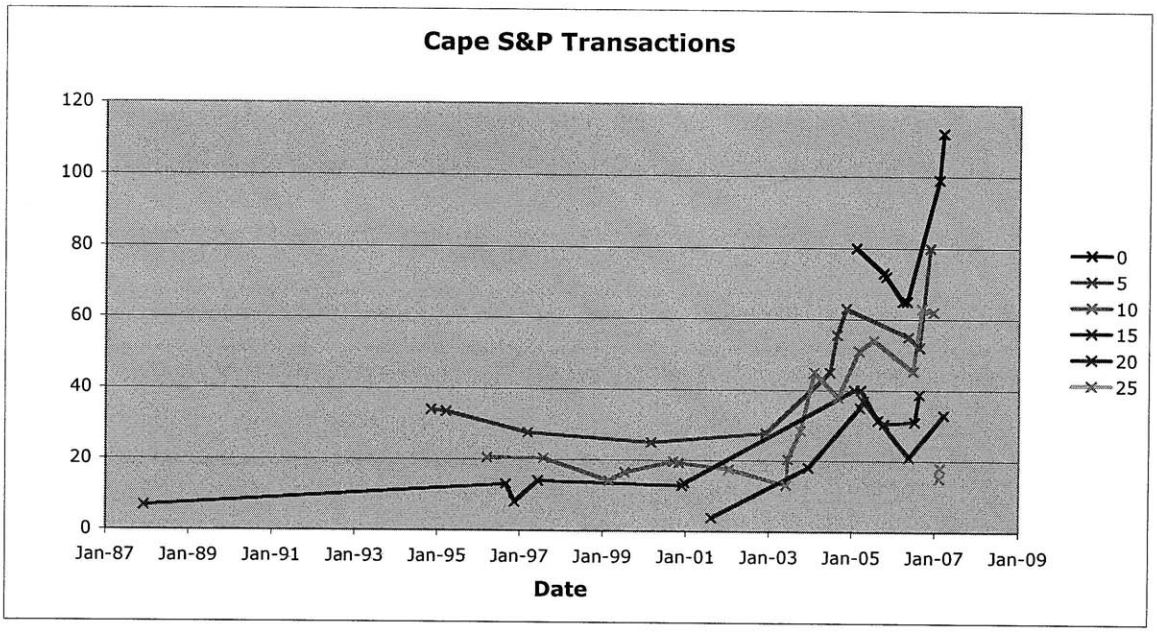


Fig. 2.5-9: Price vs. Time for Multiples of 5 Age Vessels

How to Read Fig. 2.5-9		
Consider March 2007		
Legend	Meaning	Value
0	Price of a 0 year old cape deal on 03/12/07	$112m
20	Price of a 20 year old cape deal on 03/24/07	$33m

Table 5.5-9: How to read Fig. 2.5-9

The scatter in this graph has greatly been reduced to the extent that it is sensible to connect the data points as shown in Fig. 2.5-9. The lines connecting the data points move relatively parallel with the newest ones being on top. Overlapping only occurs when there is lack of data for a specific point in time.

2.5.5 Critical Age Discounts

As we have seen, ship values fluctuate with the market and are highly dependent on age. Besides the decrease of price with age however, there are also known to be discontinuities in the age/price relationship. These typically occur at ages that are multiples of 5 after the age of 10 years for a variety of reasons.

US investors or IPO's for example, do not approve for vessels older than 10 years old. Furthermore, there are many Japanese companies whose policy is to operate vessels until the age of 10 and then sell them. They also construct them accordingly with a high percentage of high tensile steel, which provides some benefits but also has many drawbacks, which become more important during the later stages of a ship's life. Since these owners and IPO's constitute a significant portion of the market, this creates an abrupt decrease in ship values at the age of 10 years.

Most banks do not finance vessels over 15 years old while it is almost impossible to get finance for vessels over 20 years old. This creates a similar effect in the age/price relationship at the age of 15 and 20 years. Furthermore, there is an age limit of 25 years for all vessels carrying iron ore. Since iron ore is the main commodity transported by capes, this also has a big impact.

In addition to these factors there are also various age limitations of cargo contracts, which also contribute to the discontinuities in the age price relationship. In order to investigate these discontinuities, the database was used to create graphs of Price vs. Time for transactions of vessels of the critical age (e.g. 10 years old), one and two years younger, and one year older. The purpose is to show the relatively larger decrease in price at the critical age (e.g. between 9 and 10) compared to one year younger (between 8 and 9) and one year older (between 10 and 11). This was carried out for the age of 10, 15, 20 and 25 years and the graphs are shown in Fig. 2.5-10, 2.5-11, 2.5-12 & 2.5-13 respectively. Graphs of Price/Capacity vs. Time were also plotted for the same ages and shown in Fig. 2.5-14 to 2.5-17.

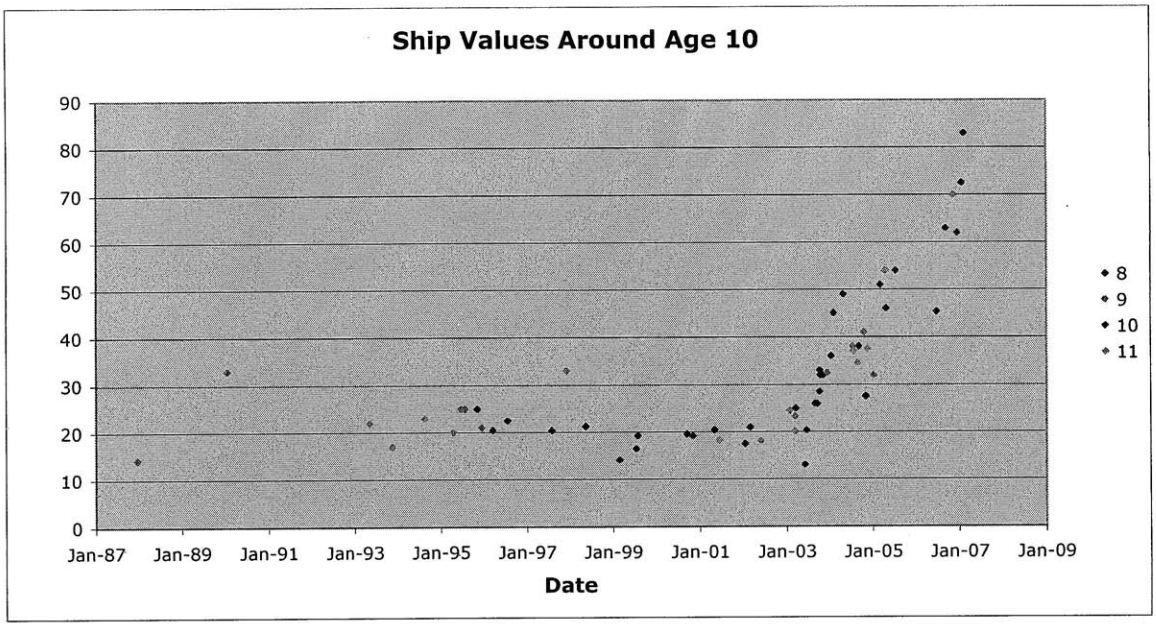


Fig. 2.5-10: Vessel Price vs. Time to Show the Discount at 10 Years Old

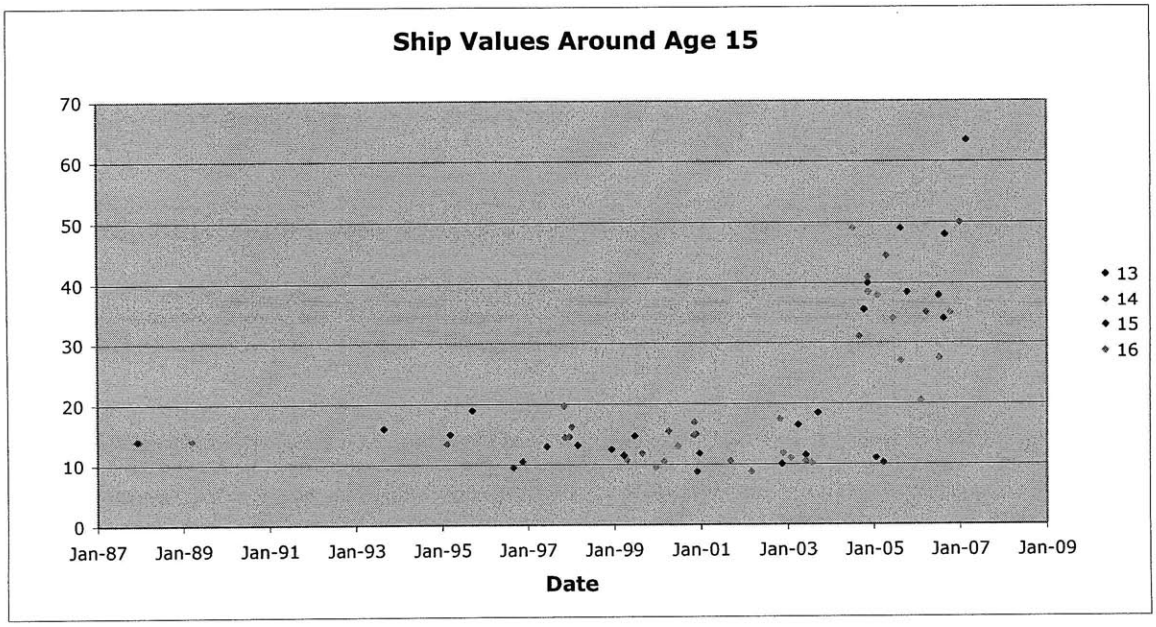


Fig. 2.5-11: Vessel Price vs. Time to Show the Discount at 15 Years Old

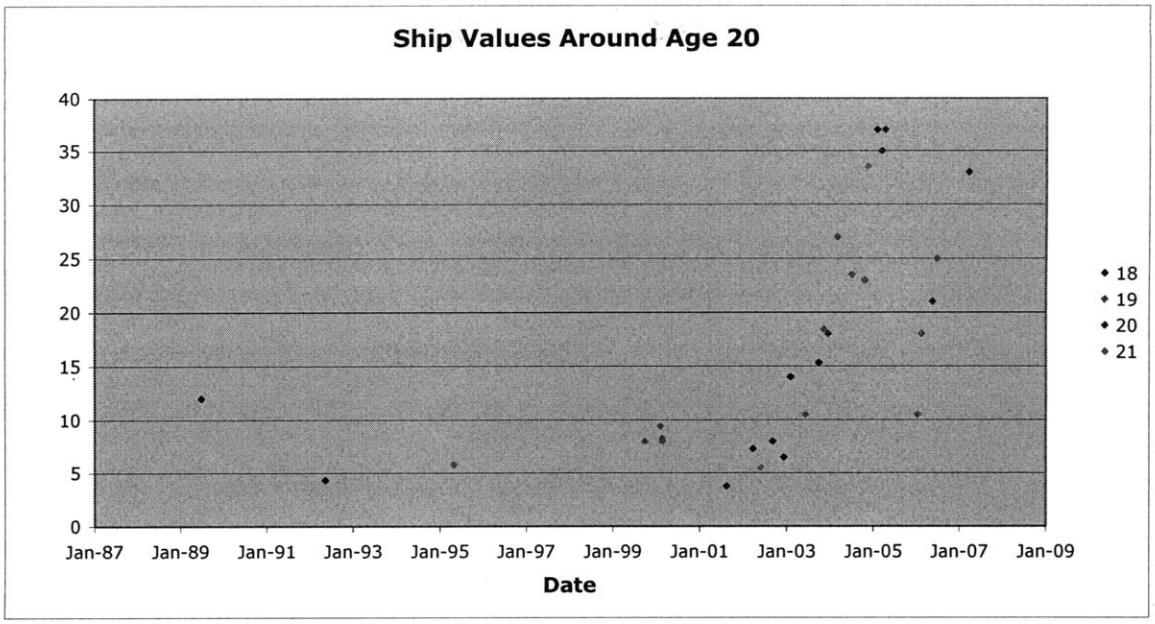


Fig. 2.5-12: Vessel Price vs. Time to Show the Discount at 20 Years Old

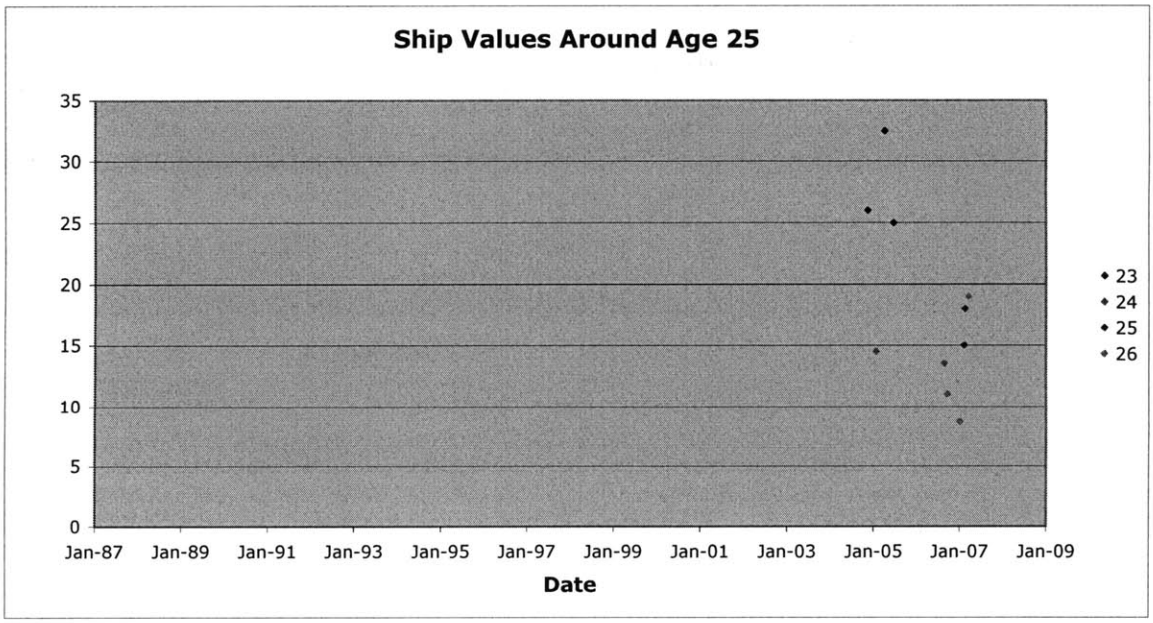


Fig. 2.5-13: Vessel Price vs. Time to Show the Discount at 25 Years Old

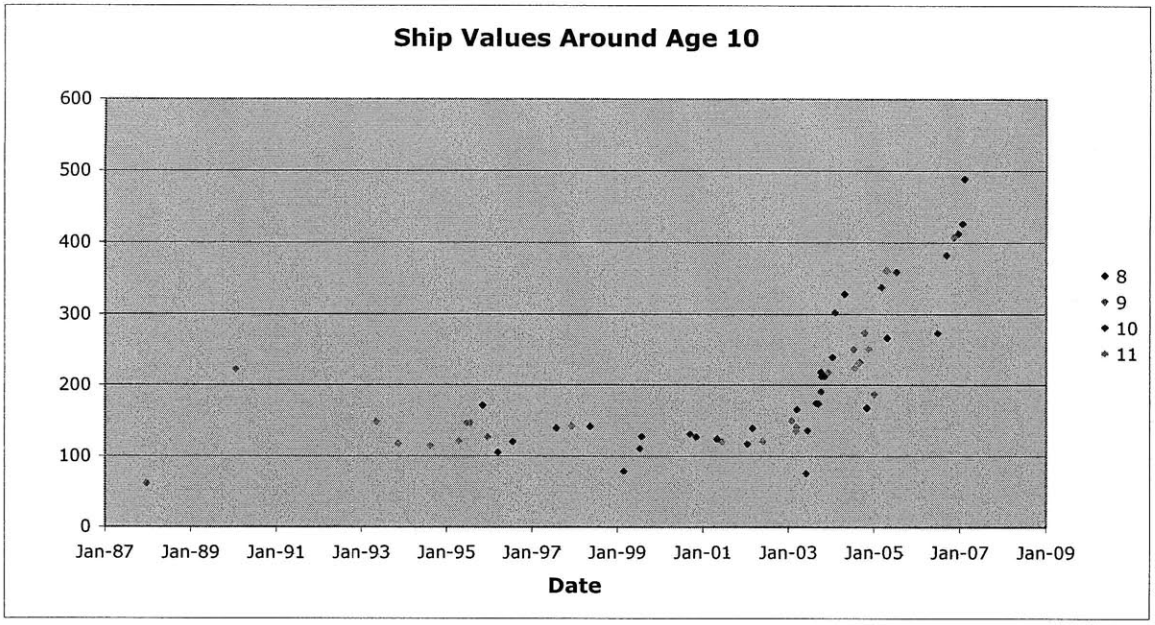


Fig. 2.5-14: Vessel Price/Capacities vs. Time to Show the Discount at 10 Years Old

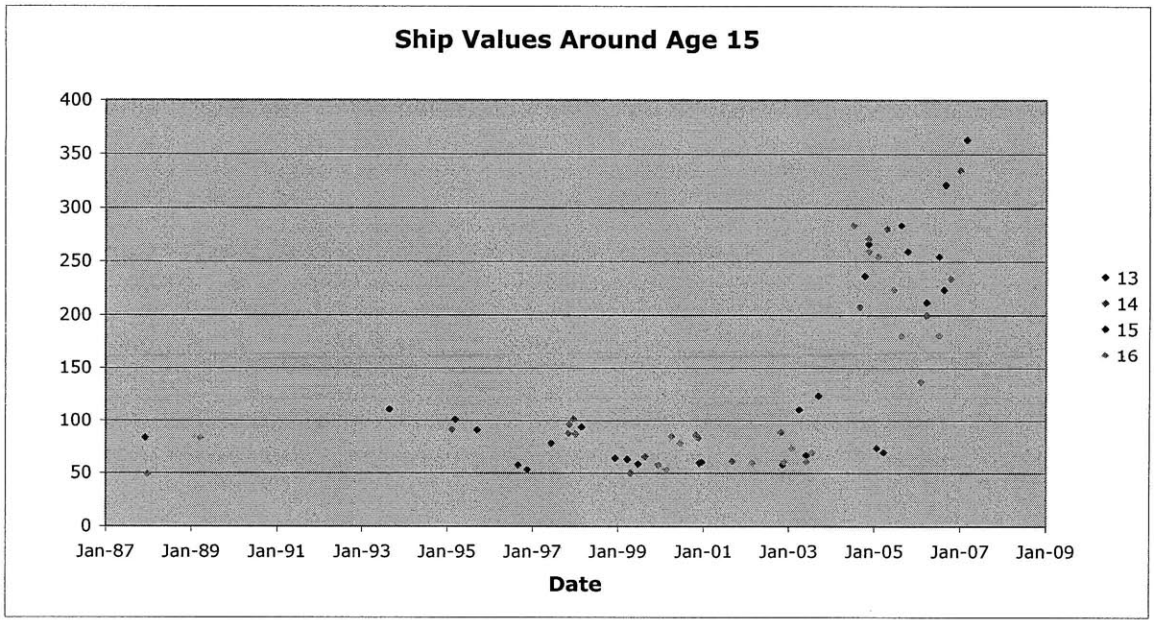


Fig. 2.5-15: Vessel Price/ Capacities vs. Time to Show the Discount at 15 Years Old

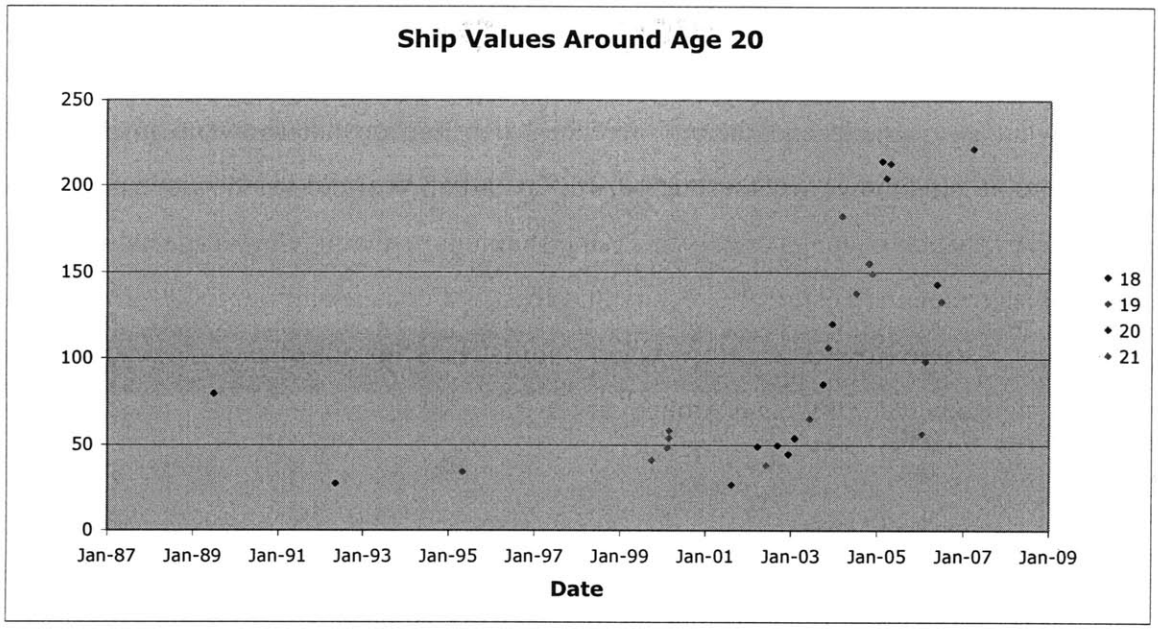


Fig. 2.5-16: Vessel Price/Capacities vs. Time to Show the Discount at 20 Years Old

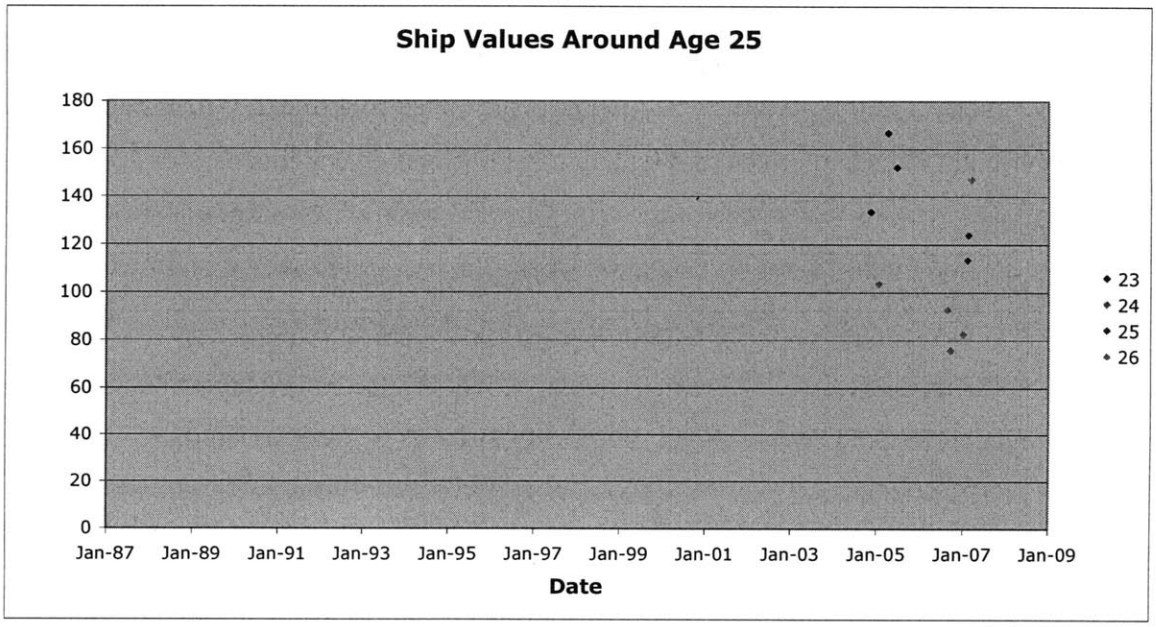


Fig. 2.5-17: Vessel Price/ Capacities vs. Time to Show the Discount at 25 Years Old

Unfortunately, the discontinuity in the age-price relationship is not clear in the diagrams. There could be many reasons for this but the most important one is insufficient data. Due to the small size of the capesize fleet and the small number of transactions each

month, it is almost never the case that a buyer will be given the choice between say a 9-year old vessel and a 10-year old vessel at a specific point in time. Buyers are therefore forced to go with what is available and their preferences therefore do not show up in the results. Furthermore, it is unknown whether the 10, 15, 20 and 25 year old vessels have passed their special survey, which is due every 5 years. One should note that passing a special survey not only involves the actual cost of the repairs and fees (which is usually in the millions for old vessels), but also the loss of earnings when pulling the ship out of the market for several weeks which can be very high in a strong market.

2.5.6 Other Determinants of Ship Values

So far, the effect of the market (time), ship age and ship size on prices has been studied. There are other factors that also play a significant role. These can be examined by considering a sample of transactions from the S&P database. The list of the reported capesize deals from January 1st 2007 to March 30th 2007 is presented in Table 2.5-10 Please note that the market (freight rates and prices) has had an upward trend during this period.

Date	Name	Built	Size	Notes	Price
02/Jan	SPRING BRAVE	1995	151,066	Delivery in May	62
08/Jan	MONTEGO II	1993	149,391	TC: 30k/d – Dec'08	50
08/Jan	CHS MOON	1990	151,227	-	45
10/Jan	BRILLIANT CORNERS	1981	105,496	-	8.7
26/Jan	LOWLANDS BEILUN	1999	170,162	TC: 37.4k/d-Mar/Jun'10	72.5
05/Feb	YUE MAY	2007	175,000	-	99
14/Feb	DYNASTY	1982	132,082	-	15
14/Feb	PANTELIS SP	1999	169,883	TC: 47.5k/d – Feb'08	83
22/Feb	THIOS COSTAS	1982	145,229	Delivery in May	18
02/Mar	CAPE PELICAN	2005	180,235	-	110

05/Mar	JOHNNY K	1994	174,770	POLAND BLT	63
12/Mar	ANANGEL WISDOM	2007	175,000	-	112
19/Mar	CAPE KASSOS	2004	171,480	Delivery in Sept	100
20/Mar	MARTHA VERITY	1995	157,991	-	62
Mar	AMERICANA	1987	148,982	-	33
Mar	IKARIA	1981	129,237	-	19

Table 2.5-10: Reported Capesize Deals from January 1st 2007 to March 30th 2007

[Vafias 2007, Braemar 2007b, Tradewinds 2007]

2.5.6.1 Ship Builder

The shipyard, or more generally the country where the ship was built, can have a significant effect on the price. Rumanian, Polish or Brazilian ships for example have always been discounted compared to similar Japanese or Korean vessels. To illustrate this, one can compare the JOHNNY K, which was built in Poland, with the MARTHA VERITY. The JOHNNY, being one year older and 10.6% (17,000dwt) larger, was sold for only 1.6% ($1m) more during the same month (two weeks difference).

2.5.6.2 TC Attachment

A t/c attachment may increase or decrease a ship's value depending on the t/c rate compared to the current market, the length of the t/c contract and the risk involved. The risk depends on the trustworthiness of the charterers and the number and kind of assets that they have. The value of a time charter attachment is equivalent to the net present value of the difference between the earnings of the attached charter and the earnings of a charter of the same period length at the current market rate. If the charter attachment is of low risk, the value of the time charter is superimposed on the vessel's charter-free price.

This can be illustrated by comparing the LOWLANDS BEILUN and the PANTELIS SP. These are very similar vessels that were sold within a few days from each other, allowing for only a small market increase. They had different t/c attachments, which explain the difference in their price. Table 2.5-11 shows some crude calculations in order to approximate the charter-free value of the two vessels.

	LOWLANDS BEILUN	*PANDELIS SP*
Deal Date	26-Jan-07	14-Feb-07
Approx. TC Period	3 years	1 year
TC Rate	$37,400/day	$47,500/day
Market Rate at Deal Date for TC Period	$53,000/day	$65,000/day
Rate Difference	-$15,600/day	-$17,500/day
Assumed days per year	355	355
Approximate TC Value	-$16.6m	-$6.2m
Price	$72.5m	$83m
Approx. Charter-Free Price	**$89.1m**	**$89.2m**

Table 2.5-11: Comparison of Capesize Deals to Illustrate the Value of TC Attachments

The charter-free value of the two vessels is very close which shows that the difference in the prices is due to the time charter. A 10-year old, charter-free, 170Kdwt vessel during the same month was worth about $83m while a 5-year old was worth $98m. It can therefore be seen that the estimated value of $89m for the 8-year old vessels is very reasonable. In fact it is the exact value one obtains through linear interpolation.

One should note however that the above are only crude approximations for illustrative purposes. Net present value calculations were not performed. Furthermore, one important factor that was not considered is the vessel's age after the charter. This will affect its residual value but in this example, and more generally in the current market, this is of relatively low importance as the later years are discounted at a much lower rate.

2.5.6.3 Delivery Time

Another factor whose importance has been highlighted over the past few years is the time of delivery of a vessel. When the market is at high levels, the earnings projected over the period that the market is expected to last affect ship prices significantly. 25 and 26-year-old small capes such as the THIOS COSTAS and IKARIA for example will be scrapped immediately if a market crisis finds them in the spot market. They are only selling at circa $20m because of their high earnings in today's market. It is therefore understandable that a later delivery time costs money and therefore reduces the value of the ship in a good market.

Consider the CAPE PELICAN that was sold for $110m, the CAPE KASSOS that went for $100m and the ANANGEL WISDOM that went for $112. The CAPE PELICAN is slightly more modern than the CAPE KASSOS, which has a delivery date in September. The 1-year age difference however does not explain the $10m difference in price since the ANANGEL WISDOM, which is 2 years younger than the CAPE PELICAN, only went for $2m higher.

Six-month charter rates in March on the other hand (until September) were about $72,000/day, so if one assumes running costs of about $5,500/day, this corresponds to earnings of about $12m. Similarly, this explains why a typical newbuilding with delivery in 2010 only costs about $80m even though it will be more modern and larger than the above vessels.

As discussed earlier, if a ship is SS-due or DD-due, meaning that it has to pass its special survey or intermediate survey (Dry Docking), this also involves having to wait for several weeks. The special survey is due every 5 years and there is an intermediate between every two consecutive special surveys. The special survey itself and all the repairs may cost about $1m for a 15-year old cape. Today, the loss of earnings at the daily rate of over $100,000/day for say a duration of 40 days deviation to the yard and repair time is about four times as much.

2.5.7 Historical Cape Prices and Price Ratios

Ship brokers and other companies, such as Marsoft, that carry out research for the maritime industry, try to keep track of ship prices, among other things. These are primarily based on actual deals like the ones in the current database. In order to be consistent however, one must keep track of a specific vessel type, age and size.

As shown earlier, ship values are affected by several factors while the few cape transactions taking place each month involve ships that differ in many aspects. As such, experience and perhaps some empirical formulae are required to convert the prices of the actual deals to those matching the chosen vessel type, age and size.

To account for age differences, one needs to use some sort of depreciation curve along with newbuilding prices for relatively new ships or scrap values for older vessels. To account for size, one needs to use their experience and historical data. Consider a 5-year old 170Kdwt vessel and a 5-year old 150Kdwt vessel for example. Fig. 2.5-18 shows the values for these ships since the beginning of 1990 until today based on data from [Carksons 2006c] and actual transactions from the database.

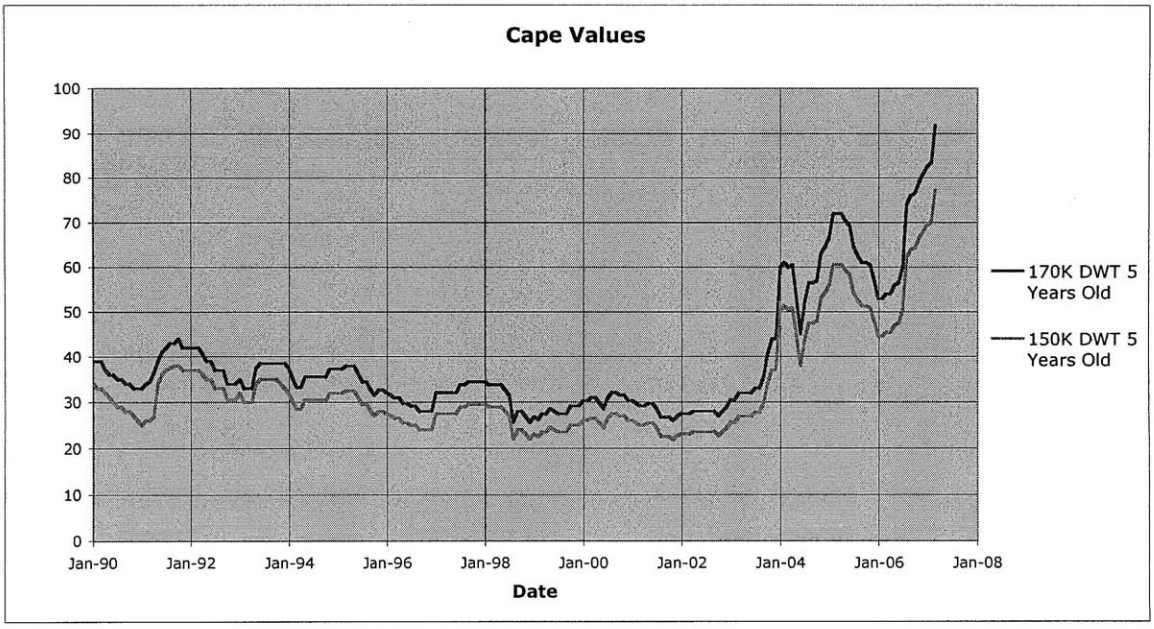


Fig. 2.5-18: Track Record of 5-Year Old 170Kdwt and 150Kdwt Cape Values since January 1990 – Using data from [Clarksons 2006c, Levine 2006, Vafias 2007, Braemar 2007b, Tradewinds 2007]

As it can be seen, the values have been relatively parallel. The price ratio of the 170Kdwt vessel to the 150Kdwt vessel has been fairly constant with an average value of 1.2. By noting the deadweight ratio of 1.13, one can see the economies of scale, which explain the steady increase in the typical size of capes over the years.

Besides converting prices from actual deals to account for factors such as size, age, shipyard, engine size etc., when there is lack of deals in the market, freight rates may also be used to predict what the prices would have been had there been a transaction. These records are therefore not exact but they are nonetheless very useful in following and trying to understand the behavior of the market.

Fig. 2.5-19 shows the historical prices of 170,000dwt capes of various ages and their scrap value. The graph was compiled using data from [Marsoft 2007a] and actual fixtures and S&P transactions from the database.

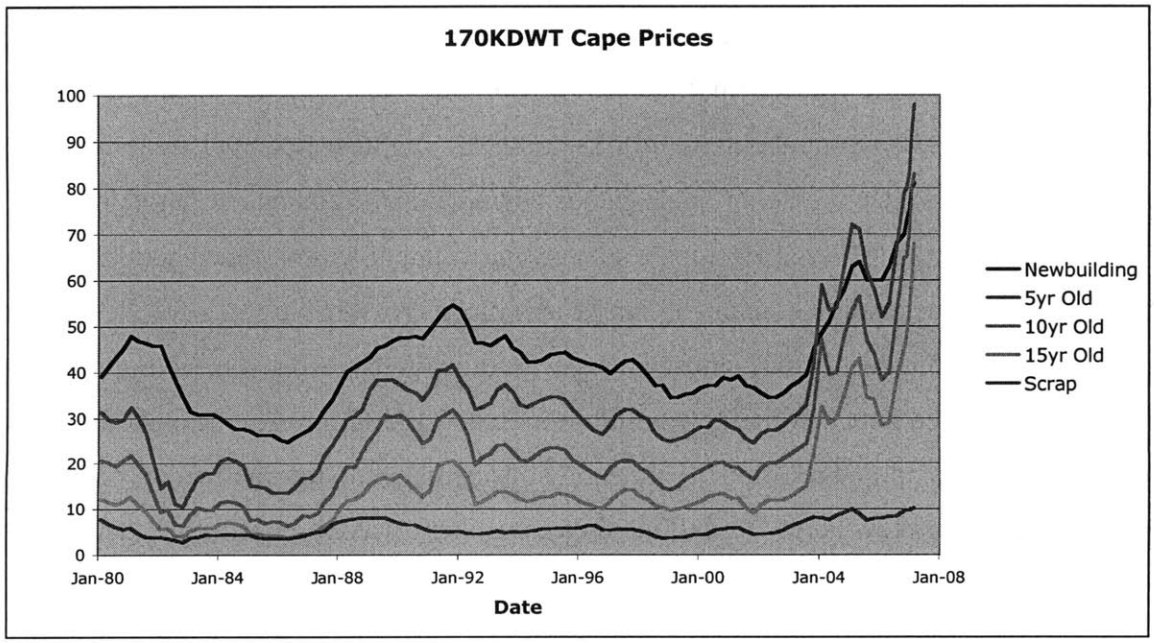


Fig. 2.5-19: Historical Track of 170Kdwt Cape Values along with Scrap Values –
Using data from [Marsoft 2007a, Levine 2006, Vafias 2007, Braemar 2007b, Tradewinds 2007]

How to Read Fig. 2.5-19		
Consider February 2001		
Legend	Meaning	Value
Newbuilding	Average price of a 170,000dwt newbuilding cape	$38.3m
5yr Old	Average price of a 170,000dwt 5 year old cape	$28.1m
10yr Old	Average price of a 170,000dwt 10 year old cape	$19.1m
15yr Old	Average price of a 170,000dwt 15 year old cape	$12.3m
Scrap	Scrap value of a 170,000dwt cape	$5.8m

Table 2.5-12: How to read Fig. 2.5-19

Prior to the market boom, which began in 2003, ships used to be valued to a crude approximation using a straight-line depreciation curve with a lifetime of 20 years. The scrap value was neglected for relatively young ships in order to account for increasing operating costs with age. The price of a newbuilding was therefore about 2 times that of the 10-year old vessel while that of a 5-year old vessel was half way between. In February 2001 for example, a 170Kdwt newbuilding was worth about $38m while a 5-year old was worth about $28m and a 10-year old was worth about $19m. Assuming a straight-line depreciation, using a 20-year lifetime and neglecting scrap value yields a gradient of $2m/year. Charter rates were about $15,000/day for 170Kdwt ships and average running costs were about $5000/day resulting in operating profits of about $3.5m/year, which is reasonable.

As shown on the graph, ships values were always capped by the NB price. Ship values therefore lied between the newbuilding price and the scrap value (minus the cost of transporting and scrapping the ship). Things obviously changed after the market boom. Spot rates went up until they exceeded $100,000/day but there was no confidence that this will last. A straight-line depreciation curve was therefore no longer appropriate.

If a straight-line depreciation curve applied, one would expect values of ships of different ages to diverge as they increase while the price ratios remain relatively constant. Instead, we see that ship prices move in parallel meaning that they increase by the same amount. This shows that the period for which the market is expected to last is valued much higher than the remaining ship's life. It is also valued approximately the same for all capes regardless of their age. Consequently, as the market stays strong, very few vessels are

scrapped. This combined with the high demand for steel causes scrap values to reach record high levels.

Fig. 2.5-20 shows the historical prices of 150,000dwt capes of various ages along with 6-month charter rates for vessels of that size. The graph was compiled using data from [Clarksons 2007a] and actual fixtures and S&P transactions.

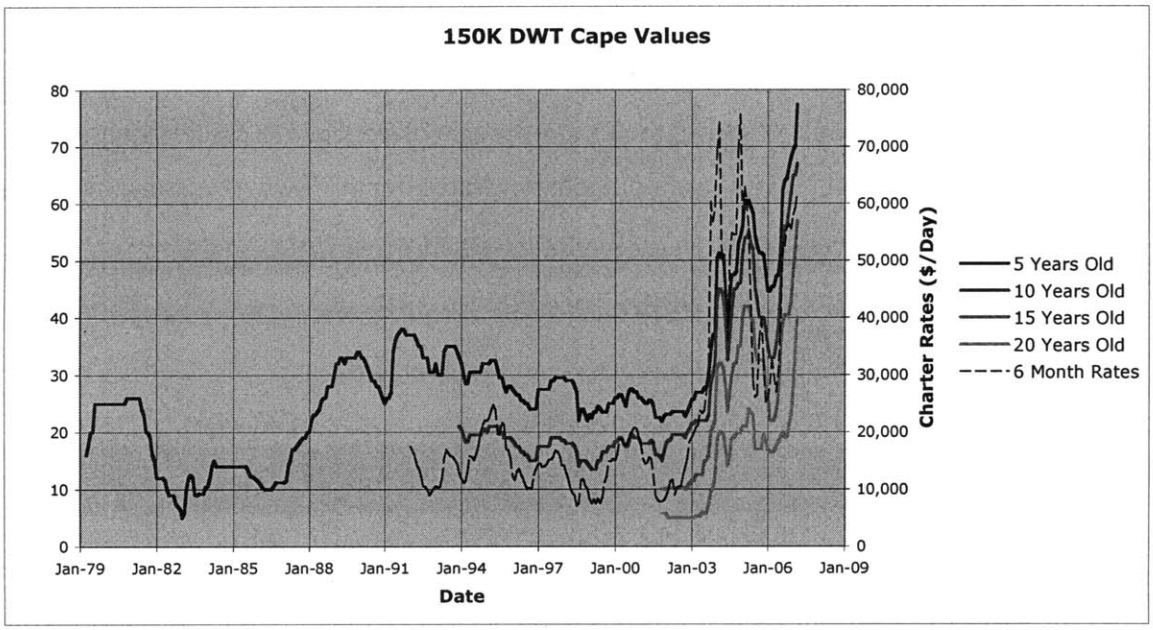


Fig. 2.5-20: Historical Track of 150Kdwt Cape Values along with 6-Month Carter Rates - Using data from [Clarksons 2007a, Levine 2006, Vafias 2007, Braemar 2007b, Tradewinds 2007]

How to Read Fig. 2.5-20		
Consider February 2001		
Legend	Meaning	Value
5 Years Old	Price of 150Kdwt 5-year old capes in March 2007	$77.38m
10 Years Old	Price of 150Kdwt 10-year old capes in March 2007	$67m
15 Years Old	Price of 150Kdwt 15-year old capes in March 2007	$57m
20 Years Old	Price of 150Kdwt 20-year old capes in March 2007	$40m
6 Month Rates	6-month charter rates for 150Kdwt capes in March 2007	$62K/day

Table 2.5-13: How to read Fig. 2.5-20

As the freight market stayed at high levels, cash reserves were built up and confidence improved. This increased buying interest so prices kept rising. One can see that even though charter rates in March 2007 were significantly lower than the peaks of February 2004 and December 2004, ship values were much higher due to the better confidence in sustainable high levels. That is why a 20year old 150Kdwt vessel today is worth about $40m whereas in a bad market it would be of scrap value.

Since the good market is experienced by vessels of all ages, while spot rates are relatively independent of age, prices remain parallel. Fig. 2.5-21 explores this phenomenon and its impact on price ratios. It shows the ratio of prices of 150Kdwt vessels of various ages with respect to time, along with 6-month charter rates for 150Kdwt vessels, which are indicative of their earnings. The graph was compiled using data from [Clarksons 2007a] and actual fixtures and S&P transactions from the database.

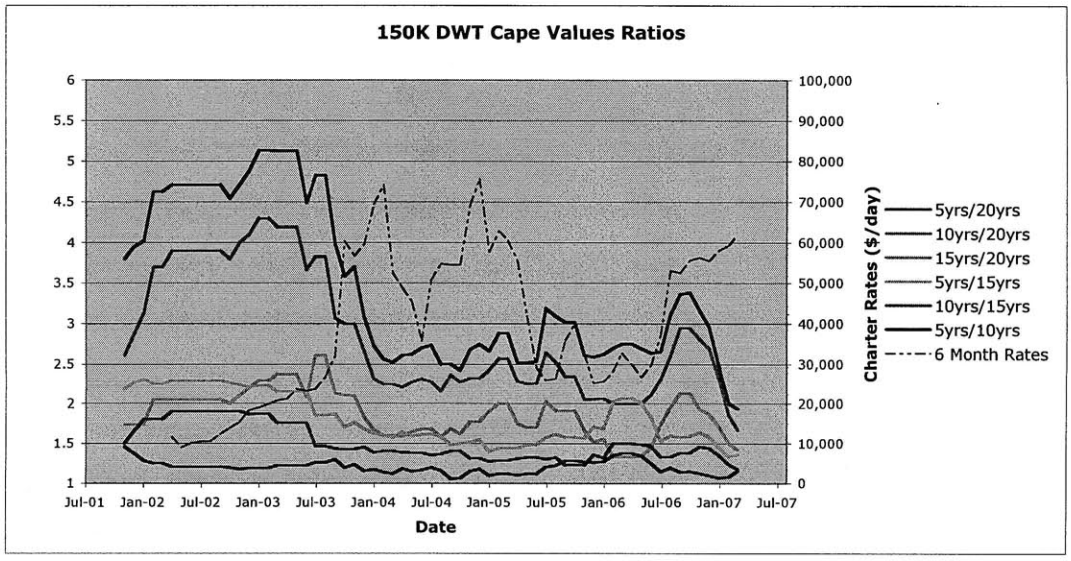


Fig. 2.5-21 Historical Track of 150Kdwt Cape Value Ratios along with 6-Month Carter Rates - Using data from [Clarksons 2007a, Levine 2006, Vafias 2007, Braemar 2007b, Tradewinds 2007]

How to Read Fig. 2.5-21		
Consider March 2007		
Legend	Meaning	Value
5yrs/20yrs	Price(5yr-old) / Price(20yr-old) for 150Kdwt in Mar-07	1.935
10yrs/20yrs	Price(10yr-old) / Price(20yr-old) for 150Kdwt in Mar-07	1.675
15yrs/20yrs	Price(15yr-old) / Price(20yr-old) for 150Kdwt in Mar-07	1.425
5yrs/15yrs	Price(5yr-old) / Price(15yr-old) for 150Kdwt in Mar-07	1.358
10yrs/15yrs	Price(10yr-old) / Price(15yr-old) for 150Kdwt in Mar-07	1.175
5yrs/10yrs	Price(5yr-old) / Price(10yr-old) for 150Kdwt in Mar-07	1.155
6 Month Rates	6-month charter rates for 150Kdwt capes in Mar-07	$62K/day

Table 2.5-14: How to read Fig. 2.5-21

When the market is low compared to previous levels, the price ratio of new to old vessels is high. New vessel prices are related to the new building cost while old vessels are related to their scrap value. In a good market however, people discount the projected earnings over the period for which they expect the good market to last (e.g. 2 years). Both new and old vessels feel the good market. The t/c rates and particularly spot rates increase disproportionately for old vessels compared to new ones. Spot rates in a good market are about the same for all vessels regardless of their age. The added value of the good market is therefore similar for all vessels. Consequently, the ratio of prices for new to old vessels decreases substantially in a good market. This is particularly evident when comparing vessels up to 10 years old that were previously valued close to newbuilding price with vessels 20 years old and over that are priced near scrap value in a bad market.

Fig. 2.5-22 and Fig. 2.5-23 show the historical prices of typical capes of various ages along with spot rates and 3-year charter rates. Typical cape refers to the predominant size of vessels at each point in time. That for example would be about 140-145Kdwt in the 1980s, 150Kdwt in the early 1990s, 170Kdwt in the late 1990s, 175Kdwt today, while the vessels that are being ordered today for delivery in 2010 are about 180Kdwt.

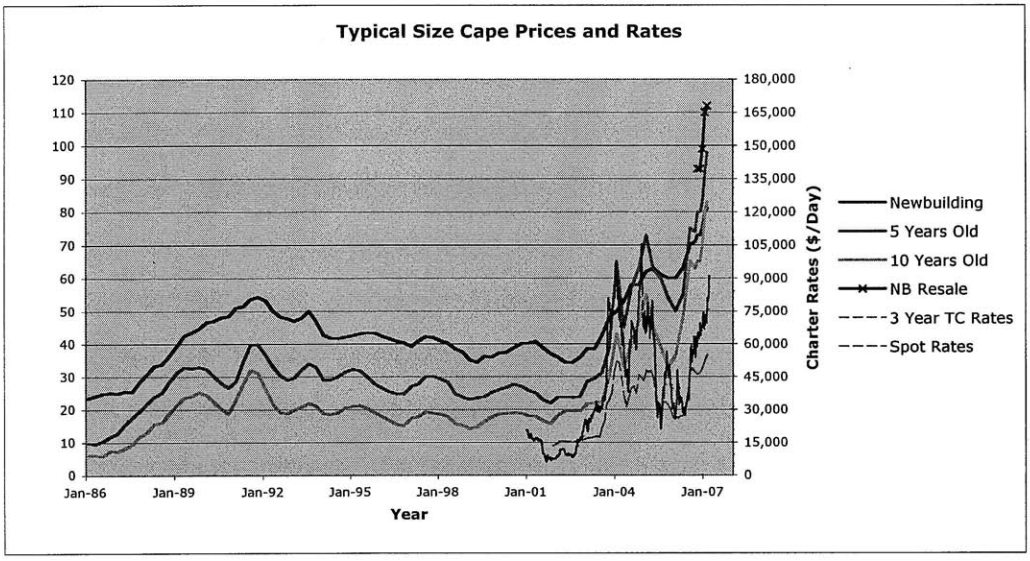


Fig. 2.5-22: Historical Track of Typical Cape Values along with spot and 3-Year Carter Rates – using data from [Braemar 2007a, Levine 2006, Vafias 2007, Tradewinds 2007, Baltic Exchange 2007, Clarksons 2007a]

How to Read Fig. 2.5-22 & Fig. 2.5-23		
Consider March 2007		
Legend	Meaning	Value
Newbuilding	Price of newbuilding typical size cape in March 2007	$112m
5 Years Old	Price of 5-year old typical size cape in March 2007	$81m
10 Years Old	Price of 10-year old typical size cape in March 2007	$98m
NB Resale	Price of new typical size cape in March 2007	$83m
3 Year tc Rates	3-year time charter rates for 170Kdwt in March 2007	$55,000/day
Spot Rates	Average spot rates for 172Kdwt cape in March 2007	$90,906/day

Table 2.5-15: How to read Fig. 2.5-22 and Fig. 2.5-23

The graph (Fig. 2.5-22) was compiled using data from [Braemar 2007a] and the S&P database for the ship values, [Baltic Exchange 2007] for the spot rates and [Clarksons 2007a] and actual fixtures for the 3-year charter rates.

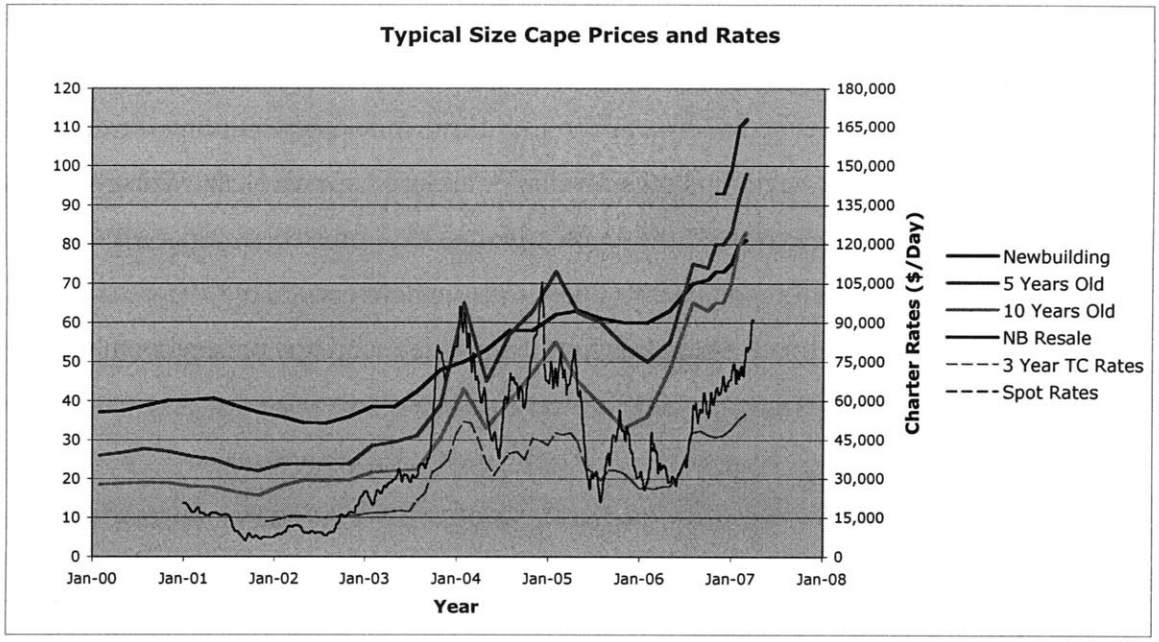


Fig. 2.5-23: Historical Track of Typical Cape Values along with spot and 3-Year Carter Rates – using data from [Braemar 2007a, Levine 2006, Vafias 2007, Tradewinds 2007, Baltic Exchange 2007, Clarksons 2007a]

The year 2003 was the first time that current months were valued so high compared to the rest of the ship's life making secondhand prices higher than that of newbuildings that have a late delivery. Today, the difference between a resale and a newbuilding is at a record high and while a 10-year old vessel is now worth more than a newbuilding.

The market started valuing the next few months much higher than the remaining ship life began when the market boom started. That is also why t/c rates were higher than the spot market and decreased with period length. The number of months that were valued higher gradually increased as the market remained at high levels and confidence built up. The following Chinese-build cape deals that took place in October 2006 illustrate this.

- Diana paid $91m for an SWS Cape resale to be delivered in Dec. 2006
- Transmed sold its last Bohai Cape newbuilding (Delivery in Nov. 2007) for $81.5m
- Golden Union ordered a 177Kdwt Cape in Waigaoqiao for $61m (delivery in 2010)

Looking at these prices, each year until 2010 was valued at around $10m. This is reasonable as one could charter a cape in October for the next three years to earn significantly more than that also to account for ageing. What is most remarkable is that the

following years of the ship's lifetime were discounted at a rate of only around $3m per year (Golden Union order), which is similar to pre-2003 valuations.

A newbuilding resale today is worth about $112m while a newbuilding for delivery in 2010 is worth about $80m. Again this puts a value of about $10m per year. When ordering a vessel, it is common practice to pay 20% upon signing, 25% on steel cutting, 20% on keel-laying (about 3 months before delivery), and 30% on delivery. Table 2.5-16 shows the amount of each payment for a $80m newbuilding order, and its present value using a discount rate of 5%.

Net Present Value of a Newbuilding Order				
	Time (years)	**% of Price**	**Amount**	**PV (i = 5%)**
Signing	0	20%	$16m	$16.0m
Steel Cutting	2	25%	$20m	$18.1m
Keel Laying	2.75	20%	$16m	$14.0m
Delivery	3	35%	$28m	$20.7m
Total		100%	$80m	**$68.9m**

Table 2.5-16: Net Present Value of a Newbuilding Order using a Discount rate of I = 5%

If one uses a linear depreciation curve after 2010, with a 20-year lifetime and zero scrap, today's value of a 3-year old vessel in 2010 is worth 17/20 times the NPV of the newbuilding. Table 2.5-17 shows the NPV of a newbuilding for a discount rate of 5%, 8% and 10% along with the corresponding today's value of a 3-year old vessel in 2010.

NPV of an Order and Equivalent PV of a 3-yr old Vessel in 2010		
	NPV for new vessel in 2010	**NPV for 3yr-old in 2010**
I = 5%	$68.9m	$58.5m
I = 8%	$65.1m	$55.4m
I = 10%	$62.9m	$53.4m

Table 2.5-17: NPV of a NB Order and the Equivalent PV of a 3-yr Old Vessel with Delivery in 2010

If one charters the resale from March 2007 until 2010 (3 years), rates are about $55,000/day. One can also assume 355 days per year and average running costs of about $6,000/day over the next 3 years for a new vessel. If the NPV of the operating profits over the three years are subtracted from its current value of $112m, this yields the effective cost of buying a 3-year old vessel for delivery in 2010. This calculation is again performed using a discount rate of 5%, 8% and 10% in Table 2.5-18.

NPV of Resale's Profits and Equivalent PV of a 3-yr Old Vessel in 2010		
	NPV of Earnings	**NPV for 3yrold in 2010**
I = 5%	$47.0m	$65.0m
I = 8%	$45.1m	$66.9m
I = 10%	$43.9m	$68.1m

Table 2.5-18: NPV of Resale's Profits and the Equivalent PV of a 3-yr Old Vessel with Delivery in 2010

By comparing Table 2.5-16 and Table 2.5-17, one can see that it does not make sense to buy a resale and charter it for 3 years at $55,000/day. Using a discount rate of 5%, this is equivalent to paying only $3.9m less for a 3-year old vessel in 2010 instead of a new vessel whereas by assuming linear depreciation, it should be worth about $10.4m less. If a higher discount rate is assumed, it is equivalent to paying even more for a 3-year old vessel than a new vessel. If one chooses the resale over the newbuilding therefore, one has to assume higher earnings during the next 3 years than can be obtained through a 3 year charter. In other words, one has to be speculative about the market. If one takes this view however, it is simpler to charter in a vessel on a 3-year time charter and then charter it out on the spot market.

The numbers show that ordering at $80 for delivery in 2010 makes far more sense than buying a resale today at $112m. Many IPO's however are concerned about other issues such as the numbers that show up on their accounts. Paying for an asset that will not be delivered and make any money for the next three years does not seem to impress investors for example.

By comparing the spot rates to the 3-year time charter rates, one can see that spot rates are usually more volatile with higher peaks and lower bottoms. They are also first to go up or down and are then followed by the 3-year time charter rates after a short time lag. In general, the shorter the charter period, the higher the peak rates, the lower the bottom rates, and the shorter the time lag from spot rates. This is primarily because they represent a bigger commitment. Similarly, there is a time lag between freight rates and ship values. The fact that it takes longer to sell a ship than to charter it has little relevance. People usually wait after a market change and often perceive new levels as temporary. It takes a far more sophisticated decision to sell a vessel than to charter it. That is also why the time lag is smaller between prices and long time charter rates. Spot rates for example began rising significantly in December 2002, 3-year charter rates picked up in July 2003, and ship values started increasing steeply in October 2003.

Optimism or pessimism about the future of the market and the owners' position regarding ships and capital is what drives ship prices. The good market helps build up healthy cash reserves and shipowners' optimism so it may take a considerable time of a bad market to depress expectations and for prices to drop. In other words, there is a very low short-term price elasticity of supply for second hand vessels as there is for newbuildings.

Fig. 2.5-24 shows the percentage by which 150Kdwt cape prices increased from October 2002 until the two subsequent price peaks in February 2004 and April 2005, and until today. The chart was compiled using data from [Clarksons 2007a] and actual S&P transactions from the S&P database.

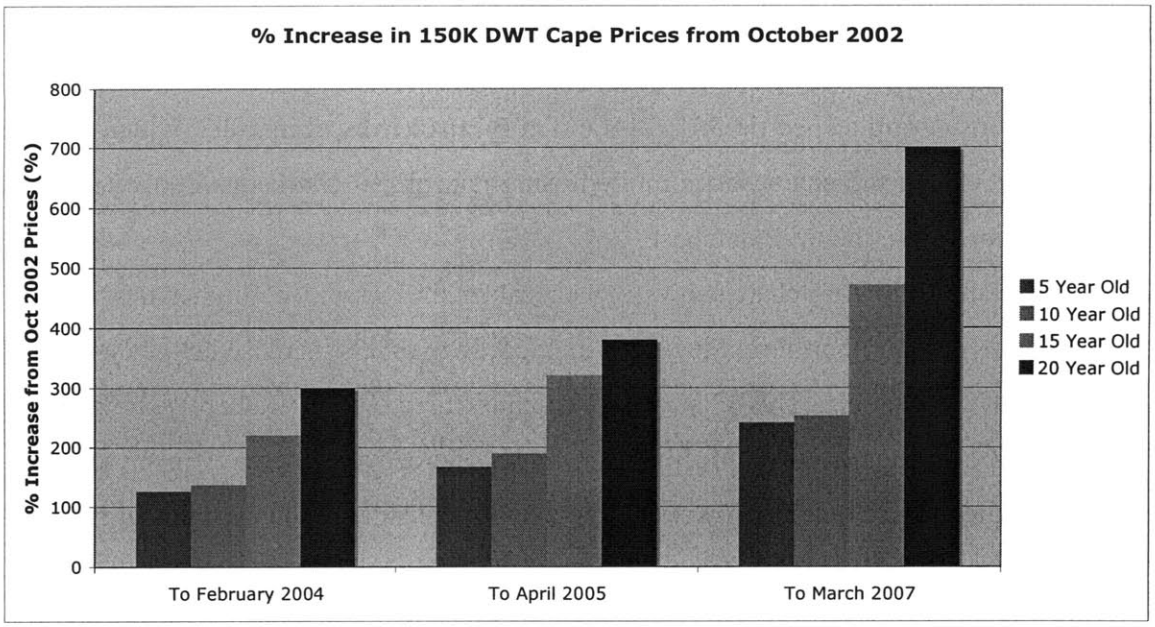


Fig. 2.5-24: 150Kdwt Cape Price Increase from Oct.2002 until the 2004 and 2005 Price Peaks and until Today – Using data from [Clarksons 2007a, Levine 2006, Vafias 2007, Braemar 2007b, Tradewinds 2007]

How to Read Fig. 2.5-24		
Consider "To March 2007"		
Legend	Meaning	Value
5 Year Old	Increase in price of 5yr old 150Kdwt from Oct'02 to Mar'07	241%
10 Year Old	Increase in price of 10yr old 150Kdwt from Oct'02 to Mar'07	253%
15 Year Old	Increase in price of 15yr old 150Kdwt from Oct'02 to Mar'07	470%
20 Year Old	Increase in price of 20yr old 150Kdwt from Oct'02 to Mar'07	700%

Table 2.5-19: How to read Fig. 2.5-24

As shown, the values of older vessels increased more than newer ones while each subsequent peak in prices since October 2002 was higher. This chart also highlights the critical age of 15 and 20 years that was discussed earlier. In a low market, vessels over 15 years old are less likely to survive to the next market boom and are therefore less preferred. Hence they are relatively cheaper. As the market picks up, people become less picky and these vessels therefore gain relatively more on prices.

Fig. 2.5-25 shows the percentage by which 150Kdwt and 170Kdwt cape prices increased from October 2002 until today, but now also accounting for ageing. This means that we are considering a specific 5, 10, 15 and 20-year old vessel in 2002, which is 5 years older in 2007. Again the chart was compiled using data from [Clarksons 2007a] and actual S&P transactions from the S&P database.

Again the following chart shows that the older the vessel, the higher the percentage increase in its price. Furthermore, the prices of 175Kdwt vessels increased slightly more than those of 150Kdwt vessels. This chart also accounts for the five years of ageing between October 2002 and March 2007 and that is why the percentage increase in price is lower compared to the previous chart. However, we have not considered the earnings of the vessels over these 5 years.

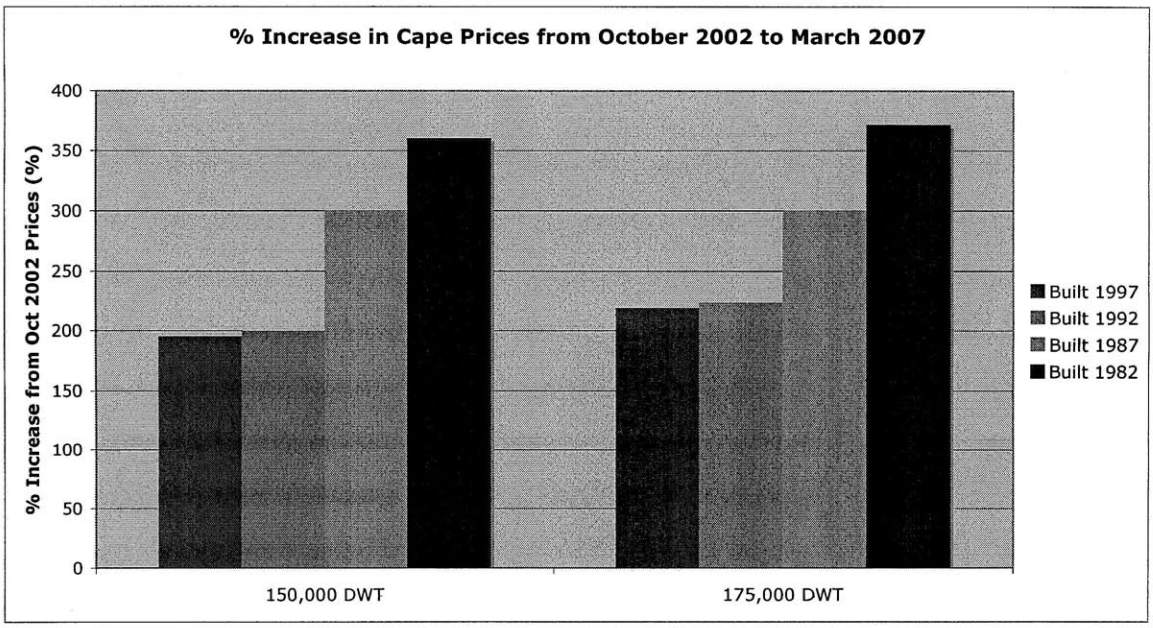


Fig. 2.5-25: 150Kdwt and 170Kdwt Specific Cape Price Increase from Oct.2002 until Today [Clarksons 2007a, Levine 2006, Vafias 2007, Braemar 2007b, Tradewinds 2007]

How to Read Fig. 2.5-25		
Consider 175,000 DWT		
Legend	Meaning	Value
Built 1997	Price increase of a 1997-built 175Kdwt from Oct'02 to Mar'07	219%
Built 1992	Price increase of a 1992-built 175Kdwt from Oct'02 to Mar'07	224%
Built 1987	Price increase of a 1987-built 175Kdwt from Oct'02 to Mar'07	300%
Built 1982	Price increase of a 1982-built 175Kdwt from Oct'02 to Mar'07	371%

Table 2.5-20 How to read Fig. 2.5-25

Average spot rates (average of the 5 routes) between October 1st 2002 and March 29th 2007 for a Baltic Cape (172Kdwt) were $50,750/day [Baltic Exchange 2007]. Assuming 355 days per year (for earnings) and average running costs of $5,500/day, results in annual profits of $16m. Assuming cumulative interest of 5%, this amounts to about $78m of profits in March 2002 over the 4.5 years. This is about the same for all the ships considered above since spot rates are relatively nondependent on ship age, running costs only increase marginally, and the number of days in a year would be only as low as 345 for the oldest ship. This means that the increase in the percentage return on investment for older vessels would be much greater that that for newer ships.

Consider the 1982 built 175Kdwt ship, which was worth $7m in October 2002 and $33m in March 2007. To be conservative, assume average earnings of 35,000/day, running costs of 6,500, 340 days in a year and a 5% interest rate over the 4.5 years. The value of the total profits is worth about $46.5m in March 2007. If this is also included in the price increase, we get a total increase of 1,036% within 4.5 years.

The question of selling or chartering a vessel is a major one in shipping. As shown above, prices are very volatile and there are times when selling seems the best option. Even though charters involve some risk and renegotiations occasionally take place, experience has shown that even before the market boom, selling was rarely the best option. Consider a 1974-built 120Kdwt vessel, which is typical of the first capes. Fig. 2.5-26 shows how the price of that particular ship varied from July 1980 until scrapping along with 3-year charter rates for 120Kdwt vessels. The graph was created using data from [Clarksons 2006c]

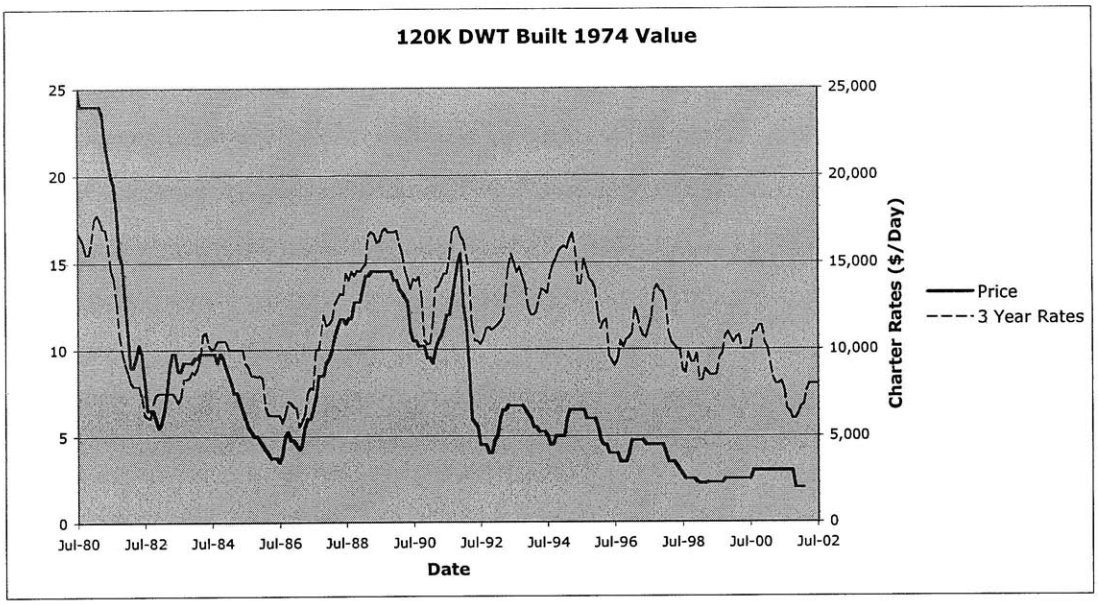


Fig. 2.5-26 Price of a 1974-built 120Kdwt Cape until Scrapping along with 3-year TC Rates – Using data from [Clarksons 2006c]

How to Read Fig. 2.5-26		
Consider December 1991		
Legend	Meaning	Value
Price	Price of a 1974-built 120Kdwt cape in December 1991	$15.5m
3 Year Rates	3-year t/c rates for 120Kdwt capes in December 1991	$16,750/day

Table 2.5-21: How to read Fig. 2.5-26

If there were a point in time when it would be worth selling, that would clearly be in December 1991 for $15.5m. Average 3-year charter rates between December 1991 and the scrapping date of February 2002 were $12,562/day. If one conservatively assumes earnings of $12,000/day, running costs of $6,000/day, 345 days per year (only for earnings) for the 10.17 years, and a discount rate of 5%, the net value of the profits in December 1991 would be about $14.8m. The scrap value in February 2002 was $2m, which translates to $1.2m in December 1991 with the same discount rate. The value of keeping the ship was therefore $16m, which exceeds its price of $15.5m. Furthermore, if one chose a 3-year charter as opposed to selling the vessel on December 1991, then they would get a rate of about

$16,750/day and average out significantly higher than $12,000/day for the remaining life of the ship

2.5.8 Conclusions

- Ship values are dictated by their earning capacity, age, newbuilding price, and scrap value. Capacity is less important than age while the current market is the most important factor

- Other parameters include the ship builder, time charter attachments that can have a positive or negative value, delivery time which is very important in a high market, SS/DD survey position, vessel and eng type etc.

- Discontinuities in the age-price curve exist for a number of reasons but are difficult to identify due to the small number of ships available in the market as well as data scatter
- Frequency of S&P transactions closely follows charter rates and ship prices

- Ship valuations have become more complicated after the market boom in 2003. Linear depreciation based on the newbuilding price and the scrap value that was once used is no longer appropriate

- The current market is not expected to last so the next few months/years are valued much higher than the remaining ship life. The period that is valued much higher increases the longer the market remains at high levels and optimism builds up

- All vessels experience the good market with similar earnings irrespective of the ship age. Prices of all ages therefore go up in parallel in a market boom reflecting potential earnings. Hence, the price ratio of newer to older vessels decreases

- There is a time lag between freight rates and ship values. This is explained by the level of commitment and peoples perception of how temporary current rates are
- The price of older vessels fluctuates significantly more percentage-wise than that of newer vessels while 175Kdwt vessel prices fluctuate slightly more than 150Kdwt vessel prices

- It is very rarely a better choice to sell a vessel than to charter it based on an analysis over the period from 1980 until today

- The market boom since 2003 has led to record-high newbuilding and second hand prices along with record-high freight rates and daily earnings

- Despite record-high scrap values, there has been negligible scrapping since autumn 2003 due to the extremely high earnings

- Investing $7m to buy a 1982 175Kdwt vessel in October 2002 and keeping it in the spot market would yield a return of over 1,000% until March 2007 (4.5 years)
- Delivery time has become a very important parameter making the newbuilding (delivery 2010/11) worth about as much as a 13-year old or 150% the price of a modern vessel. This is the opposite extreme of the 1986 crisis when a 9-year old vessels was worth its scrap value

- It currently makes more economic sense to order a vessel at $80m for delivery in 2010 than to buy a resale at $112m but there are also issues such as the numbers that show up in the accounts of IPOs and related cash flow considerations

- The good market helps to build up healthy cash reserves and shipowners' optimism so ship values are unlikely to drop for a relatively long time even if rates go down

2.6 Newbuildings

2.6.1 Introduction

As for secondhand capes, a database of cape orders was used in order to examine newbuilding prices. The records of [Braemar 2007a] were used and these were completed by adding data from [SSY 2006c], [Vafias 2007] and subsequent reports from [Braemar 2007b]. The database includes a total of 194 orders from May 2003 until March 2007. May 2003 was chosen in order to capture the last few months before the market boom.

The 194 orders include some large ore carriers but no newbuilding resales or newbuilding options. John Angelicousis for example who sold the *"Anangel Wisdom"* in March 2007 for a record high $112m, ordered 4 capes the same month from Daewoo-Mangalia at $78 each, with an option for another 4 at the same price. Only the original 4 were included.

It has to be noted that some orders are occasionally not reported. Furthermore, shipyards have started building vessels in some cases without having an order and these are therefore not reported either. They do this in order to sell the vessels close to the delivery date and take advantage of the much higher resale prices. As such, a database like the current one can never be complete. Due to the multiple sourcing of data and cross-referencing however, it can be treated as complete in terms of the reported orders. Details regarding the database are summarized in Table 2.6-1.

DATABASE DETAILS	
Period	May'03 - Mar'07
Number of Ships	194 Orders
Average Size	181,934 dwt
Average Price	$66.3 m
Average Wait	38 months

Table 2.6-1: Newbuilding Database Information

2.6.2 Time Distribution of Newbuilding Orders

The first part of the analysis was to examine how the newbuilding orders were distributed through time. In order to compare with the S&P market, a graph was constructed showing the time distribution of orders per month along with secondhand transactions per month over the same period. This is shown in Fig. 2.6-1.

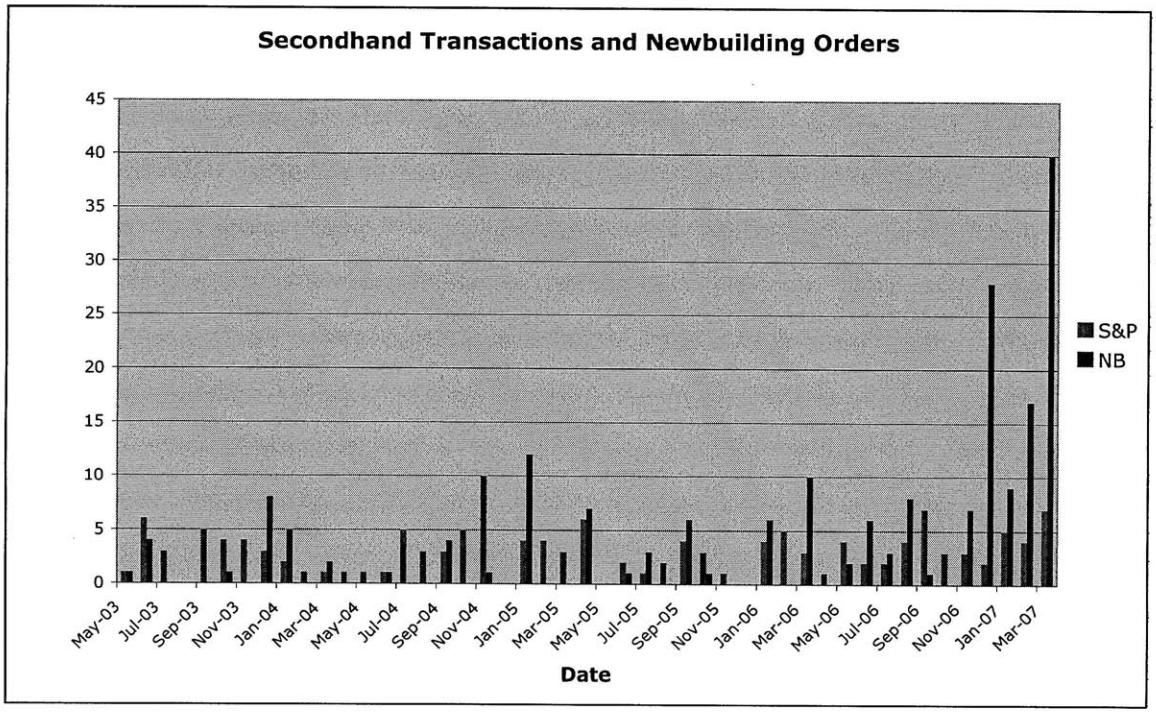


Fig. 2.6-1: Monthly Orders and S&P Deals using data from the S&P Database and the Newbuilding Database

Between May 2003 and March 2007, 145 secondhand transactions and 194 newbuilding orders were reported. The frequency of newbuilding orders appears to have increased substantially over the past few months while activity in the secondhand market has been relatively constant. Interestingly, it is observed that as for the secondhand transactions, the number of orders per month was higher during the months that the market was strong. Fig. 2.6-2 shows the number of orders per month over the investigated period along with the average spot rates. The time series of the average of the 4 TC routes for Baltic Capesize Index (BCI) was obtained from [Baltic Exchange 2007].

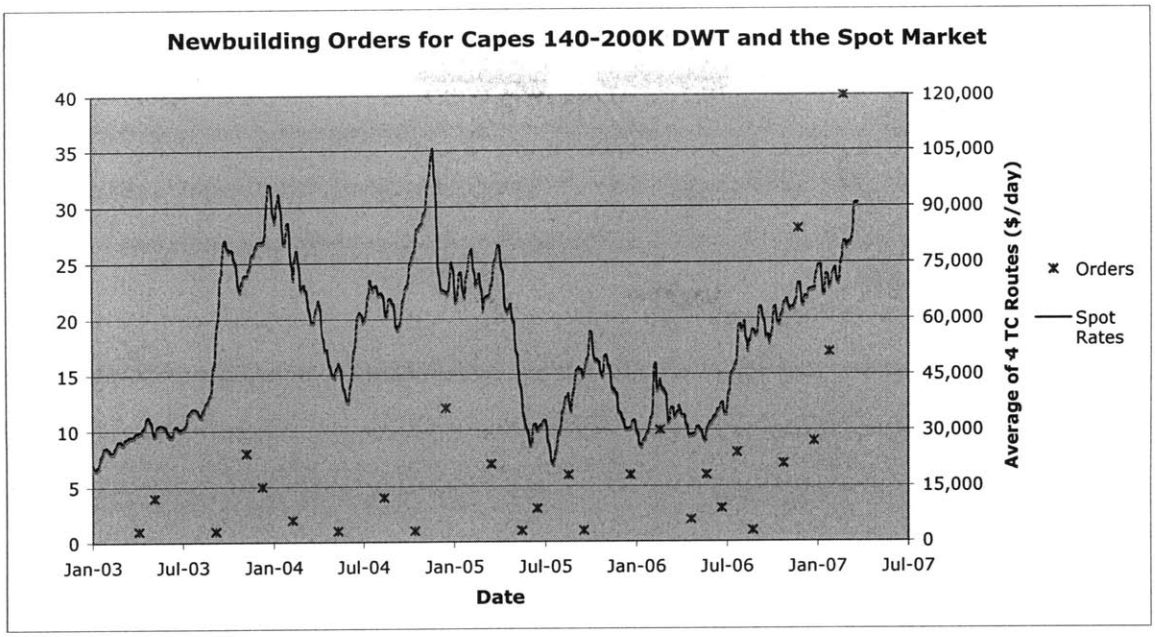


Fig. 2.6-2: Orders per Month along with Spot Rates -
Using data from the Newbuilding Database and [Baltic Exchange 2007]

How to Read Fig. 2.6-2		
Consider March 29th 2007		
Legend	Meaning	Value
Spot Rates	Average of the 4 t/c routes for 172Kdwt on Mar-29-2007	$90,906/day
Orders	Number of newbuilding orders placed within March 2007	40

Table 2.6-2: How to read Fig. 2.6-2

There is clearly a strong correlation between ordering and daily earnings. This may at first seem reasonable but if one notes the average delivery time of 38 months along with the fact that it is a highly cyclical market, it is clear that the ships being ordered in the high market will not necessarily be delivered in a high market. Furthermore, a strong market is most likely associated with high newbuilding prices. Fig. 2.6-3 shows the number of orders per month along with newbuilding prices.

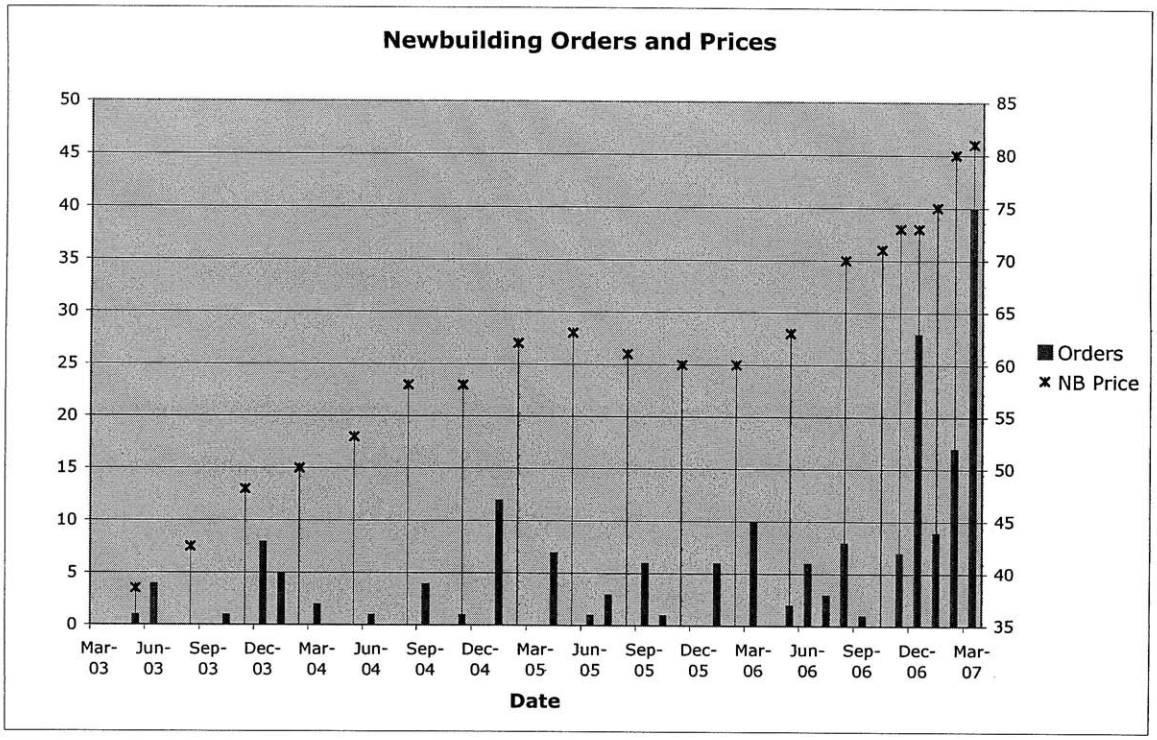


Fig. 2.6-3: Orders per Month along with Newbuilding Prices – Using data from the Newbuliding Database and [Braemar 2007a]

How to Read Fig. 2.6-3		
Consider March 2007		
Legend	Meaning	Value
Orders	Number of newbuilding orders placed within March 2007	40
NB Price	Average typical cape newbuilding price in March 2007	$81m

Table 2.6-3: How to read Fig. 2.6-3

It can be seen that indeed more ships are ordered when newbuilding prices are high. One way to view this is that more orders are made when the market is high and therefore newbuilding prices are also high. Another way to look at it is that newbuilding prices increase when many orders are made.

The average price of typical NB Cape between May 2003 and March 2007 was $62m. By taking the average price of all orders in each month, and by interpolating for the months without orders, a price for that type of Capes that were actually ordered is obtained for each

month. The average of this price between May 2003 and March 2007 was $55.3m. The average price of all orders during the same period was $66.3m, which is significantly higher than both and verifies the argument that relatively more ships are ordered when newbuilding prices are high.

Fig. 2.6-4 shows the total amount of money invested in newbuilding capes per month along with the spot rates. Some approximations had to be made to create this graph due to lack of data. When the price an order was unknown, the average price of the other orders within the same month was taken as an approximation. When the prices of all orders in a month were unknown, linear interpolation was used to assign a value.

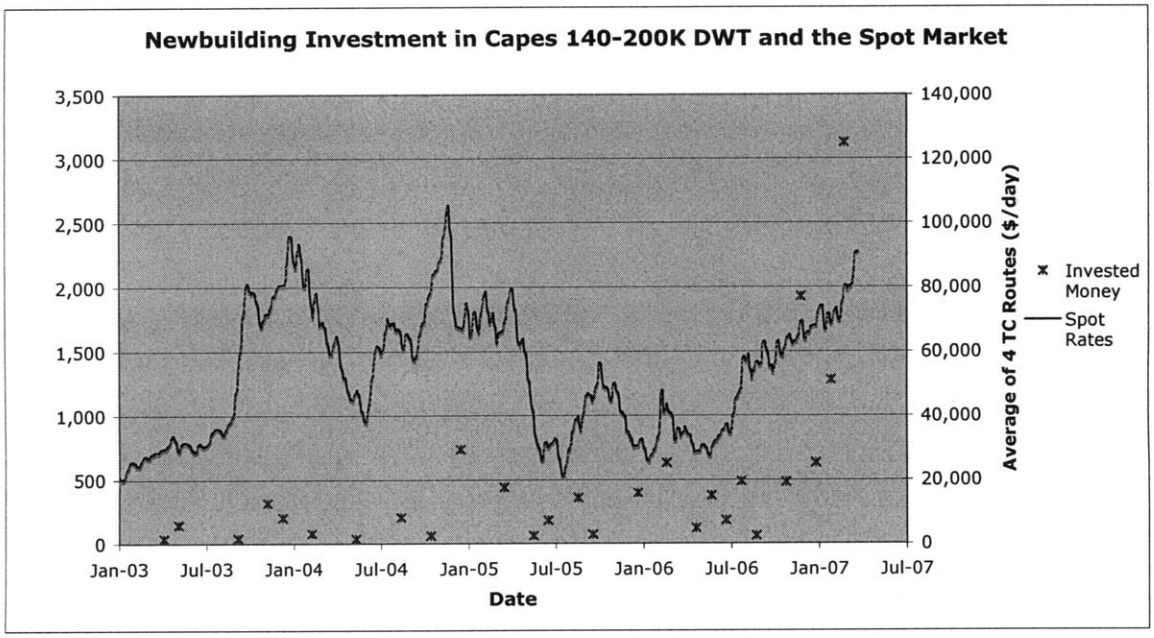


Fig. 2.6-4: NB Investment per Month along with Spot Rates –
Using data from the Newbuilding Database and [Baltic Exchange 2007]

How to Read Fig. 2.6-4		
Consider March 29th 2007		
Legend	Meaning	Value
Invested Money	Money invested in cape orders within March 2007	$3.125bn
Spot Rates	Average of the 4 t/c routes for 172Kdwt on 03/29/07	$90,906/day

Table 2.6-4: How to read Fig. 2.6-4

A total of about $12.9bn was invested in newbuilding capes between May 2003 and March 2007 and about a quarter of that was in March 2007 alone. Again it is clear from the graph that more money is invested in newbuildings when earnings are high even though the market is cyclical and average delivery times exceed 3 years. Fig. 2.6-5 shows the actual prices and points in time at which the 194 capesize orders were placed since May 2003.

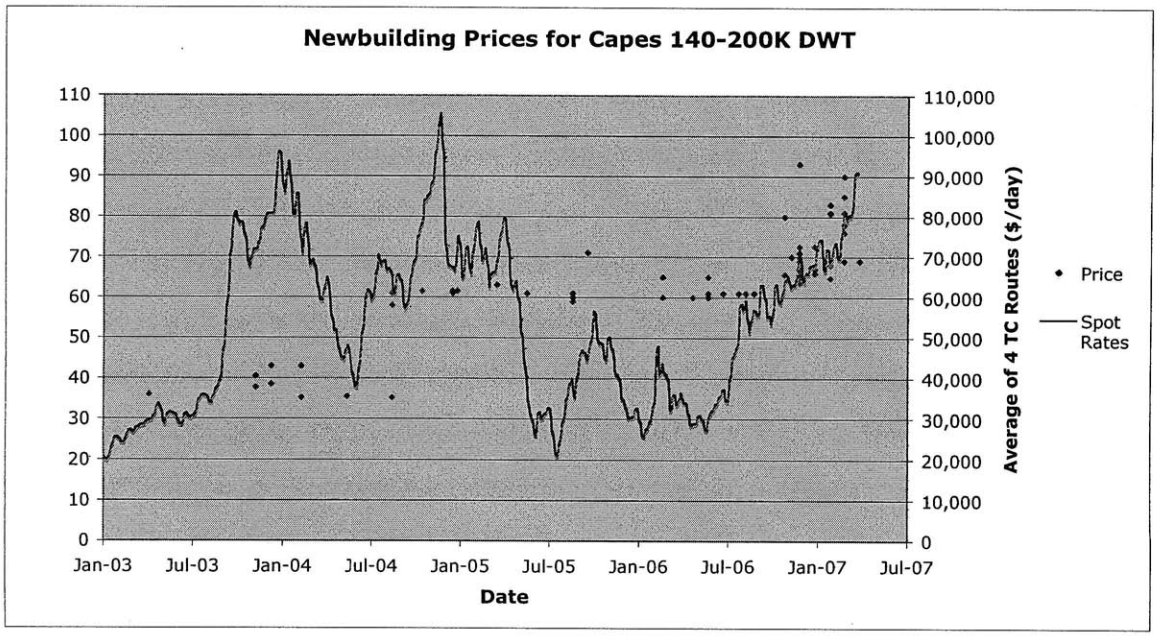


Fig. 2.6-5: Order Times and Prices for all reported orders since May 2003 along with Spot Rates - Using data from the Newbuilding Database and [Baltic Exchange 2007]

How to Read Fig. 2.6-5		
Consider June 1st 2005		
Legend	Meaning	Value
Price	Price of an order that was placed in June 2005	$61m
Spot Rates	Average of the 4 t/c routes for 172Kdwt on 06/01/07	$39,070/day

Table 2.6-5: How to read Fig . 2.6-5

It is clearly shown that the majority of orders were made at high prices when spot rates were high. Furthermore, one can see that shipyard prices remained low during the

beginning of the boom, which was then only perceived as very temporary, and then sudden increased in early 2004.

There are two vessels that stand out as more expensive towards the end of 2006. The one that was contracted in December 2006 for $93m was a 250Kdwt Ore Carrier. The $80m vessel that was contracted on Nov-2006 was a typical 175Kdwt but it had a delivery time of only 14 months, making it significantly more expensive than the other November orders that had delivery times of 37-62 months.

2.6.3 Delivery Times

Fig. 2.6-6 shows the delivery time (in months) along with the time each order was placed for the 194 orders of the database. The vessel that was ordered in Nov-2006 and stood out in Fig. 2.6-5 as being significantly more expensive, can also be identified in Fig. 2.6-6 as the one with the lowest delivery time (14 months).

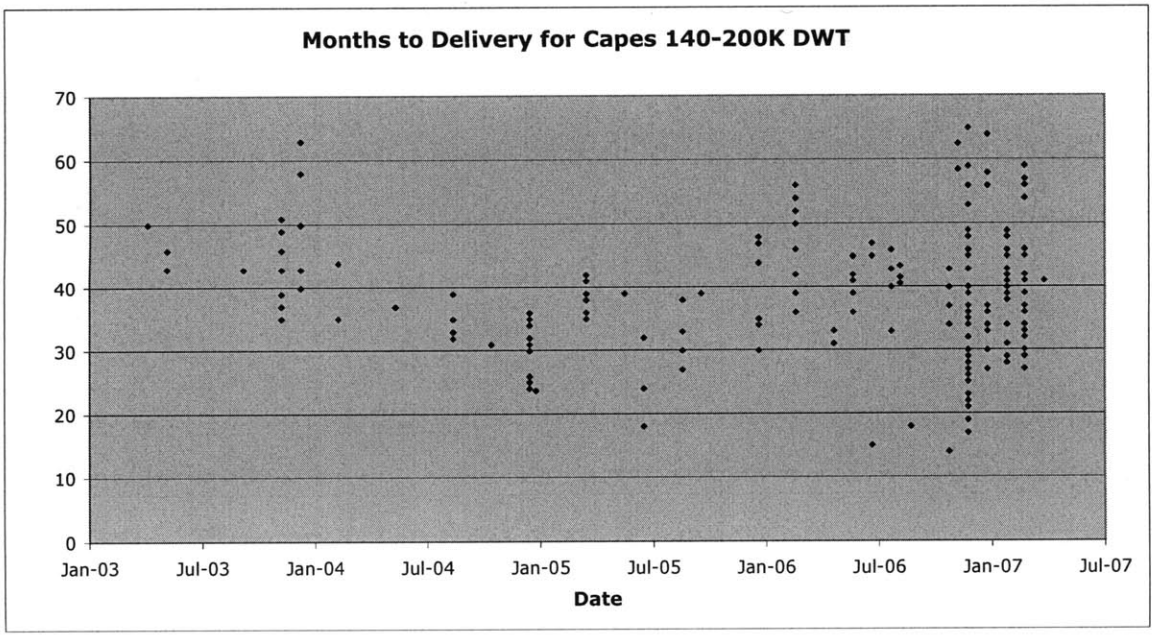


Fig. 2.6-6: Newbuilding Capesize Delivery Times for all reported orders since May 2003

It can be seen that even though prices were late to catch up, waiting times were high since the beginning of the boom. The average delivery time was 38 months (3.17 years) and the range was 14 to 65 months. Evidently, orders with reasonable delivery times are still available but a high premium is usually paid for this as examined below.

An analysis was carried out to investigate the value of delivery time for newbuilding orders. Ore carriers were ignored for this part of the analysis while only capes of 170 – 181Kdwt for which the price was reported were considered. Graphs of price against time until the delivery date were plotted for each month. This was done for December 2006, January 2007, February 2007 and March 2007 and all orders within the size range for which the price was known, were included. Newbuilding resales with zero delivery time were also used when available in order to obtain the y-intercept of each graph. Regression models (least squares) were added to provide the basis for qualitative discussion. The results are shown in Fig. 2.6-7 to 2.6-10, while Fig. 2.6-11 shows all the orders considered between December 2006 and March 2007 on one graph.

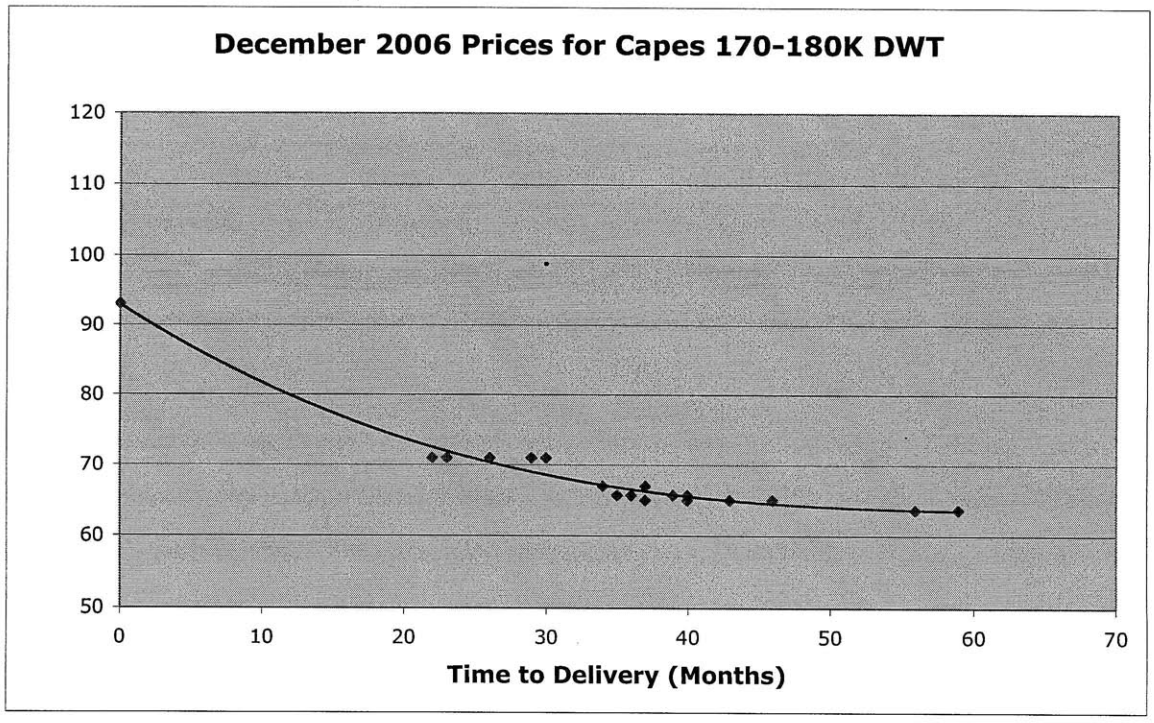


Fig. 2.6-7: Newbuilding Price against Delivery Time for all Orders Reported in December 2006

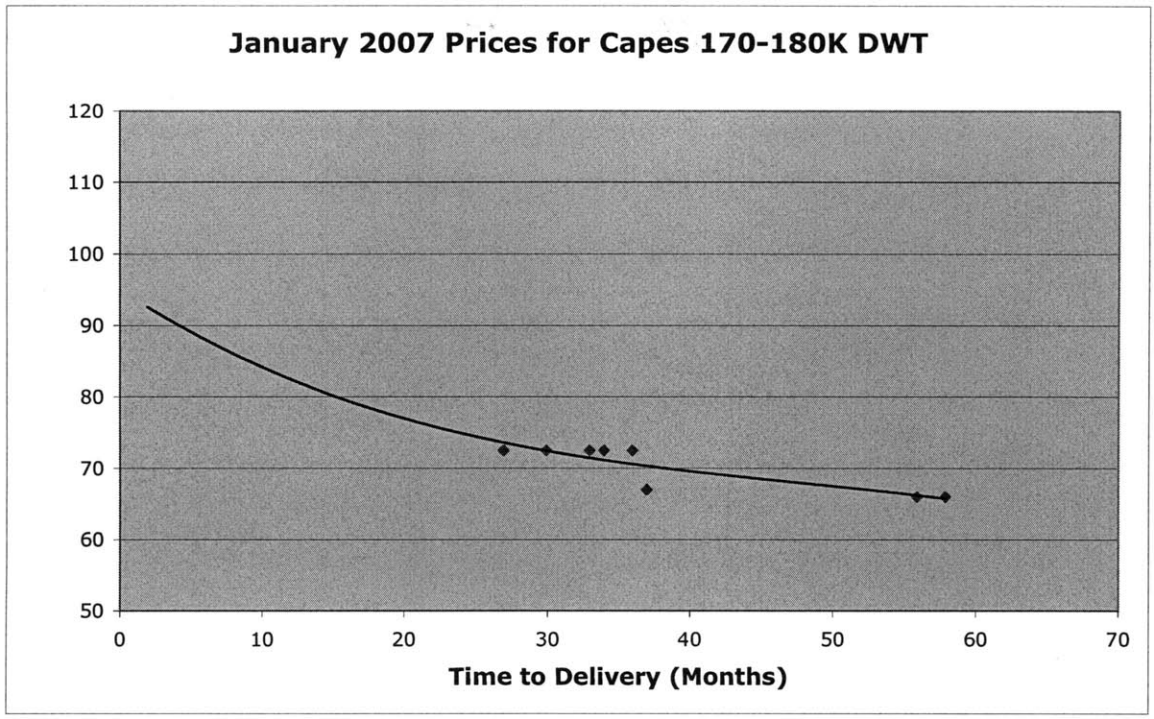


Fig. 2.6-8: Newbuilding Price against Delivery Time for all Orders Reported in January 2007

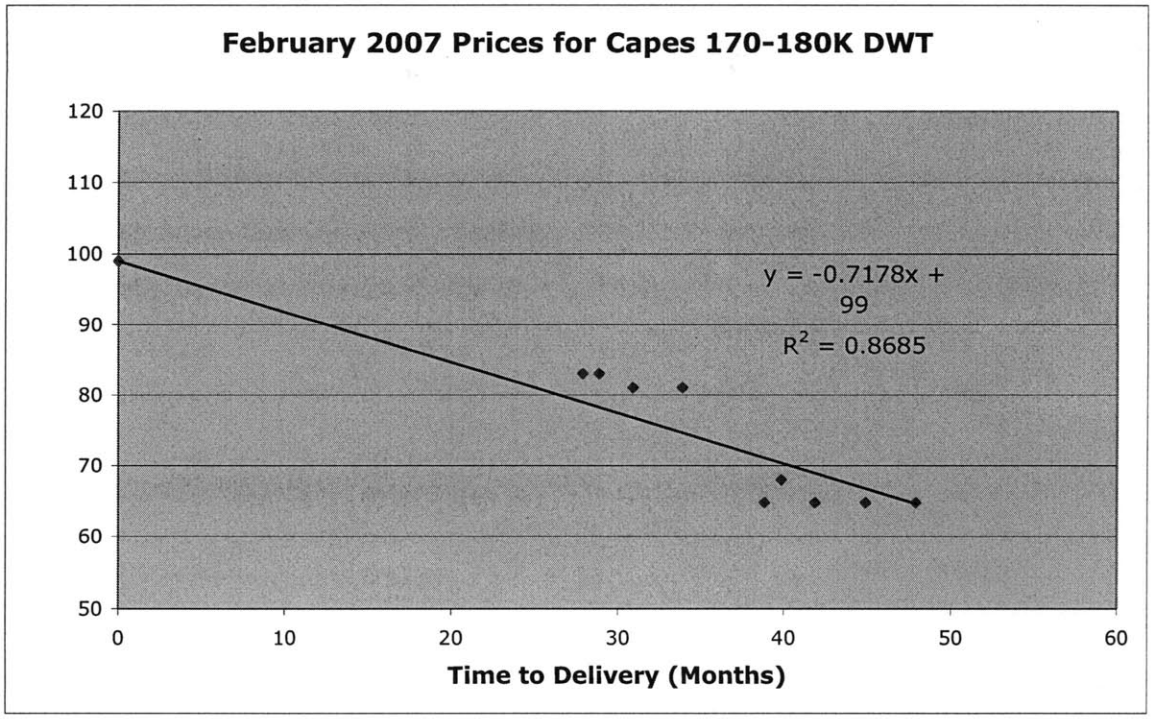


Fig. 2.6-9: Newbuilding Price against Delivery Time for all Orders Reported in February 2007

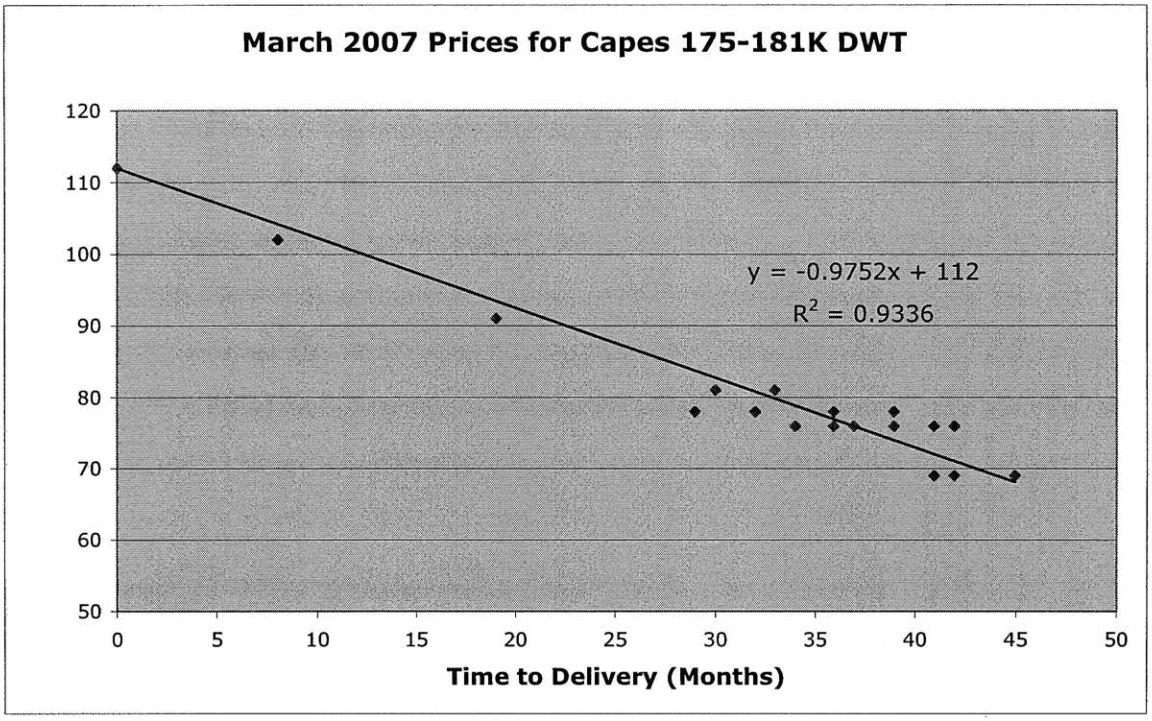


Fig. 2.6-10: Newbuilding Price against Delivery Time for all Orders Reported in March 2007

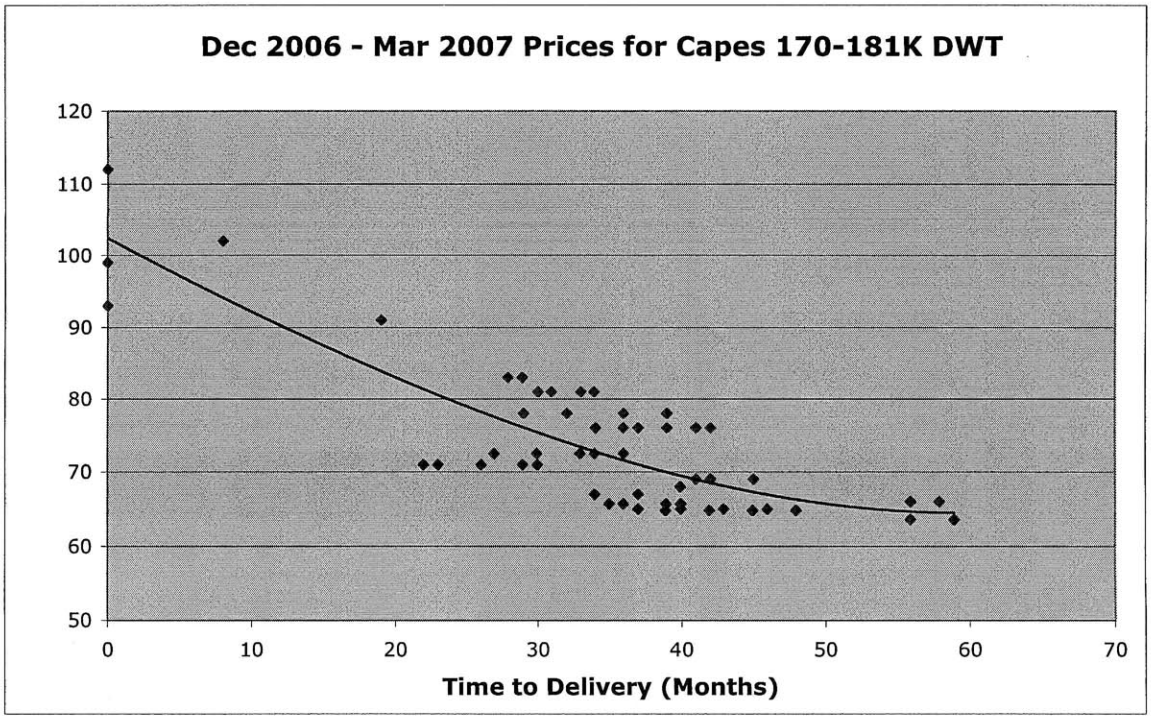


Fig. 2.6-11: Price against Delivery Time for all Orders Reported between December 2006 and March 2007

The regression models show that price decreases with delivery time towards a plateau. The point at which this plateau is reached is the time after which there is no discount for a later delivery date. However, the relationship for February seems to be linear (perhaps due to lack of data), and the relationship for March can also be approximated as linear without much loss in accuracy (R^2 = 0.9336 as opposed to R^2 = 0.9551 for a third order polynomial regression).

The purpose of using a linear regression is to obtain a constant gradient, which indicates the value of each month in delivery time. This is equal to $718,000/month for February and $975,000/month for March. Intuitively if people are paying about $1m for each month earlier delivery, this means that over the next three or four years (when the plateau is reached), a vessel is expected to earn about $1m per month more than compared to the rest of its life.

The average capesize spot earnings from April 1999 when the Baltic started reporting them, until September 2003 when the market boom started, were $17,157/day. From October 2003 until March 2007, which was the good market, the average was $57,621/day. This difference between the two values corresponds to about $1.2m/month, which is close to the $1m. This shows that people expect the average market in the remaining life of the ship to be almost as low as the period between April 1999 and September 2003 before the market boom.

The y-intercept, which is the price of a new ship with immediate delivery, is $99m for February and $112m for March. We can see that besides the increase in actual ship values, there is also an increase in the value of delivery time. This is more clearly shown in Fig. 2.6-12, which is a combination of all the above graphs (Fig. 2.6-07, Fig. 2.6-11).

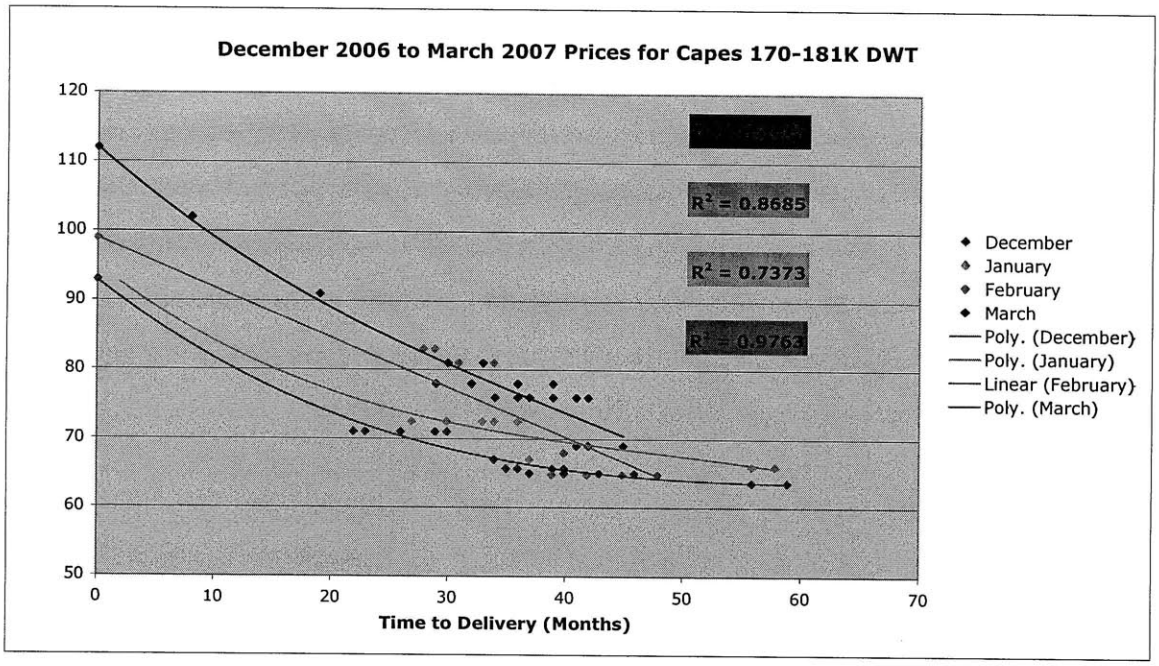


Fig. 2.6-12: Price against Delivery Time for the Orders of Each Month from December 2006 to March 2007

It is shown that during the months from December 2006 until March 2007 when the market was increasing, prices have increased for all delivery dates. This is indicated by the fact that the lines are relatively parallel with minor overlapping while the ones of the more recent months are higher. The fact that the blue line, which refers to March 2007, is slightly steeper than the other ones indicates that the value of delivery time is also higher. The regression models show that price decreases with delivery time towards a plateau level. Their accuracy, which is relatively high, is indicated by the R^2 values that are highlighted on the diagram with corresponding colors to the lines of the regression models and the data points.

2.6.4 Other Determinants of Newbuilding Prices

The above analysis examined the effect of delivery time on newbuilding prices. There are several other factors that play a role and some of these will be discussed by considering the Newbuilding orders and newbuilding resales that took place in March 2007. The

Newbuilding database consists of 40 orders in March 2007. These are summarized in Table 2.6-6 along with the 4 resale transactions that took place that month.

No.	*Buyer Name*	*Yard Name*	*Yard Country*	*Size Kdwt*	*Del. Mos*	*P ($m)*
NEWBUILDING ORDERS						
4	ANANGEL	STX	China	181	38.3	76
2	ANANGEL	Daewoo	Korea	180	31.5	81
4+4	ANANGEL	Daewoo-Mangalia	Rum.	180	34	78
4	TRANSMED	Hanjin	Philipp.	180	-	78
1	KAWASAKI KISEN KAISHA	NACKS	China	300	46	90
2	KAWASAKI KISEN KAISHA	Namura	Japan	250	56.5	85
2	GOLDEN FLAME SHIPPING	STX	China	181	38	76
2	ZOSCO HANGZHOU SHPG	Dalian	China	180	43.5	69
1	-	-	Korea	170	36	80
1	-	Dalian	China	180	42	69
2	ORION BULKERS	SWS	China	177	50.5	-
8	HEBEI	Quingdao	China	180	-	-
4	GOLDEN OCEAN SHIPPING	Jinhaiwan	China	176	31.5	-
2	PHOENIX ENERGY	Sungdong	-	-	-	-
1	MEIJI SHIPPING	Mitsui	Japan	176.7	57	-
NEWBUILDING RESALES						
1	DIANA	SWS	China	177	10	112
1	CHANG MYUNG	Bohai	China	174	8	112
1	-	Bohai	China	175	8	102
1	-	-	Korea	170	19	91

Table 2.6-6: March Resales and March Section of the Newbuilding Database [Braemar 2007b, Vafias 2007]

As analyzed previously, delivery time has a big impact on price. This can be seen most clearly in the table by comparing the prices of the 4 resale deals with the 40 newbuilding orders. Size is another important factor particularly due to the high economies of scale. This is highlighted by the price paid for the K-Line ore carriers (Kawasaki Kisen Kaisha), which is significantly higher than all other newbuildings.

Another important parameter is the specification of the vessel. Many yards have a standard design, which they sell but this is often tailored to the needs of the particular shipowner. People generally prefer to pay some extra money and make modifications particularly when ordering a series of vessels. It is also very often the case that shipyards learn by the modifications of their clients and then introduce them as standard in their subsequent designs.

The price of a newbuilding can be high compared to one from another shipyard due to modifications requested by a specific owner or because of the yard's standard specification. Dalian for example offers a double hull design, which is generally less preferable since IMO decided not to go forward with this requirement in 2005. The design specification offered by STX therefore is preferred and that's why STX vessels are more expensive than Dalian vessels by $7m as shown in Table 2.6-6. Following the previous analysis, it is clear that the difference in price cannot be explained by the 4-5 months difference in delivery time. One can also compare the two Bohai resales with the SWS resale, which is the same price as one and more expensive than the other despite its later delivery time.

2.6.5 Shipbuilding Country Analysis

Beside the particular shipyard, a more general factor that is taken into account is the country where the vessel was built. Ships from certain countries like Japan for example are valued higher than those from other countries such as Rumania for example and Japan can therefore charge higher prices.

One can see in Table 2.6-6 that the Rumanian vessels ordered by Anangel were at a lower price than those that were ordered in Korea even though Daewoo who is building the ships in Rumania is actually a Korean yard. Similarly, the vessels ordered by Transmed in the Philippines are also at a relatively low price compared to the typical Korean and Japanese vessels.

The vast majority of capes today are built in Korea, Japan and China. An analysis was carried out to investigate how the prices offered by these countries have varied over time. Data from the newbuilding database was used along with data from [SSY 2006] to produce the graph shown in Fig. 2.6-13, which shows historical newbuilding prices for these countries.

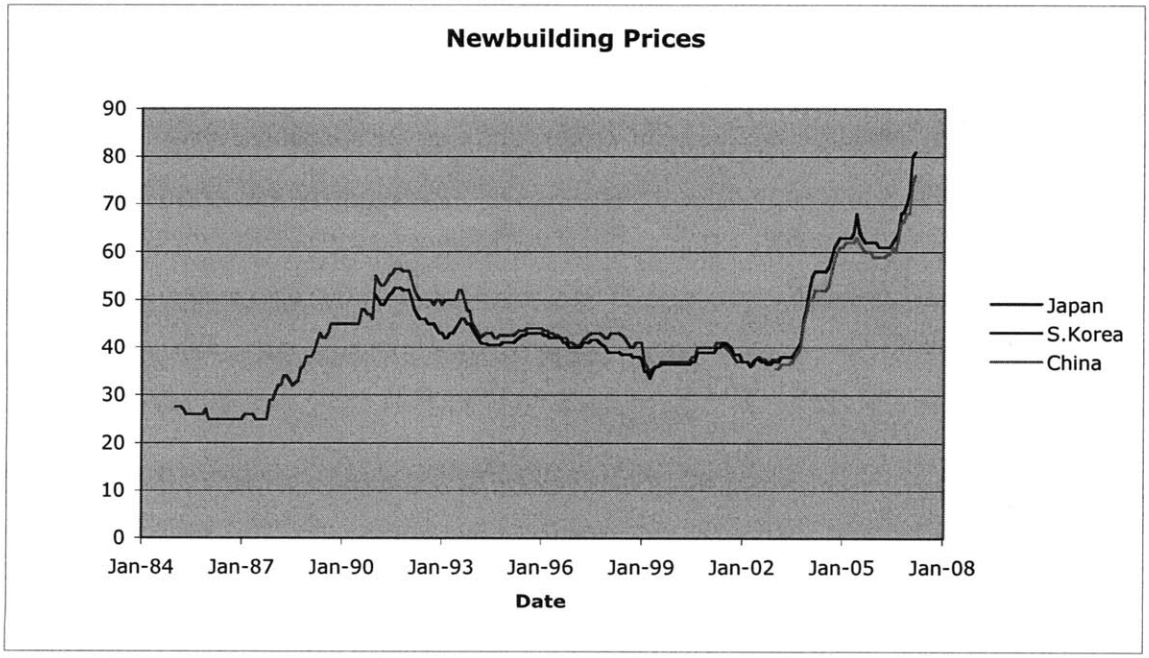


Fig. 2.6-13: Japanese, Korean and Chinese Newbuilding Prices – using data from The Newbuilding Database and [SSY 2007a]

How to Read Fig. 2.6-13		
Consider January 2003		
Legend	Meaning	Value
Japan	Average Japanese newbuilding prices in January 2003	$37.5m
S.Korea	Average South-Korean newbuilding prices in January 2003	$37.0m
China	Average Chinese newbuilding prices in January 2003	$35.5m

Table 2.6-7 How to read Fig. 2.6-13

It is clear that newbuilding prices in these countries are directly correlated and move in parallel, meaning that they can be regarded as very close substitutes. Japan, which is the oldest player, has been the most expensive on average, followed by Korea and then by China, which is a relatively new and fast growing player. Newbuilding prices in all three countries picked up together a few months after the market boom. Fig. 2.6-14 shows how the absolute difference between Japanese and Korean prices, and between Japanese and Chinese prices has varied over time.

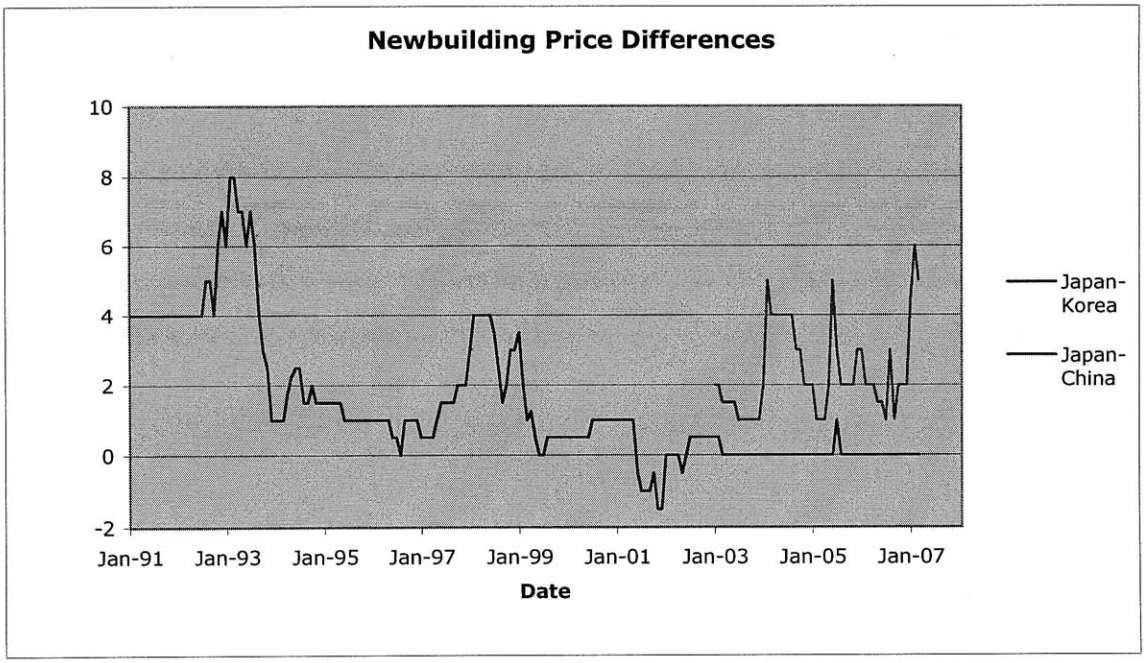


Fig. 2.6-14: Japan, Korea & China Newbuilding Price Difference - using data from The Newbuilding Database and [SSY 2007a]

How to Read Fig. 2.6-14		
Consider January 2003		
Legend	Meaning	Value
Japan-Korea	Average Japanese - South Korean NB prices in January 2003	$0.5m
Japan-China	Average Japanese - Chinese NB prices in January 2003	$2.0m

Table 2.6-8: How to read Fig. 2.6-14

It can be seen that Japan started off as being the most expensive but the difference between Japanese and Korean prices gradually decreased until virtually zero where it has remained over the past few years. There was an instance where the difference was actually negative meaning that Korea was more expensive for a few months in 2001.

There are two possible reasons for this. First, the Korean ships could have been of better specification than the Japanese orders at the time. One must note that Korean yards are happy to allow design modifications by their clients. Japanese yards on the other hand have relatively good standard designs but allow no changes or improvements. They don't want to allow their clients to bring their own production schedule. Furthermore, they generally don't even allow the owner's supervision during construction unless carried out by an approved Japanese company on the owner's behalf. The other possible reason is that there may have been many internal Japanese contracts at the time, which are conducted in Yen, while the Yen - USD fluctuations may make them look cheaper.

China is relatively new to the market and growing fast. Though it has many yards offering a wide range newbuilding prices, it only recently moved into capes so the majority is mainly being built by experienced yards. SWS is considered the best with the most experience in capesize vessels. Bohai also has experience with capes but offers a Double Hull design, which is generally less preferred. NAKS, which is a Kawasaki – COSCO venture, has high experience with Handymaxes and is now also building capes.

China has always been cheaper than Japan though the difference in prices appears to be fluctuating over time between $1m and $6m. Since there is a wide range of prices available and different yards may be taking the majority of the orders at different points in

time, this may contribute to the fluctuations in the average price difference between Japan and China. Quality in China is improving fast but Chinese vessels are still being discounted against the Korean and Japanese vessels.

2.6.6 Conclusions

- Newbuilding Orders are strongly correlated to current earnings and newbuilding prices even now that average delivery times are 38 months while it is a highly cyclical market

- About a quarter of the $12.9bn that was invested in newbuilding capes between May 2003 and March 2007 was invested in March 2007
- There is a significant time lag between charter rates and newbuilding prices

- Delivery time is the most important factor determining newbuilding prices in today's market. Price decreases with delivery time towards a plateau level at about 4 years

- Newbuilding orders between December and March showed that the value of delivery time was increasing as well as prices for all delivery dates

- Other parameters affecting newbuilding prices include ship size, design specification, country of built, shipyard etc.

- The main countries where capes are built today are Japan, Korea and China, which is a relatively new and fast growing player

- China is most flexible regarding the design specification and monitoring during construction while Japan is the least

- Japanese prices used to be the highest but have been about the same as Korean since January 2003

- China offers a big range of quality and prices but has always been cheaper than Korea and Japan on average

2.7 Information Cascades in the Cape Market

2.7.1 Intoduction

As of Dec 2009, there are currently 946 capes in the world fleet and 745 on order [Clarksons 2009a]. Fig. 2.7-1 shows the orderbook as a percentage of the current fleet along with the average daily earnings since the 1990s.

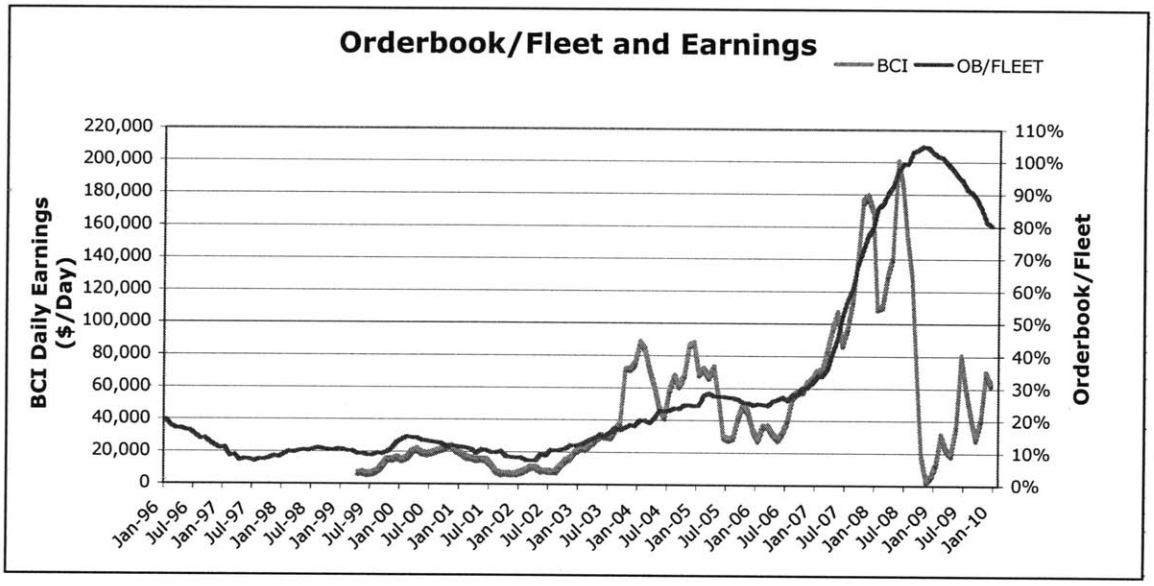


Fig. 2.7-1: Cape Orderbook in terms of Fleet Size, and Earnings – Based on data from [Clarksons 2009a]

Even though the market is cyclical and orders take a few years to be delivered, there is a clear trend between orders relative to the current fleet and the current level of the market. Intuitively this does not make sense for two reasons. First, orders are more expensive when the market is high, and second, since the market is cyclical, an order on a crest will likely be delivered during a trough.

What is worse is that the huge orderbook that builds up, itself brings the market down. That is inevitable when the orderbook exceeds the current fleet size (as in 2008), because the demand is very unlikely to double from already high levels and stay that high for

25 years (a ship's typical lifetime). Furthermore, the yards that are constructed to build these ships will have to keep building to pay off their CAPEX and stay in business.

The theory of reflexivity by George Soros may be helpful in understanding how this process evolves. In brief, the theory states that the fundamentals used to determine market prices are shaped by the biases of the market participants. The participant's views and the actual market thereby enter into a process of dynamic disequilibrium. In The Alchemy of Finance, he applies this concept in a wide variety of fields including exchange rates, lending, stock prices etc. For example, capital outflows which determine exchange rates are affected by market participants who are trying to predict exchange rates, while banks who decide whether to lend based on debt ratios, and influence these ratios through their lending activities [Soros 1987]. The cape market is a similar example whereby shipowners order ships based on their expectation of what the market will look like in a few years time when they are in effect shaping that market with their newbuilding orders. This leads to a constant disequilibrium, giving rise to the high market cyclicality.

The Minsky Moment can also be used to explain the massive orderbook of 2008. Minsky describes the instability of the financial system particularly during times of prosperity. He talks about "hedge borrowers", "speculative borrowers" and also "Ponzi borrowers" who are rewarded with higher profits by levering up in a booming market but who also rely on selling assets or on refinancing based on asset appreciation to pay back interest on their loans. He also describes how lenders are attracted by the performance of borrowers during "good times", and keep lending them until a crisis is inevitable [Minsky 1992]. This closely resembles the "shipping good times" since 2003, after which a massive number of shipowners levered up to place orders. Today, these banks are busy signing loan covenant waivers to these borrowers whose assets' fair market value has decreased below the outstanding debt, in order to avoid having to take in those ships and sell them at huge losses.

It seems obvious that it is wrong to order when the orderbook is higher than the size of the current fleet, and when people keep ordering and are projected to continue doing so like crazy. However, based on the number of people doing so, I suspect this behavior can also be explained in part through information cascades, and I will attempt to demonstrate this using the current orderbook of capes.

2.7.2 Information Cascades

Baysian updating is the classical method through which one can calculate posterior beliefs based on their prior beliefs and new information that arrives. Denote P(T) as the prior probability that a hypothesis is true, then the posterior probability given information "I" is:

$$P(T \mid I) = P(T)\frac{P(I \mid T)}{P(I)} \tag{2.7-1}$$

Alternatively, if we have two hypotheses (e.g. true and false), we can conveniently rewrite Bayes' rule in terms of prior and posterior odds (ratio of probabilities) as:

$$\frac{P(T \mid I)}{P(F \mid I)} = \frac{P(T)}{P(F)}\frac{P(I \mid T)}{P(I \mid F)} \tag{2.7-2}$$

This has been used extensively in a variety of settings and one of the most useful applications is the Black-Litterman model, developed by Goldman Sachs in 1990 to determine optimal portfolio allocation. The model takes in as a prior the output of another model, such as the capital asset pricing model (CAPM) and updates it using the specific views of the investor.

Information Cascades are a simple idea from game theory which explains how many companies or individuals inevitably end up making the same choices (herding) even when acting on rational grounds. Party A observes the actions of party B and presumes that Party B is acting on their information. Then through Baysian updating, the beliefs of party B are tilted towards making the same choice as party A. If party B follows the action of party A, then party C, who sees the actions of both party A and party B has an even stronger influence to act in the same way. This leads to an information cascade in which parties end up acting based on the actions of others, which outweigh their own private information. No additional information can therefore be inferred by the actions of a single party after a certain point in the cascade.

The classical way of demonstrating information cascades is through a simple experiment with two urns. Urn A contains 2 white balls and a black, while urn B contains two black balls and a white. Each individual picks a ball and puts it back without anybody else seeing it. Then they publicly announce their guess of whether it is urn A or B. If rational, the first two individuals will guess the urn corresponding to the color which they picked. From the third individual onwards however, everyone is influenced by the previous guesses of others. This leads to interesting outcomes where everyone keeps guessing the same urn regardless of what they picked. It is particularly interesting when the choice being made by everyone is actually the wrong choice because of some initial unlikely event that triggers the cascade in the wrong direction. Fig. 2.7-2 shows the probability of ending up in a correct or an incorrect cascade based on the probability of the signal being correct.

In real life applications however, life is more complicated since this does not capture the impact of our choices on the outcome itself, as discussed earlier under Soros' theory of reflexivity.

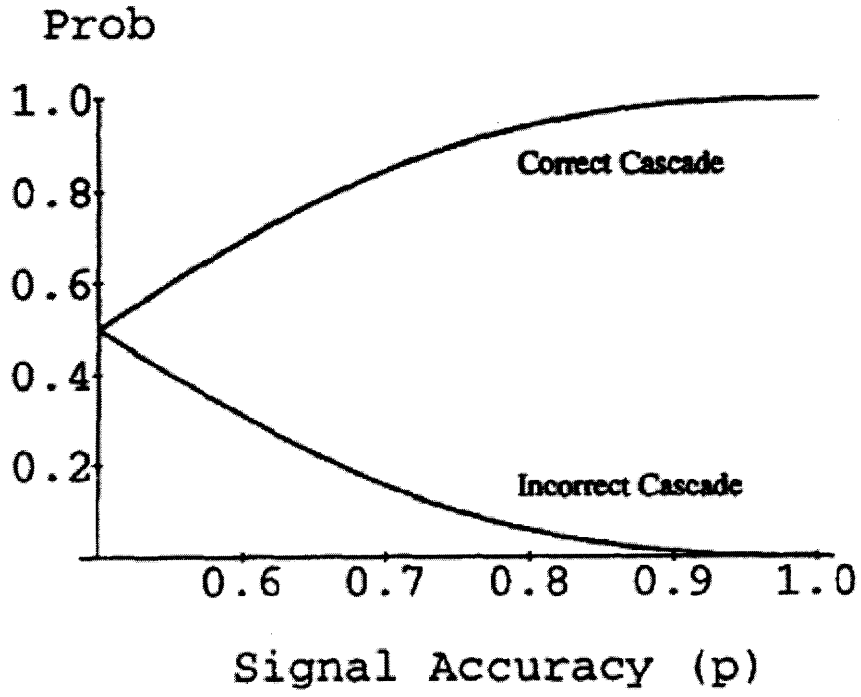


Fig. 2.7-2: Chances of a correct or incorrect cascade as a function of signal accuracy "p", where "p" is the probability of the signal being correct [Bikhchandani et al 1992]

Information cascades appear frequently in economies especially since exchange of information is possible between individual players of the market. Many terms have been used in the past to express this process, such as bandwagon effect, herding, etc. The theory of information cascades has been used in the past to explain different social phenomena where information about others' choices plays a significant role for the aggregate outcome of a process, such as selection of a movie or of social activities to participate in, purchase of a product etc.

Several researchers have worked in this area proposing different models to capture information cascades behavior. In [Bickhchandani et al 1992], information cascade is defined as a compliance towards actions followed by others disregarding personal preferences. [Anderson and Holt 1997] worked on inducing information cascades in a laboratory setting using the model of [Bikhchandani et al 1992]. On a relevant paper, while working on an optimal model to describe agents' influence on decision making, [Banerjee 1992] concluded that information cascades lead to inefficient equilibriums. More specifically, he concluded that speculations about information and decision making reasoning grow fast leading to inefficient markets. The value of personal information is traded for the value of the decision of others.

Another approach has been followed by [Scharfstein and Stein 1990] focusing on an agency problem; where the agent gets rewards for convincing a principal for making a decision. This approach increases the inefficiency of the final outcome. This derives partly from lack of information about the reasoning of other agents' actions, leading subsequent agents to disregard actual information and also due to lack of structure of information exchange between agents. Another parameter that leads to inefficient results is the herd externality's positive feedback that, i.e. after joining the herd you invite others to join in order to better self-justify making a decision based on others' preferences.

Different fields have been analyzed using information cascades modes. More specifically, [Keynes 1936] work suggested that investors' behavior in asset markets is governed by information cascades. Other examples of applications of this theory include the study by [Lee 1998] that examines information aggregation failures in a security market under sequential trading causing high market volatility and inefficiency due to "informational avalanches".

Information cascades have also been introduced by [Ghashghale et al 1996] for the modeling of Foreign Exchange market dynamics in comparison with hydrodynamic problems in turbulence. Information exchange between different timescale traders causes information cascades, i.e. forced behaviors in a similar way as energy is forced towards certain scales in turbulence.

2.7.3 Information Cascades in Shipping

In shipping, there are many individuals of various sizes and influence. Each plays a different role and has different sources of information. Charterers for example or cargo owners may be better informed about future demand for transportation whereas groups owning shipyards may be better informed about future supply. Furthermore, some companies have closer ties to governments of key countries such as China, whereas others buy information from special research companies such as Marsoft.

People talk to each other and their brokers and they also read shipping newspapers which play a big role in shaping people's perceptions of the market. They try to infer what type of information others have by their moves which are published through newspapers and brokers reports. This clearly seems like an environment that would foster information cascades.

There are at least two areas in shipping where one could directly examine the presence of information cascades. One is in the futures market and the other one is in newbuilding orders. Regarding futures, a big Taiwanese owner, Nobu Su, leader of TMT, is known to have great influence, having cornered the market in 2006. Lloydslist wrote an article about him having flown with a helicopter and seen the mines and stocks in Australia and the empty stocks in China. He rushed to buy futures, inducing others to follow him and also chartered in ships from the physical market, keeping them idle [Lewis 2007a]. These two simultaneous moves caused the market to spike, allowing him and those who followed him to cash in high profits. Articles have been written about his influence in the market and information cascades among people who watch him are very probable [Lewis 2007a, Lewis 2007b].

However, it is hard to demonstrate an information cascade in the futures market because whenever someone takes a position, there is always a counterpart taking the exact opposite position. All that we witness when there is a cascade of going long, is an increase in trading volume and an increase in futures prices. But one could argue that in the meantime, following that logic, there should be an information cascade going the other way (short) which would net out the effects of the first cascade.

Information cascades can perhaps be demonstrated more effectively, with more concrete support, in the case of newbuilding orders from shipyards. An outstanding example where this may have been the case was with handymaxes in the early 1980s. In 1984, a big Japanese company, Sanko acted on some information that they had which indicated that the world economy would recover. They went and ordered 140 HMX (40-42kwt) vessels which triggered several European companies to go and order another ~140 (in total). This increased supply dramatically in 1986 after the deliveries, outweighing any increase in demand anticipated by Sanko. The resale value of these ships was then ~$7m while the orders had been placed two years earlier ~ $17m to $18m.

Current Orderbook Analysis

The database I will analyze consists of the full capesize orderbook as of Dec 2009. A list of all the cape orders that have not been delivered yet has been provided by London based Clarksons Brokers Ltd. The data includes 329 orders between Dec-10-2004 and 27-Nov-2009. The average order size is 2.26 ships with a standard deviation of 1.83. The database includes 672 capes from 138 companies, plus 73 from unknown owners (total orderbook of 745 capes). Note that some orders may have been made in addition to those in the database but are not included because the ships have been delivered. Fig. 2.7-3 shows the number of orders under each order size, while Fig. 2.7-4 shows the orders on the dates that they have been placed.

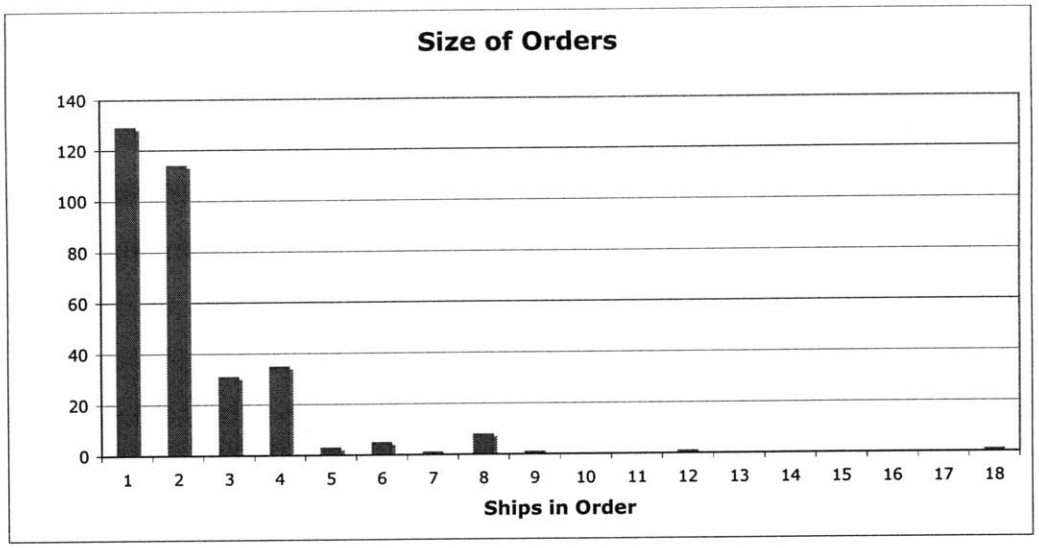


Fig. 2.7-3: Number of orders for each Order Size – Based on data from [Clarksons 2009a]

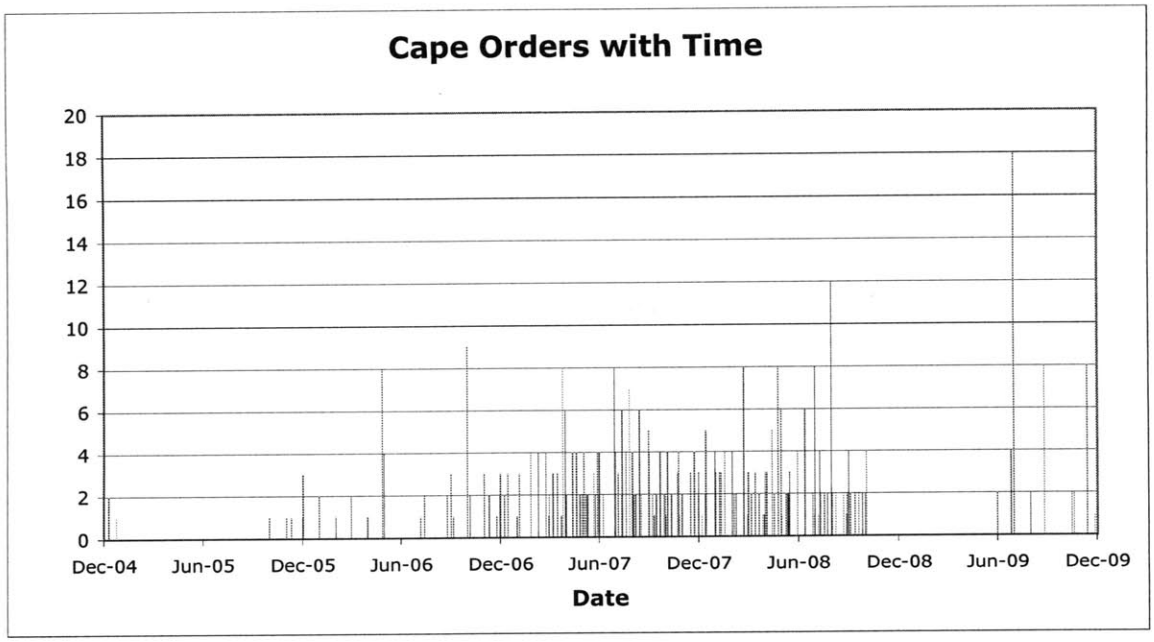


Fig. 2.7-4: Size and Timing of all orders of the Dec-2009 Orderbook – Based on data from [Clarksons 2009a]

By examining Fig. 2.7-4, we notice that orders tend to be clustered and follow patterns indicating the existence of information cascades. An information cascade for example seems to have led the orders up until Oct 2008 where the cascade breaks down following the market crash. A new information cascade then seems to initiate after 8 months of no orders, with a 2 ship order in June 2009, followed by a 4 ship order the same month,

and then several orders including an 18 ship order in July. Note that the information in this case regards the state of the market a few years ahead, when the ships ordered today will be delivered.

The interesting question is what sort of events triggers these information cascades. Based on intuition, I will examine 3 types of events, namely the biggest one-time orders, orders by companies with the biggest orderbooks, and orders by companies with the biggest cape fleets. Big orders resemble big commitments, so they are likely to trigger a cascade because people can more easily conclude that they contain reliable information. Companies with big cape fleets are likely to trigger a cascade when ordering because, presumably, they are players with more access to relevant information. Orders by companies with the large orderbooks are likely to be based on additional information access, and they resemble big commitments (adding to an already-big orderbook).

I devised a simple method to examine whether an order triggers other orders. This compares the number of ships ordered during the month following the event with the those ordered during the month preceding the event (the day of the event is excluded). If the events have no influence, on average, the increase in orders should be zero. By using a large enough sample size, if we consistently get positive increases following the events, we can infer that they trigger other orders leading to an information cascade. The length of time for which the event has an effect is unknown but a sensitivity analysis is carried out by repeating the analysis using 2 months before and after the event.

Big Orders

The 10 largest orders include those that are equal to or greater than 8 capes. They are analyzed under Table 2.7-1. We can see that on average, the 10 largest orders of the current orderbook, stimulated an increase of 52% in the orders in the following month compared to the preceding month before, and an increase of 29% in the following 2 months compared to the two preceding months.

Date of Order	*Current Owner*	*Order Size*	*1Month Before*	*1Month After*	*2 Mos before*	*2 Mos after*	*1Month % inc.*	*2Month %inc.*
28-Apr-06	Enterprises Shpg.	8	1	4	3	4	300%	33%
01-Oct-06	Unknown	9	14	5	18	23	-64%	28%
26-Mar-07	HOSCO	8	16	40	32	83	150%	159%
29-Jun-07	COSCO	8	19	38	57	76	100%	33%
22-Feb-08	Nordcapital	8	13	25	30	48	92%	60%
25-Apr-08	COSCO	8	24	28	48	42	17%	-13%
01-Jul-08	COSCO	8	12	28	38	48	133%	26%
31-Jul-08	Vale	12	26	14	38	31	-46%	-18%
01-Jul-09	Grand China Logist.	18	6	2	6	10	-67%	67%
26-Aug-09	Vale	8	2	0	28	4	-100%	-86%
	Average	9.5	13.3	18.4	29.8	36.9	**52%**	**29%**
	Exc. 4 Irrelevant	8	14.2	27.2	34.7	50.2	**132%**	**50%**

Table 2.7-1: Analysis of 10 Largest Orders of Database

There are, however, 4 orders which are irrelevant and distort the results. Grand China Logistics acquired the shipyard and made an order of 18 capes that had recently been cancelled by the previous owners in order to prevent the yard from closing. This actually deters shipowners from investing as they rely on some shipyards shutting down in order to let the market recover. Vale is the major exporter of iron ore from Brazil to China. It competes with exporters from Australia who are a quarter of the distance away. Their recent bulk orders of mammoth 400,000dwt iron ore carriers (not even classified as capes) was a strategic move to keep its variable (transportation) costs down and restore its competitiveness.

This again has the effect of deterring shipowners from investing as it has negative implications for future demand. This is because Vale, a major charterer, will now rely on its own ships to cover its transport needs. Finally, there is a 9 vessel order at Imabari shipyard

by an unknown shipowner which could also be a combination of smaller owners by unknown shipowners on the same day. The mere fact that it is by an unknown owner also means that it was probably not reported at the time or that it could have been interpreted as a false signal, so it could not have led to an information cascade. If we exclude these 4 data points, the percentage increase becomes 132% and 50% using 1 month and two month periods respectively.

Heavily Invested Owner's Orders

The current orderbook includes 627 orders from 338 known owners and another 73 orders from unknown owners. For this part of the analysis, we have to exclude orders by unknown owners. Fig. 2.7-5 shows the companies ranked by orderbook size (smallest to largest) and Fig. 2.7-6 shows the number of companies with each orderbook size.

Fig.2.7-5: Companies Ranked by Orderbook Size

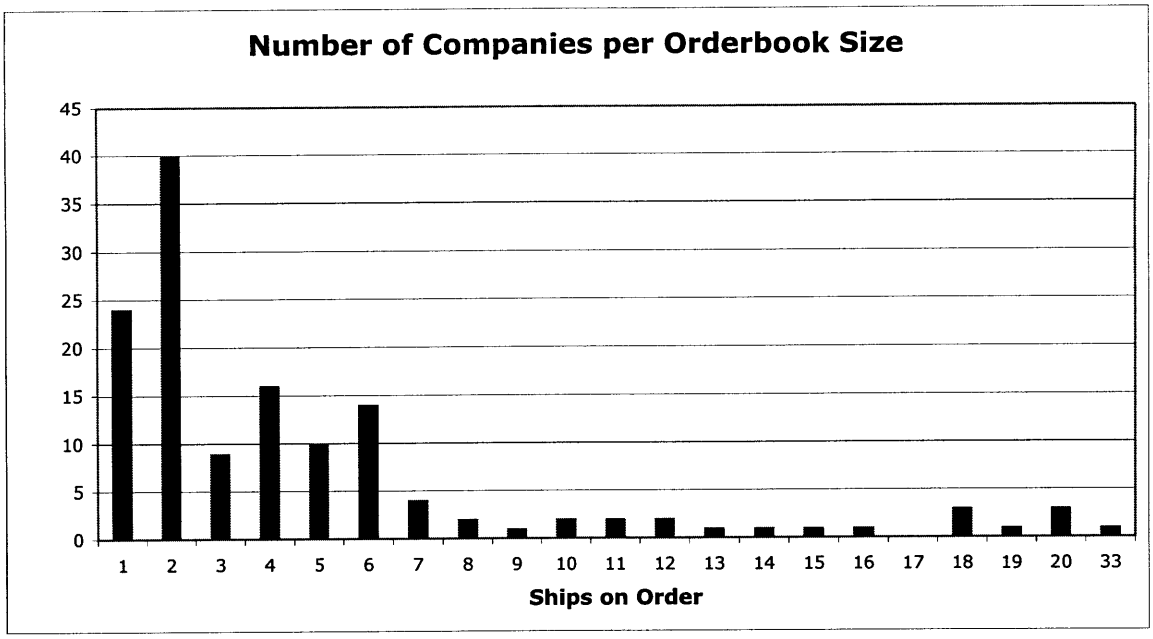


Fig. 2.7-6: Number of Companies with each Orderbook Size

Table 2.7-2 lists the 5 biggest companies in terms of orderbook size, while Table 2.7-3 shows the analysis of all the orders made by these companies.

Company	*Capes on Order*
Mitsui O.S.K. Lines	19
Korea Line	20
STX Pan Ocean	20
Vale	20
China Ocean (COSCO)	33

Table 2.7-2: The 5 Biggest Companies By Orderbook Size

Date of Order	*Current Owner*	*Order Size*	*1Month Before*	*1Month After*	*2 Mos Before*	*2 Mos After*
01-Feb-06	Mitsui O.S.K.	1	3	2	7	5
05-Sep-06	Mitsui O.S.K.	1	14	10	21	15
30-Nov-06	Korea Line	2	10	14	22	22
01-Dec-06	Mitsui O.S.K.	2	14	7	26	15
05-Jan-07	Korea Line	3	7	4	25	24
01-Mar-07	Mitsui O.S.K.	2	17	39	26	63
04-May-07	STX Pan Ocean	1	24	50	63	70
11-May-07	COSCO	2	43	33	78	64
25-May-07	Korea Line	2	36	19	82	75
31-May-07	Korea Line	2	42	29	87	67
29-Jun-07	COSCO	8	11	24	57	76
01-Jul-07	COSCO	4	29	39	75	82
20-Jul-07	COSCO	1	42	45	75	71
14-Aug-07	STX Pan Ocean	6	25	33	81	64
01-Sep-07	Korea Line	2	47	21	85	53
23-Nov-07	STX Pan Ocean	4	9	35	44	73
01-Dec-07	Korea Line	1	15	40	45	57
07-Dec-07	Korea Line	1	33	36	55	55
07-Dec-07	Mitsui O.S.K.	1	33	36	55	55
31-Dec-07	Korea Line	3	33	17	50	39
01-Feb-08	Mitsui O.S.K.	1	17	26	71	49
01-Mar-08	Mitsui O.S.K.	3	22	23	39	59
01-Apr-08	STX Pan Ocean	1	25	44	47	58
04-Apr-08	Korea Line	1	23	30	49	52
04-Apr-08	Korea Line	3	23	30	49	52
25-Apr-08	COSCO	8	24	28	48	42
01-Jul-08	COSCO	8	12	28	79	48

31-Jul-08	Vale	12	26	14	64	31
08-Aug-08	Mitsui O.S.K.	2	27	18	53	30
03-Oct-08	Mitsui O.S.K.	4	10	0	30	0
01-Jul-09	Mitsui O.S.K.	1	6	2	6	10
26-Aug-09	Vale	8	2	0	28	4
13-Nov-09	STX Pan Ocean	8	4	1	13	1

Table 2.7-3: Analysis of Orders by the 5 Biggest Companies in terms of Current Orderbook Size

Table 2.7-4 shows a summary of the results from Table 2.7-3.

Current Owner	*Number Orders*	*Mean Size*	*1Month Before*	*1Month After*	*2 Mos before*	*2 Mos after*	*1Month % inc.*	*2Month %inc.*
COSCO	6	5.2	26.8	32.8	68.7	63.8	48%	-5%
Vale	2	10.0	27.0	7.0	46.0	17.5	-73%	-69%
STX	4	4.8	15.5	29.8	50.3	52.0	89%	-9%
Korea Line	10	2.0	26.9	24.0	54.9	49.6	5%	-6%
Mitsui	10	1.8	16.3	16.3	33.4	30.1	-12%	-1%
Top 5 (Avg.)	33	3.3	22.2	23.5	49.5	44.9	**15%**	**-8%**
Top 4	31	2.9	21.9	24.6	49.8	46.6	**21%**	**-4%**

Table 2.7-4: Summary of Results of Orders by the 5 Biggest Companies in terms of Current Orderbook Size

Here we see that the average increase is 15% and -8% using 1-month and 2-month intervals respectively. Again the results are slightly distorted by the smallest of the top 5 owners, the big charterer Vale, who only has 2 orders. One of those was also preceded by the 18-ship order of Grand China Logistics further distorting the results. If we exclude Vale and consider the top 4 owners in terms of orderbook, the average percentage increase increases to 21% and -4% for one month and two months respectively.

This analysis shows that these events have a significant positive impact on orders during the next month but no impact in the second month.

Big Owner's Orders

Current fleet consists of 946 ships owned by 217 owners. The top 50 fleets account for 650 ships while 296 are owned under fleets of 5 or fewer ships. Fig. 2.7-7 shows the distribution of current fleet sizes and Table 2.7-5 shows the 5 biggest fleets.

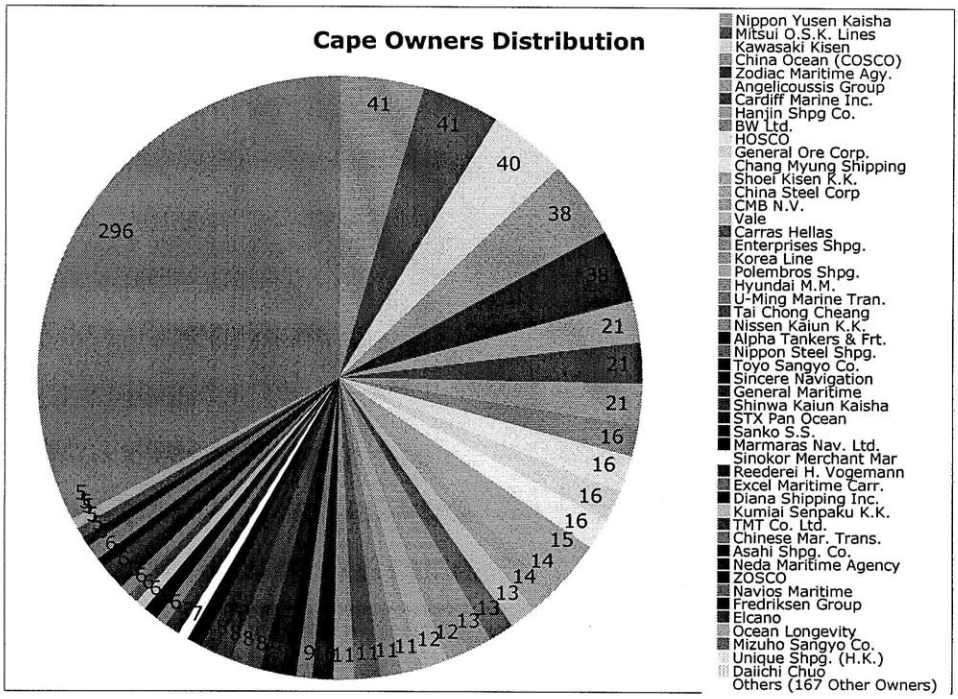


Fig. 2.7-7: Distribution of Current Fleet Sizes

Company	*Capes*
Nippon Yusen Kaisha	41
Mitsui O.S.K. Lines	41
Kawasaki Kisen	40
China Ocean (COSCO)	38
Zodiac Maritime Agy.	38

Table 2.7-5: Top 5 Current Fleets

Table 2.7-6 shows the analysis of the orders made by those 5 owners

Date of Order	*Current Owner*	*Order Size*	*1Month Before*	*1Month After*	*2 Mos Before*	*2 Mos After*
01-Nov-05	N.Y.K.	1	1	2	4	8
10-Nov-05	N.Y.K.	1	1	4	5	7
01-Jan-06	N.Y.K.	1	4	3	6	5
31-Mar-06	N.Y.K.	1	2	9	3	13
06-Oct-06	N.Y.K.	2	10	3	24	21
01-Dec-06	N.Y.K.	3	14	7	26	15
01-Jan-07	N.Y.K.	1	13	8	27	28
11-May-07	N.Y.K.	1	43	33	78	64
01-Dec-07	N.Y.K.	2	15	40	45	57
01-Dec-07	N.Y.K.	3	15	40	45	57
09-May-08	N.Y.K.	2	30	15	57	41
01-Feb-06	Mitsui	1	3	2	7	5
05-Sep-06	Mitsui	1	14	10	21	15
01-Dec-06	Mitsui	2	14	7	26	15
01-Mar-07	Mitsui	2	17	39	26	63
07-Dec-07	Mitsui	1	33	36	55	55
01-Feb-08	Mitsui	1	17	26	71	49
01-Mar-08	Mitsui	3	22	23	39	59
08-Aug-08	Mitsui	2	27	18	53	30
03-Oct-08	Mitsui	4	10	0	30	0
01-Jul-09	Mitsui	1	6	2	6	10
01-Jan-06	Kawasaki	2	4	1	6	3
07-Jul-06	Kawasaki	1	0	3	0	21
01-Sep-06	Kawasaki	1	4	14	11	19
16-Mar-07	Kawasaki	3	7	36	28	78
01-Dec-07	Kawasaki	2	15	40	45	57
01-Jan-08	Kawasaki	2	54	23	71	43

04-Sep-08	Kawasaki	2	20	12	48	12
20-Oct-09	Kawasaki	2	2	9	2	10
11-May-07	COSCO	2	43	33	78	64
29-Jun-07	COSCO	8	11	24	57	76
01-Jul-07	COSCO	4	29	39	75	82
20-Jul-07	COSCO	1	42	45	75	71
25-Apr-08	COSCO	8	24	28	48	42
01-Jul-08	COSCO	8	12	28	79	48
21-Mar-08	Zodiac	2	21	24	43	24
09-May-08	Zodiac	2	30	15	57	41
30-May-08	Zodiac	2	28	12	62	38

Table 2.7-6: Analysis of Orders by Owners with the 5 biggest Cape Fleets

The highlighted example of Kawasaki has no orders preceding it while 3 ships were ordered in the following month and 21 in the following 2 months. This is the perfect example of an information cascade initiation but it yields an infinite % increase so it is excluded from the following results of Table 2.7-7.

Current Owner	*Number Orders*	*Mean Size*	*1Month Before*	*1Month After*	*2 Mos before*	*2 Mos After*	*1Month % inc.*	*2Month %inc.*
NYK	11	1.6	13.5	14.9	29.1	28.7	75%	38%
Mitsui	10	1.8	16.3	16.3	33.4	30.1	-12%	-1%
Kawasaki	8	1.9	13.3	17.3	26.4	30.4	144%	73%
COSCO	6	5.2	26.8	32.8	68.7	63.8	48%	-5%
Zodiac	3	2.0	26.3	17.0	54.0	34.3	-31%	-37%
All	*38*	*2.3*	*17.3*	*18.8*	*37.9*	*35.4*	***52%***	***21%***

Table 2.7-7: Summary of Results for Orders by the 5 Biggest Owners

An average of 52% and 21% using 1 month and 2 month intervals is observed respectively. It is also interesting to see how some owners, such as NYK seem to have more influence on the market than others such as Zodiac on average.

2.7.4 Summary of Results and Conclusions

Table 2.7-8 provides a summary of the key results.

Type of Triggering Orders	*No. of Orders*	*Avg. Size of Order*	*Avg. %Increase (1-Month)*	*Avg. %Increase (2-Month)*
Biggest Orders (Excl. 4 Irrelevant)	6	8.2	**132%**	**50%**
By Top 4 Order Book Owners	31	2.9	**21%**	**-4%**
By Top 5 Owners (by fleet size)	38	2.3	**52%**	**21%**

Table 2.7-8: Summary of Key Results

Based on the results we can infer that indeed some events have a significant impact, triggering more orders. This provides the basis for information cascades which are witnessed by examining patterns in historical orders. Interestingly, big orders (irrespective of party) have the biggest impact followed by orders by owners with big fleets. Presumably, that is because big orders indicate a big commitment allowing observers to infer that the party is acting on reliable data. Furthermore, players with big current fleets are perhaps believed to have access to more information, and are therefore watched more carefully and imitated. Finally, it is also interesting to see that consistently across the three types of cases, we get weaker results using 2-month intervals compared to 1-month intervals. This shows how the impact of the event gradually decays.

2.8 Freight Forward Agreements (FFAs)

2.8.1 Introduction

A futures contract is an agreement between two parties to buy or sell a certain underlying instrument at a future date (the settlement date), at a pre-set price (the futures price). The contract imposes an obligation on the holder to buy or sell at the settlement date.

Futures traders are either hedgers or speculators. Hedgers include producers and consumers of a commodity who try to hedge out the risk of price changes. Producers can thereby guarantee certain future revenue, while consumers can plan on fixed future costs. Speculators try to make a profit by predicting the market and buying or selling the commodity on paper accordingly. Futures markets thus serve to increase liquidity and transfer the risk between traders such as hedgers and speculators who have different risk and time preferences or a different perspective of the market.

In the capesize bulk carrier market, the most commonly traded futures are the time charter Index (in $/day) and the freight rates (in $/ton) along the various trade routes. The t/c Index is the average time charter rate of the four routes (front-haul, back-haul, transatlantic and transpacific). It is common to trade these futures for a certain contract period that could be a month, quarter or year. The last day of each month during the contract period is then a settlement date and the payment day is the 7th day of the following month. A Baltic capesize bulk carrier, meaning a 172,000dwt vessel up to 7 years old, is assumed for pricing.

An example of a future that might be traded today might be the T/C Index for 2008 (this will involve 12 settlement dates). The futures price is $45,000/day. A charterer who knows they will need a capesize vessel in 2008 might therefore buy this contract, which will effectively guarantee that price. If the physical market in 2008 is say $50,000/day then they will have to pay that much to charter a vessel, but they will receive the $5,000/day difference from the counterparty of the futures contract. On the other hand, if the market is say $40,000/day, they will be paying less to charter a vessel but will have to pay the $5,000/day difference to the counterparty of the futures contract. A shipowner who owns a cape might

also hedge in a similar fashion, which would be equivalent to chartering out a vessel today for the year 2008 at 45,000$/day.

A trader, who buys the future for 2008 today, may sell and buy back futures for that contract period several times before they mature. A speculator can thus also hedge their bet and make a profit or a loss on paper much earlier. This means that a profit can be made on a correct forecast of the market fluctuation between the futures buying and selling date (or vice versa), regardless of the physical market on the settlement date (2008).

On a note of caution, the traders must be aware that the solvency of their counterparts is their own risk. There have been cases where counterparts have failed to fulfill their obligation. The latest example is North American Steamship Limited (NASL) who declared its inability to fulfill its obligation on a series of contracts in November 2006. Increasing involvement of banks has been witnessed over the past few years. At a commission, banks act as a counterpart on account of their approved client. The risk of the solvency of the counterpart is thereby diminished. Furthermore, on a cross-trade with the bank, the settlement is effected immediately. This means that when a profit (or loss) is made on paper by buying and then selling a future with the bank, it goes directly into the trader's bank account without having to wait for the settlement date.

2.8.2 Data

Futures prices are published every day for the capesize t/c index and for freight on some trade routes. It is important to note that these are changing continuously even though they are only quoted once a day. The Bid and Offer is published for each future period and the mean value is taken as the price regardless of the number of transactions taking place. It is not always necessary however that a transaction is made at the quoted price. Month to date values, showing the average so far since the beginning of the month, and year to date values, showing the average since the beginning of the year, are also published every day along with the spot rates.

Daily forms which denote the futures price of the t/c index and trade routes C4 (Richards Bay/Rotterdam) and C7 (Bolivar/Rotterdam), were collected for the last day of each month since July 2004 from [FIS 2007]. These were then tabulated in a form that could be used to carry out a comparative analysis and to present the results in graphical form. The results are presented in the following sections.

Please note that the spot rates are the rates in the last day of each month, while actual values for a period (month, quarter, two quarters or a year) refer to the average value over that period.

2.8.3 Time Charter FFAs

Since hedging through the paper market is possible as discussed earlier, buying or selling a futures contract can be seen as almost equivalent to chartering in or chartering out a vessel for the futures contract period. Charterers will therefore look for the cheapest option and shipowners will look for the highest paying option between the two substitutes. As a result, when futures move up or down, this inevitably causes period charter rates to follow and vice versa.

Ideally, futures prices and T/C rates at a given point in time and for a given contract period should be identical. There are however some discrepancies owing to the fact that the futures and the physical markets are separate. Fig. 2.8-1 shows a comparison between futures prices and physical time charter rates over the same contract period.

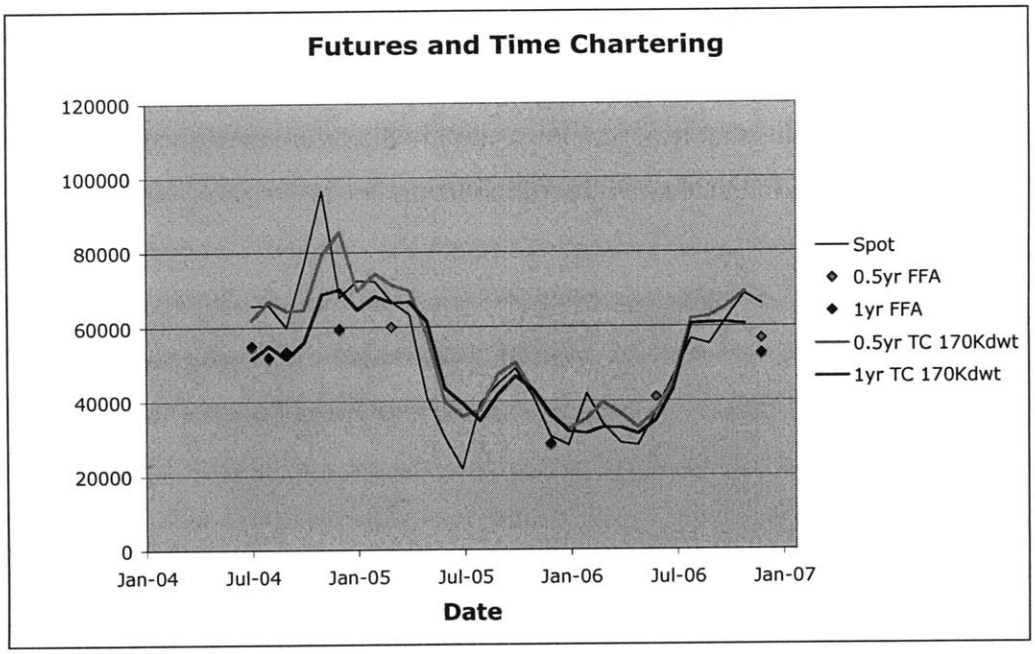


Fig. 2.8-1: Comparison of Futures Market and Physical Market - using data from [Clarksons 2007a & FIS 2007]

How to Read Fig 116		
Consider July 2004		
Legend	Meaning	Value
Spot	t/c Index value on the last day of July 2004	$65,724/day
1yr FFA	Futures price for 1 year t/c on the last day of July 2004	$55,000/day
0.5yr TC	6 month physical t/c rate in July 2004	$62,000/day
1yr TC	1 year physical t/c rate in July 2004	$51,500/day

Table 2.8-1: How to read Fig 116

As mentioned in the introduction, futures prices assume a vessel of 172,000dwt up to 7 years old. These are therefore compared with the physical market for similar vessels for 6 and 12-month period t/c. A close relation is evident between the futures and the physical market. The small differences are mainly explained by the fact that futures values refer to the end of each month whereas time charter values are an average for each month. Another reason is that the time charter involves an optional period a the end.

Fig. 2.8-2 shows the futures price for the t/c index for the next one to eighteen months along with the spot rates since June 2004. Note that the number of months in this case is the contract period. This means that for each point, trading the future is equivalent to chartering a vessel at that time for the indicated number of months.

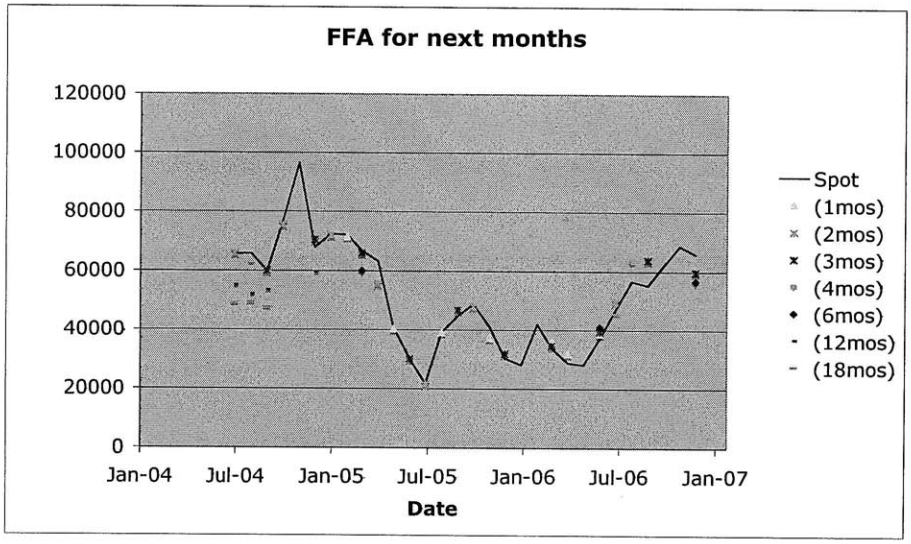


Fig. 2.8-2: Futures Prices for the T/C Index along with the spot rates - using data from [FIS 2007]

How to Read Fig. 2.8-2		
Consider September 2004		
Legend	Meaning	Value
Spot	t/c Index value on the last day of Sept. 2004	$59,846/day
(3mos)	Futures price for Oct'04 – Dec'04 as of End Sept. 2004	$60,000/day
(12mos)	Futures price for Oct'04 – Sept'05 as of End Sept. 2004	$53,500/day
(18mos)	Futures price for Oct'04 – Mar'06 as of End Sept. 2004	$47,500/day

Table 2.8-2: How to read Fig. 2.8-2

As shown, futures prices, particularly those for few months ahead, are closely aligned with the spot market. This shows that even though the market is fluctuating between $20K/day and $100K/day in the investigated period, traders consistently value futures close to the present market. Furthermore, it can be seen that when the market is declining, the futures prices are usually slightly lower than spot rates (points lie below the line).

Conversely, when the market has a positive gradient, futures prices are often slightly above the line. Futures values therefore also depend on the market direction.

The above conclusion can also be drawn by examining futures curves at various points in time. Fig. 2.8-3 shows three futures curves along with the spot market to illustrate this. The flat portion of each line shows the contract period.

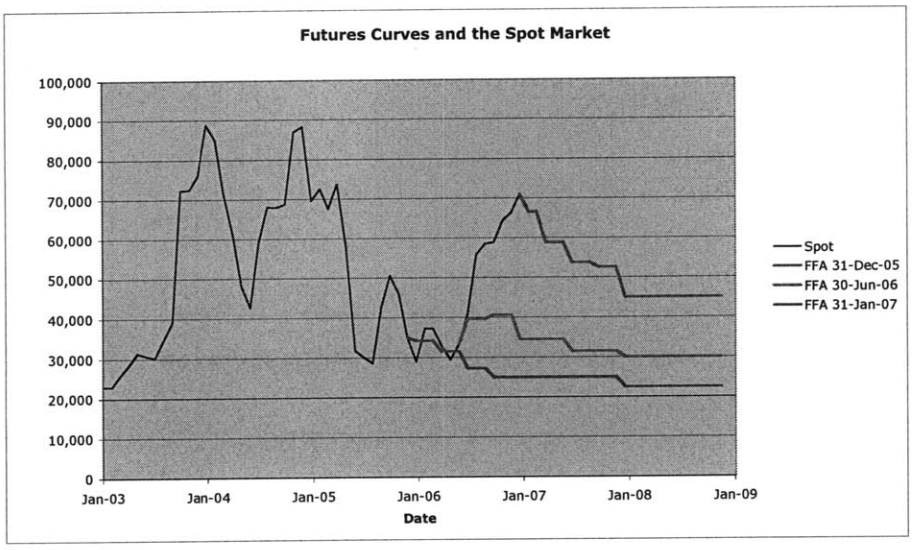


Fig. 2.8-3 Futures curves for the T/C Index along with the spot rates - using data from [SSY 2007b]

How to Read Fig. 2.8-3		
Consider June 2007		
Legend	Meaning	Value
FFA 31-Jan-07	Futures price for Q3-2007 as of January 31st 2007	$58,875/day
FFA 30-Jun-06	Futures price for H1-2007 as of June 30th 2006	$34,500/day
FFA 31-Dec-05	Futures price for 2007 as of December 31st 2005	$25,000/day

Table 2.8-3: How to read Fig. 2.8-3.

In 31-Dec-06, the market was at $34,973/day with a negative gradient. In 30-Jun-06, the market was at $33,460/day with a positive gradient. As can be seen by the futures curves on these two dates, the positive gradient of the market has a strong effect on futures prices. Even though the market was slightly lower in 30-Jun-06, futures prices were significantly higher due to the positive direction of the market. The FFA curve of 31-Jan-07, indicated in

blue, was above both as the market was even higher and with a positive gradient. The blue curve however declines more steeply than the other two showing that futures curves with different origins tend to converge into the future. This is reasonable, as the influence of the current market on futures values should theoretically be lower for contract periods that are further ahead.

Fig. 2.8-4 shows the futures price of the t/c index for the following quarter or year and those beyond since June 2004 along with the spot market. Note that the contract period in this case is one quarter, two quarters, or one year.

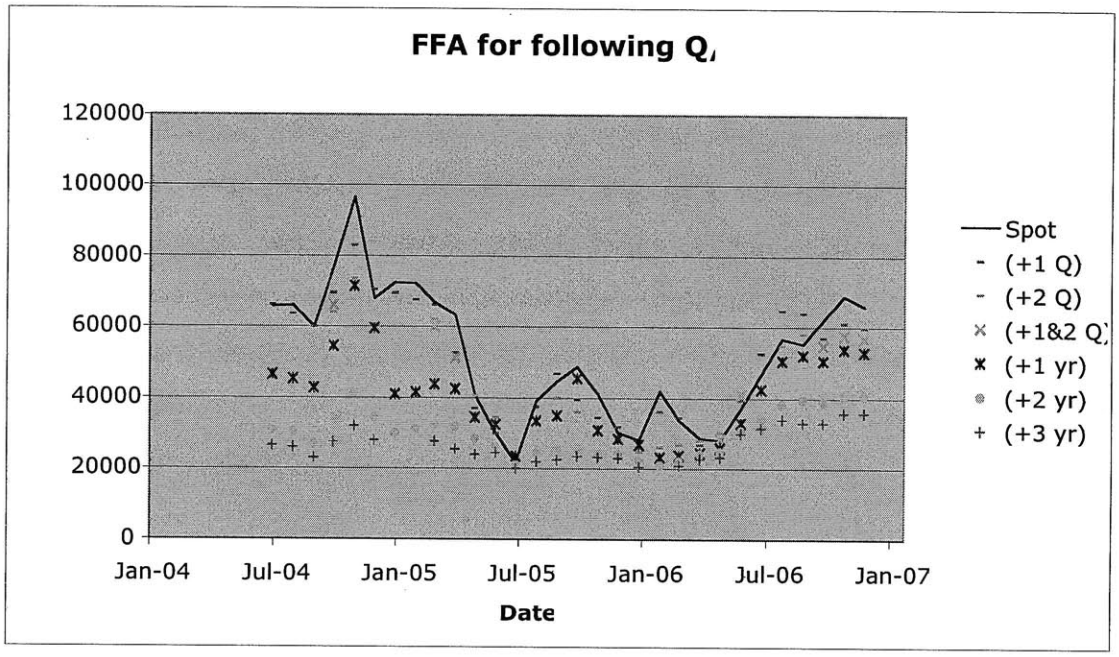


Fig. 2.8-4: Futures Prices for the T/C Index along with the spot rates using data from [FIS 2007]

How to Read Fig. 2.8-4		
Consider October 2004		
Legend	Meaning	Value
Spot	t/c Index value as of End October 2004	$76,792/day
(+1 Q)	Futures price for Q1-2005 as of End October 2004	$69,500/day
(+2 Q)	Futures price for Q2-2005 as of End October 2004	$64,000/day
(+1&2 Q)	Futures price for H1-2005 as of End October 2004	$66,000/day

(+1 yr)	Futures price for 2005 as of End October 2004	$54,500/day
(+2 yr)	Futures price for 2006 as of End October 2004	$34,500/day
(+3 yr)	Futures price for 2007 as of End October 2004	$27,500/day

Table 2.8-4: How to read Fig. 2-8-4

It is evident again that the current market and its direction affects futures prices, and more so for the closer contract periods. Looking at the prices for the following year (+1 yr) and one or two years beyond that (+2 yr and +3 yr), the general opinion has continuously been that the market will decline and keep declining in the long term. This is logical as the market is at record high levels. It can also be seen that futures prices fluctuate less than the spot market and they also fluctuate less the further ahead their maturity is. (+1 Q) for example fluctuates the most after the spot market, while (+3 yr) fluctuates the least.

Fig. 2.8-5 and Fig. 2.8-6 show the futures prices for each quarter and each half-year contract period respectively from Q4-2004 until Q1-2007. These are presented along with the actual values in those periods and the spot market. Futures values and actual values referring to the same quarter are shown in the same color for clarity.

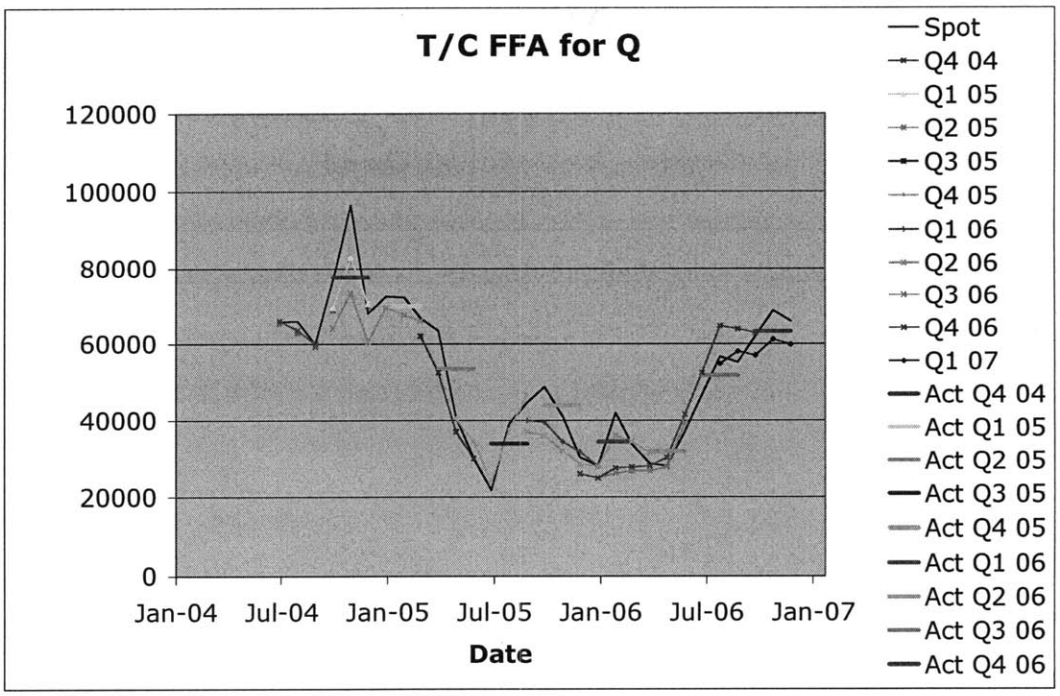


Fig. 2.8-5 Futures Prices for the T/C Index along with actual values - using data from [FIS 2007]

How to Read Fig. 2.8-5		
Consider December 2006		
Legend	Meaning	Value
Spot	t/c Index value as of End December 2006	$65,870/day
Q1 07	Futures price for Q1-2007 as of End December 2006	$59,750/day
Act Q4 06	Average value of the t/c Index over Q4 2006	$63,148/day

Table 2.8-5: How to read Fig. 2.8-5

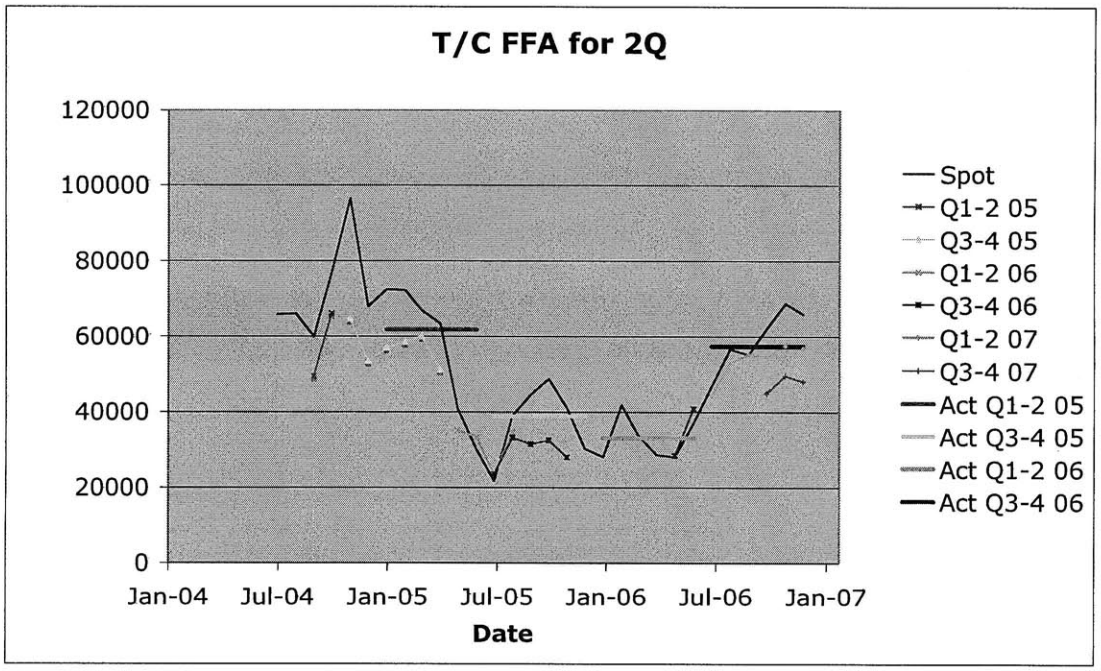


Fig. 2.8-6 Futures Prices for T/C Index from H1-05 until H2-06 and actual values – Using data from [FIS 2007]

How to Read Fig. 2.8-6		
Consider December 2006		
Legend	Meaning	Value
Spot	t/c Index value as of End December 2006	$65,870/day
Q1-2 07	Futures price for H1-2007 as of End December 2006	$56,750/day
Q3-4 07	Futures price for H2-2007 as of End December 2006	$48,125/day
Act Q3-4 06	Average value of the t/c Index over H2 2006	$57,415/day

Table 2.8-6: How to read Fig. 2.8-6

As can be seen, the fact that the futures prices are so closely aligned with a highly cyclical market, leads to large discrepancies between futures and actual values. The futures value for Q4 2006 in January 2006 ($24,875/day) for example (in pink), was off the actual value ($63,148/day) by $38,273 per day, which amounts to more than $3.5m. The futures value for H2-2006 in July 2005 was $23,500/day while the actual value was $57,415/day, amounting to $6.24m. This obviously allows room for high profit that can be made if one employs a more sophisticated forecasting approach than merely based on the current market.

Marsoft's predictions of the market, which are based on the estimated fleet utilization, tend to be less "flat" than futures. Fig. 2.8-7 Shows Marsoft's predictions of the cape spot market on January 2005 and January 2006 along with actual values.

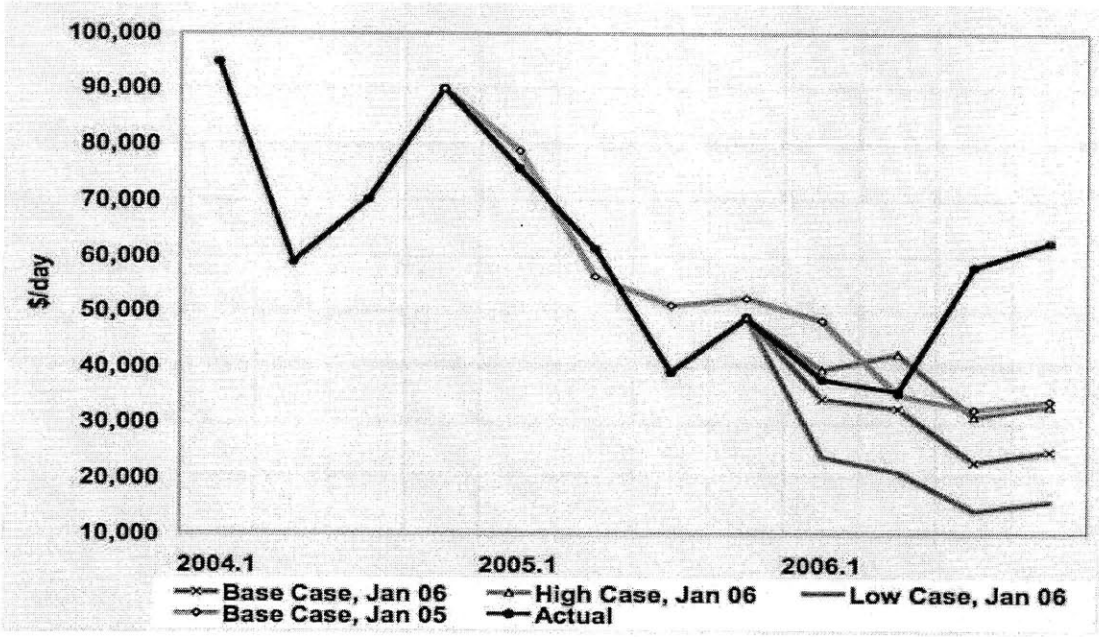


Fig. 2.8-7: Marsoft Forecasts for the Capesize Spot Earnings along with Actual Rates [Marsoft 2007b]

Estimating fleet utilization can be very difficult and sometimes inaccurate as highlighted by the January 2006 estimates. This approach however is clearly more reliable than using futures as a forecasting tool.

In general, futures tend to converge towards the actual value as the maturity date is approached meaning that they are more accurate for closer contract periods. This is not always true however as futures may undergo large cycles along with the spot market during the last few months. The futures value for Q4 2005 in May 2005 ($40,500/day) for example was a much closer than that of July 2005 ($23,750/day) even though both were lower than the actual value of $43,939/day.

Fig. 2.8-8 shows the futures prices for years 2007 to 2009 and the actual values for years 2004 to 2006.

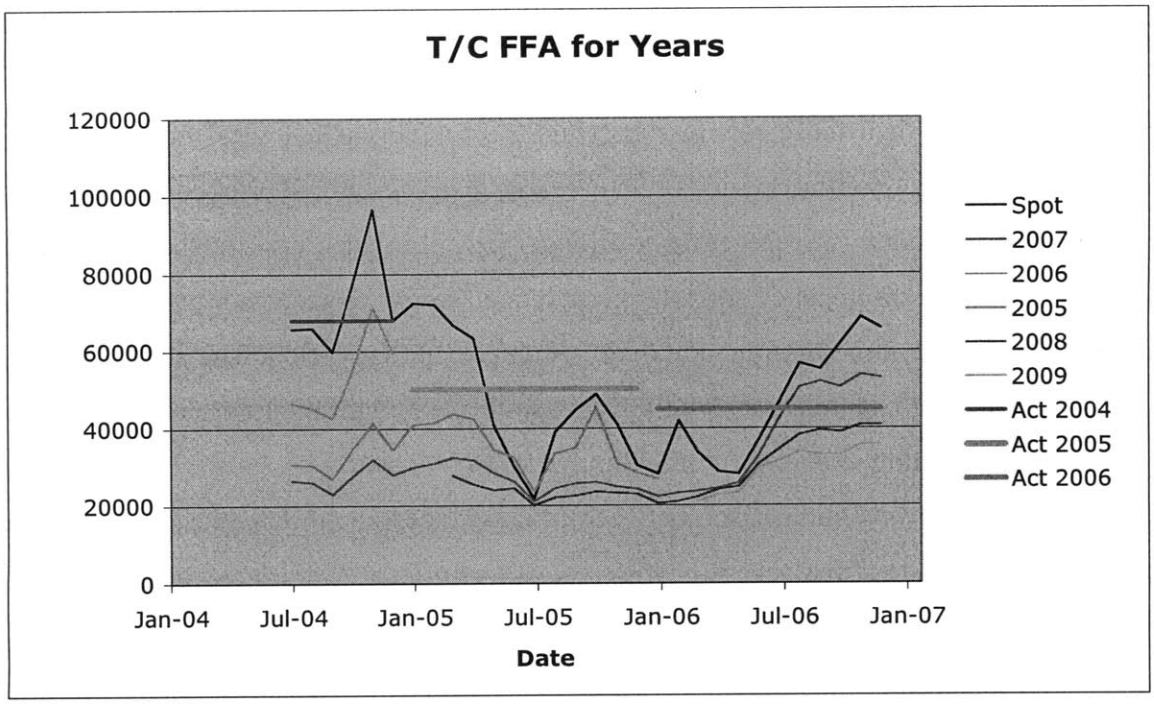


Fig. 2.8-8: Futures Prices for the T/C Index along with actual values using data from [FIS 2007]

How to Read Fig. 2.8-8		
Consider December 2006		
Legend	Meaning	Value
Spot	t/c Index value as of End December 2006	$65,870/day
2007	Futures price for 2007 as of End December 2006	$52,875/day
2008	Futures price for 2008 as of End December 2006	$40,750/day
2009	Futures price for 2009 as of End December 2006	$35,750/day
Act 2006	Average value of the t/c Index over 2006	$44,867/day

Table 2.8-7: How to read Fig. 2.8-8

The right end of this diagram demonstrates most clearly how the current market influences futures prices depending on the closeness of the contract period. After May 2006, when futures prices for years 2007, 2008 and 2009 were approximately the same, the spot rates began increasing and futures followed. They also diverged however as the price for 2007 was most affected and that for 2009 was affected the least. Again this shows how the influence of the current market is lower for contract periods far ahead.

The difference between futures prices and actual values for whole years (Fig. 2.8-8) appear to be slightly smaller on average than those for half years (Fig. 2.8-6), which are in turn slightly smaller than those for quarters (Fig. 2.8-5). This is a logical outcome as the actual values for longer contract periods fluctuate less than those for shorter contract periods. This is because the index is averaged over a longer period in each case. It should be noted however that a given discrepancy for a longer contract period represents a greater potential profit or loss than the same discrepancy over a shorter contract period. The actual value of the index for 2006 for example was $44,867/day, so if one bought the future in July 2005 at $23,500/day, this would yield a profit of $7.8m.

Fig. 2.8-9 shows a comparison between futures prices one month ahead (in red) and actual values of the index (in black).

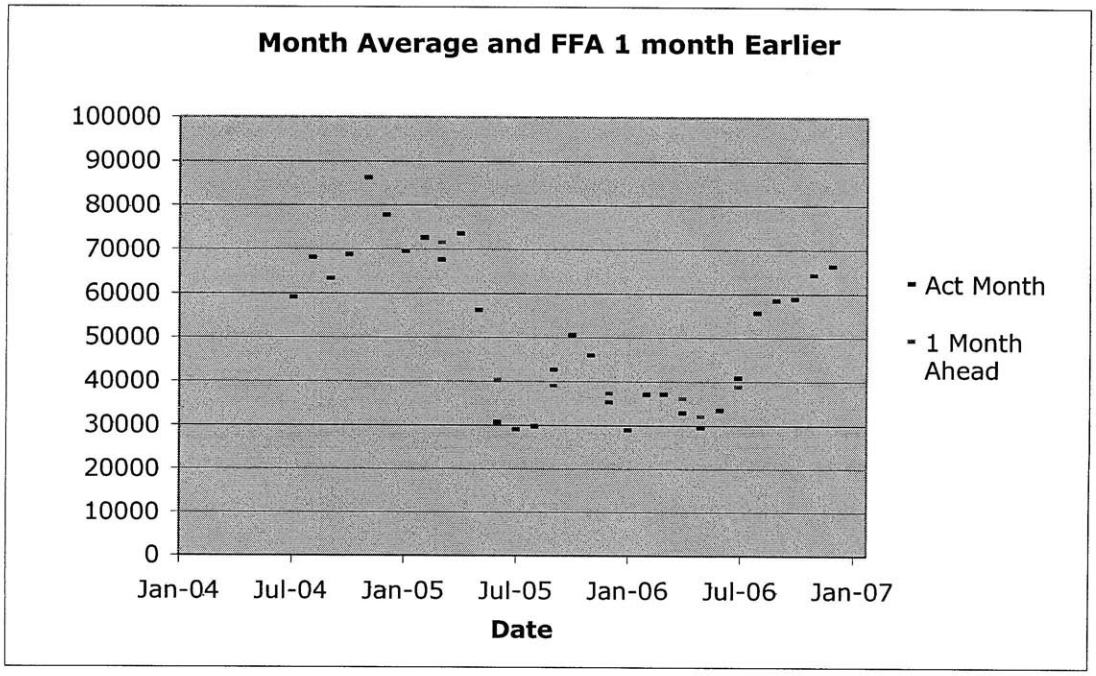


Fig. 2.8-9: Futures Prices for the T/C Index along with actual values - using data from [FIS 2007]

How to Read Fig. 2.8-9		
Consider July 2006		
Legend	Meaning	Value
Act Month	Average t/c Index value over July 2006	$40,828/day
1 Month Ahead	Futures price for July 2006 as of End June 2006	$38,750/day

Table 2.8-8: How to read Fig. 2.8-9

As shown, futures prices are relatively accurate for the next month. The maximum difference that can be observed between futures prices and actual values in Fig. 2.8-9 is $9,579/day in June 2005. A comparative analysis was carried out in order to assess the effect of time ahead on the similarity between futures prices and actual values for each quarter from Q4 2004 until Q4 2006. The results are shown in Fig. 2.8-10.

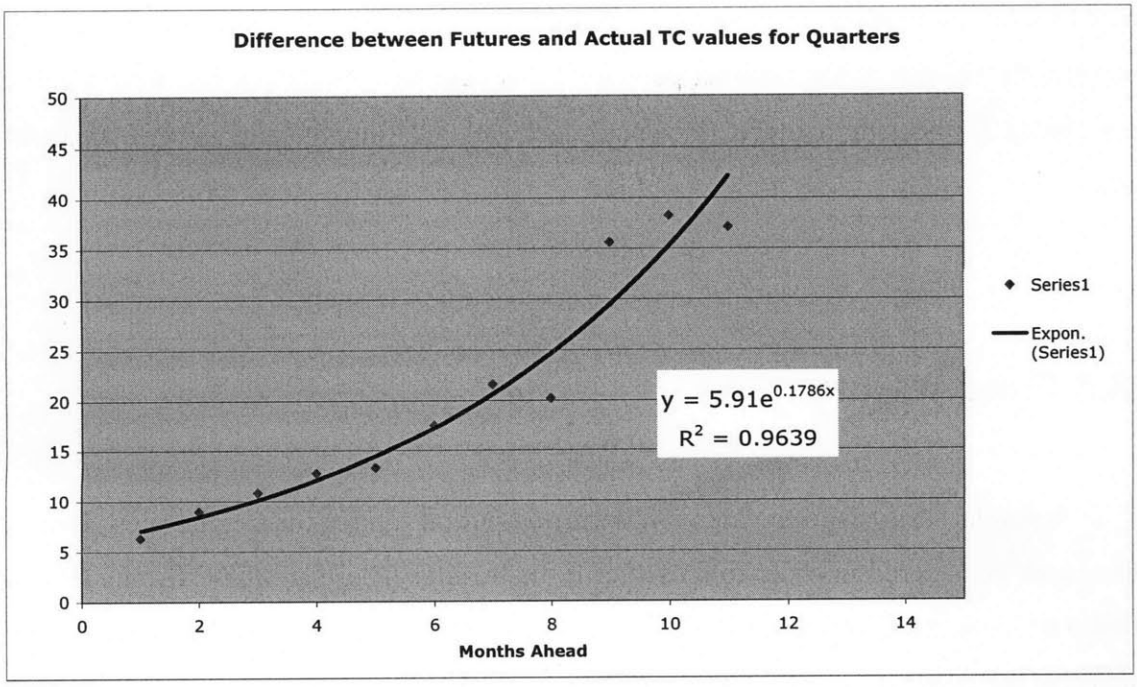


Fig. 2.8-10 Average difference between futures for T/C Index and actual values - using data from [FIS 2007]

How to Read Fig. 2.8-10		
Consider 6 Months Ahead		
Legend	Meaning	Value
Series1	Average difference between the actual t/c Index value over a quarter and its futures price 6 months earlier, for all quarters from Q4'04 to Q4'06.	$17,571/day
Expon.(Series1)	Exponential Regression Model	$17,257/day

Table 2.8-9: How to read Fig. 2.8-10

As shown, the relationship between the time ahead and the average difference between futures price and actual value can be characterized as exponential with reasonable accuracy ($R^2 = 0.964$). This indicates that there is potential for much greater profit/loss in contracts for a period far ahead. Perhaps a regression model of the form y = a + be^(cx) would be even more accurate, where "a" resembles the average difference accrued during the time until the middle of the contract period (in this case half a quarter), and would hence be proportional to the length of contract period considered (month, quarter, two quarters or year).

2.8.4 Freight Rate FFAs

A similar analysis to the above was carried out on futures for freight rates. Two trade routes were considered in order to cross verify the results. These are the C4 route (Richards Bay/Rotterdam) and C7 (Bolivar/Rotterdam). The graphs resulting from the analysis are very similar for the two trade routes.

Fig. 2.8-11 shows futures prices for each month from Sept 2004 until June 2007 relative to the spot market. Fig. 2.8-12 shows the futures prices for a number of months ahead along with the spot rates at the last day of each month since June 2004. Note that in both cases, the contract period is one month.

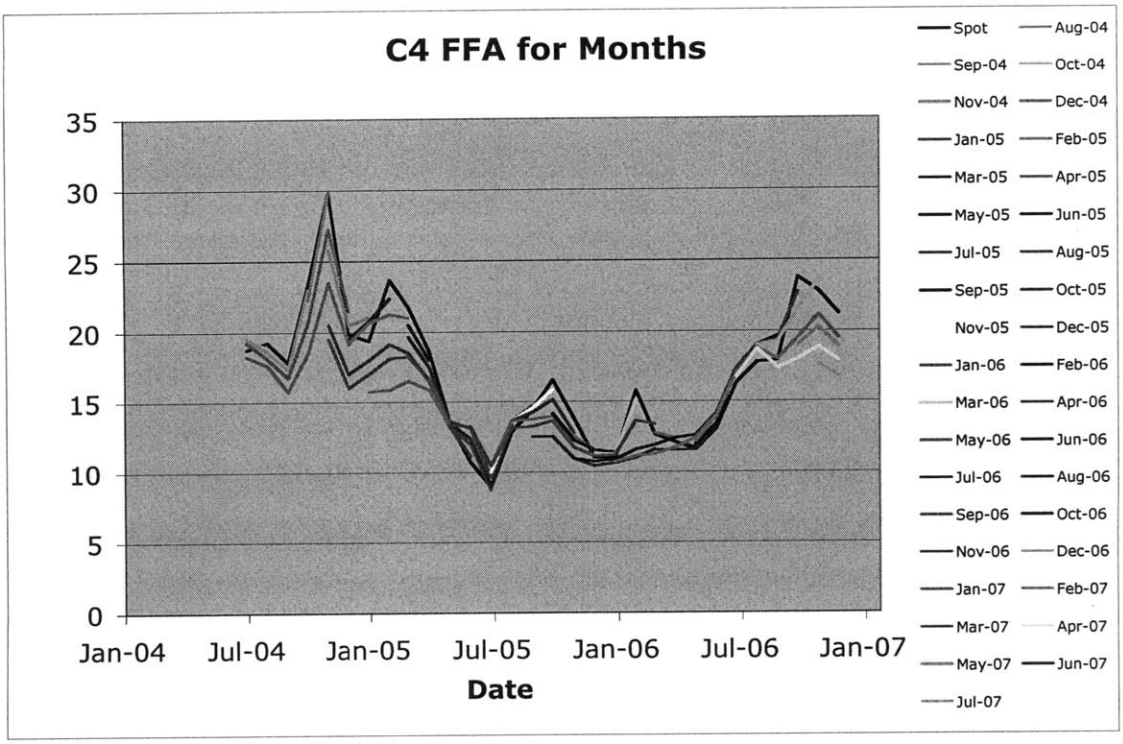


Fig. 2.8-11: The spot market and futures prices for C4 freight rates in various months – Using data from [FIS 2007]

How to Read Fig. 2.8-11		
Consider December 2006		
Legend	Meaning	Value
Spot	Freight rates on C4 as of End Dec. 2006	$21.21/ton
Jan-07	Futures price for January 2007 as of End Dec. 2006	$19.50/ton
Feb-07	Futures price for February 2007 as of End Dec. 2006	$18.88/ton
Mar-07	Futures price for March 2007 as of End Dec. 2006	$18.25/ton
Apr-07	Futures price for April 2007 as of End Dec. 2006	$17.88/ton
Jul-07	Futures price for July 2007 as of End Dec. 2006	$16.75/ton

Table 2.8-10: How to read Fig. 2.8-11

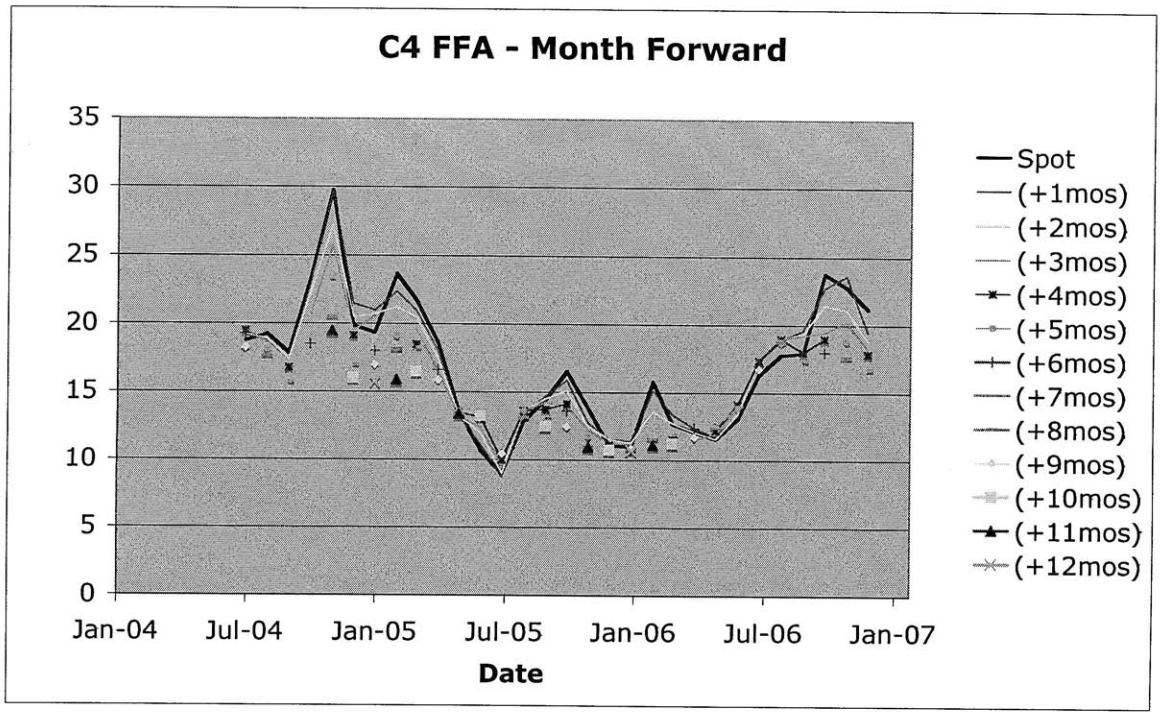


Fig. 2.8-12: The spot market and futures for C4 freight rates 1-12 months ahead - using data from [FIS 2007]

How to Read Fig. 2.8-12		
Consider December 2006		
Legend	Meaning	Value
Spot	Freight rates on C4 as of End Dec. 2006	$21.21/ton
(+1mos)	Futures price for January 2007 as of End Dec. 2006	$19.50/ton
(+2mos)	Futures price for February 2007 as of End Dec. 2006	$18.88/ton
(+3mos)	Futures price for March 2007 as of End Dec. 2006	$18.25/ton
(+4mos)	Futures price for April 2007 as of End Dec. 2006	$17.88/ton
(+7mos)	Futures price for July 2007 as of End Dec. 2006	$16.75/ton

Table 2.8-11: How to read Fig. 2.8-12

As with the futures for the t/c index, it is clear how futures prices, even for a number of months ahead, are to a great extent dictated by current rates. This is particularly evident in Fig. 2.8-11, where the futures lines appear to be going as a group following the spot market.

The general pessimism over the past several months that was witnessed for t/c is also apparent regarding freight rates. In both Fig. 2.8-11 and Fig. 2.8-12, the spot market (black line) is most of the time above all futures lines. Furthermore, futures prices decrease with time ahead as indicated for example by the futures prices in December 2006 shown in Table 2.8-10 and Table 2.8-11. This is also emphasized when the market is on a downturn as shown in Fig. 2.8-12. The same conclusion can also be drawn from Fig. 2.8-13, which shows the futures prices for a contract period of one year, one to four years ahead, along with the spot rates since June 2004.

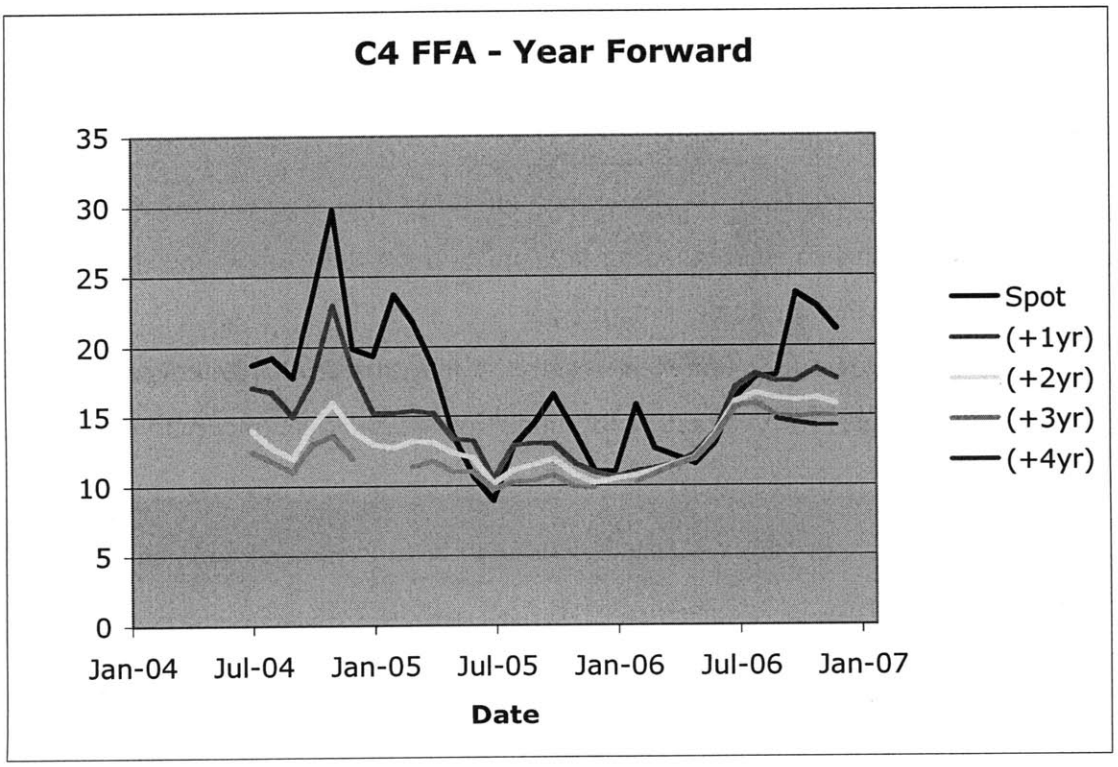


Fig. 2.8-13: The spot market and futures prices for C4 freight rates 1-4 years ahead – Using data from [FIS 2007]

How to Read Fig2.8-13		
Consider December 2006		
Legend	Meaning	Value
Spot	Freight rates on C4 as of End Dec. 2006	$21.21/ton
(+1yr)	Futures price for 2007 as of End Dec. 2006	$17.65/ton
(+2yr)	Futures price for 2008 as of End Dec. 2006	$15.80/ton
(+3yr)	Futures price for 2009 as of End Dec. 2006	$14.95/ton
(+4yr)	Futures price for 2010 as of End Dec. 2006	$14.25/ton

Table 2.8-12: How to read Fig. 2.8-13

As for t/c it can also be seen that futures prices fluctuate less than the spot market and are more stable the further ahead their maturity is.

Fig. 2.8-14 shows the futures prices for years 2005 to 2010 along with the spot market and actual values for years 2004 to 2006. Note that the contract period is again one year.

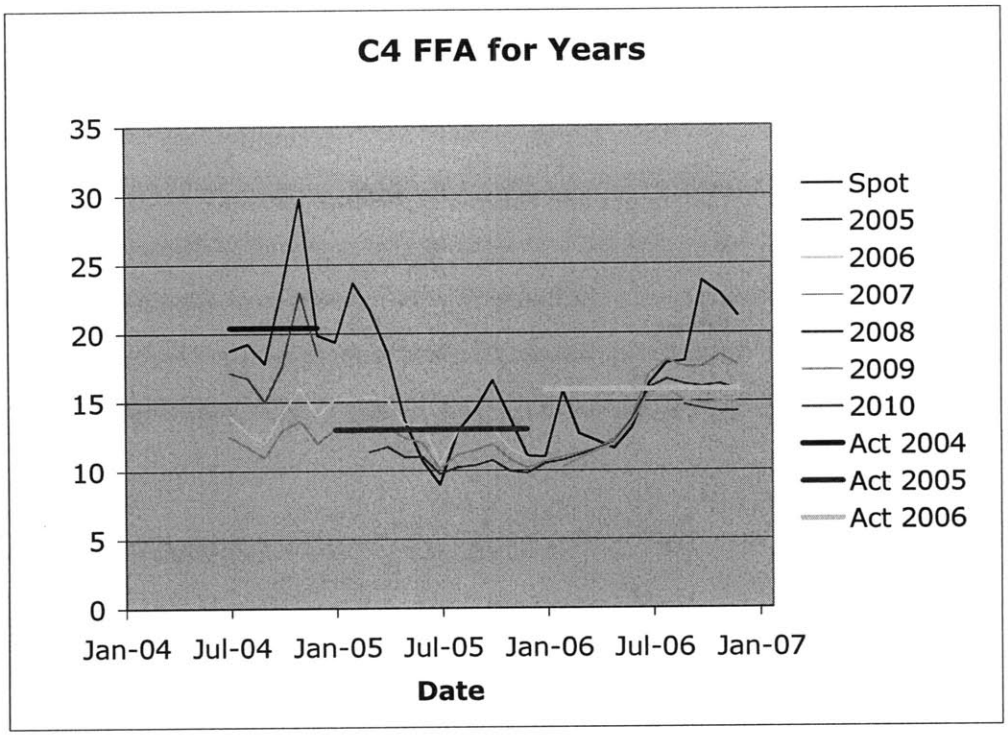


Fig. 2.8-14: The spot market, C4 futures prices for years and average annual values – Using data from [FIS 2007]

How to Read Fig. 2.8-14		
Consider December 2006		
Legend	Meaning	Value
Spot	Freight rates on C4 as of End Dec. 2006	$21.21/ton
2007	Futures price for 2007 as of End Dec. 2006	$17.65/ton
2008	Futures price for 2008 as of End Dec. 2006	$15.80/ton
2009	Futures price for 2009 as of End Dec. 2006	$14.95/ton
2010	Futures price for 2010 as of End Dec. 2006	$14.25/ton
Act 2006	Average value of freight rates on C4 over 2006	$15.89/ton

Table. 2.8-13: How to read Fig. 2.8-14

Futures have consistently been lower the further the contract period showing the same pessimism as futures for the time charter index. Again large differences from actual values are observed.

Fig. 2.8-15 shows the spot rates at the end of each month, the average value of each month, and the futures for that month one to twelve months earlier.

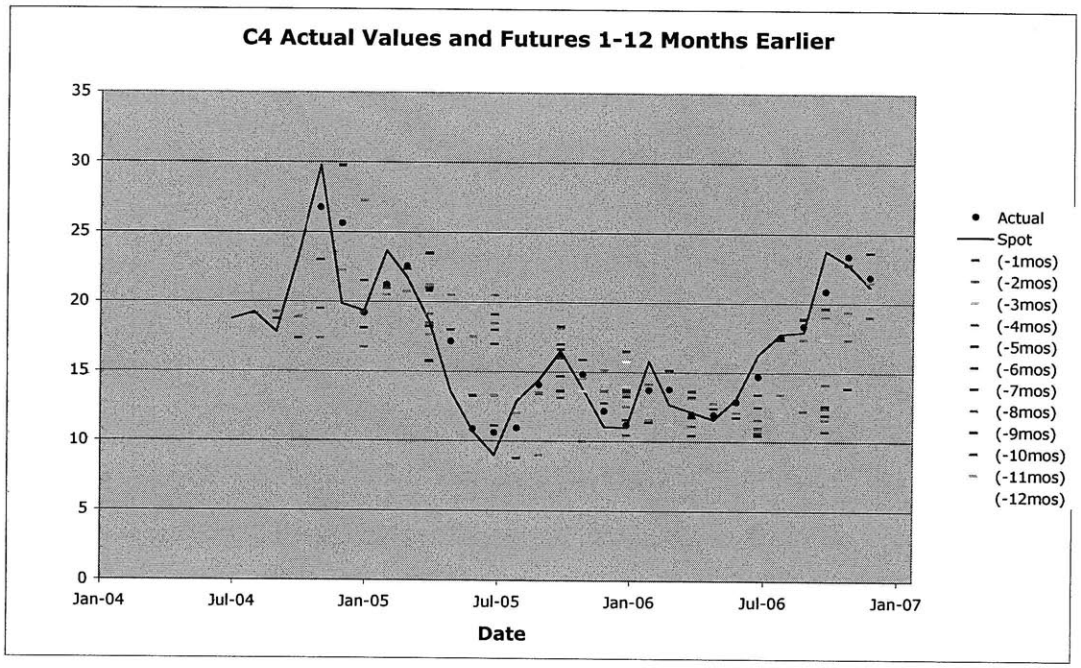


Fig. 2.8-15 The spot market and futures prices for C4 freight rates 1-12 months ahead – Using data from [FIS 2007]

How to Read Fig. 2.8-15		
Consider November 2006		
Legend	Meaning	Value
Actual	Average freight rates on C4 over November 2006	$23.38/ton
Spot	Freight rates on C4 as of End November 2006	$22.81/ton
(-1mos)	Futures price for Nov. 2006 as of End Oct. 2006	$22.75/ton
(-2mos)	Futures price for Nov. 2006 as of End Sept. 2006	$19.38/ton
(-3mos)	Futures price for Nov. 2006 as of End Aug. 2006	$19.00/ton
(-4mos)	Futures price for Nov. 2006 as of End Jul. 2006	$17.38/ton
(-5mos)	Futures price for Nov. 2006 as of End Jun. 2006	$13.88/ton

Table 2.8-14: How to read Fig. 2.8-15

As shown in Fig. 2.8-15, the closer the month is, the smaller the difference between the futures price and the actual value. It is sometimes the case, for example in October and November 2006 that the further back the futures contract was made, the lower the futures price relative to the actual value. In other months such as June and July 2005, the further back the contract, the higher the futures price relative to the actual value.

Fig. 2.8-16 demonstrates the effect of time ahead on the similarity between futures prices and actual values for each month from November 2004 until December 2006.

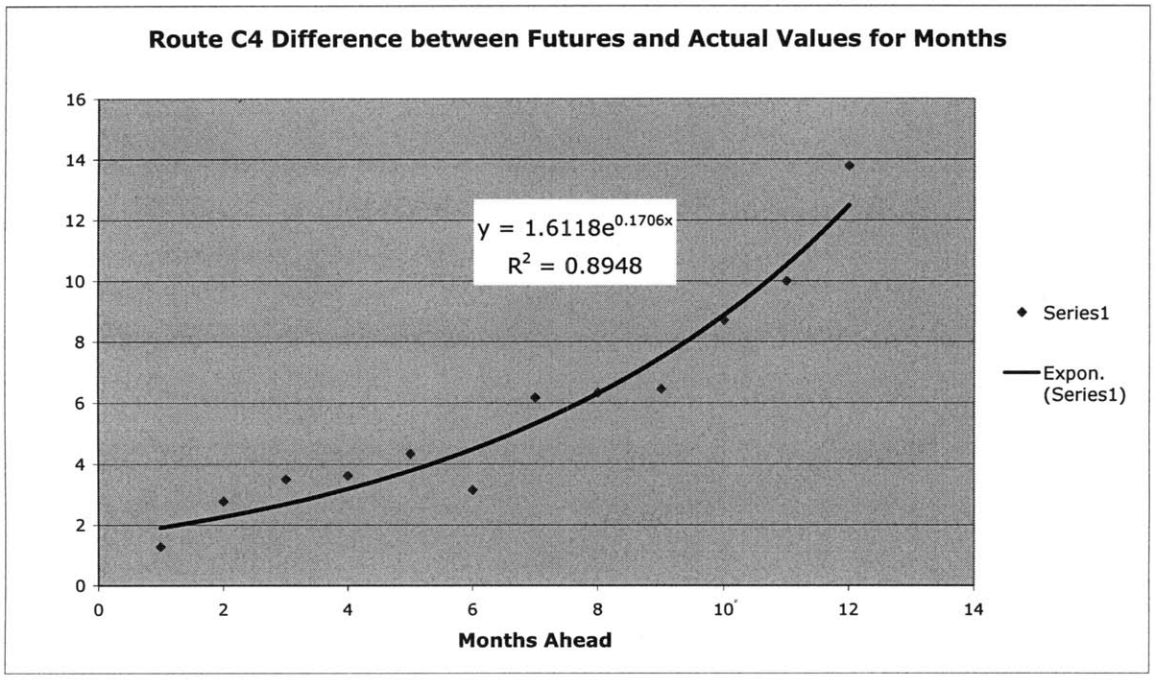


Fig. 2.8-16: Average difference between futures for freight rates and actual values – Using data from [FIS 2007]

How to Read Fig. 2.8-16		
Consider 10 Months Ahead		
Legend	Meaning	Value
Series1	Average difference between the actual C4 freight rate over a month and its futures price 10 months earlier, for all months from June-2004 to Dec-2006.	$8.71/ton
Expon.(Series1)	Exponential Regression Model	$8.88/ton

Table 2.8-15: How to read Fig. 2.8-16

As for the t/c index, the relationship between time ahead and the average discrepancy between futures prices and actual values is evidently of an exponential form with a high grade of accuracy ($R^2 = 0.895$). A similar result was also obtained in the combined analysis of trade routes C4 and C7. As discussed earlier, the inclusion of a constant "a" in the regression model to make it of the form y = a + be^(cx) would be less important than when the contract period is a quarter as opposed to a month.

The corresponding results for trade route C7 are shown in Fig. 2.8-17 to 2.8-22.

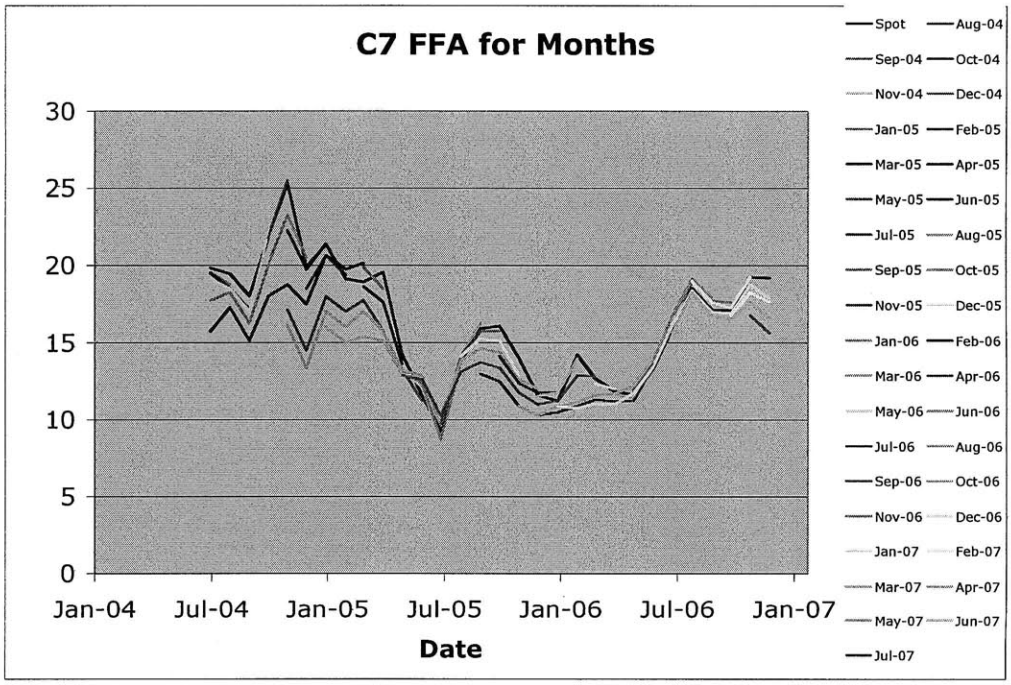


Fig. 2.8-17: The spot market and futures prices for C7 freight rates in various months – Using data from [FIS 2007]

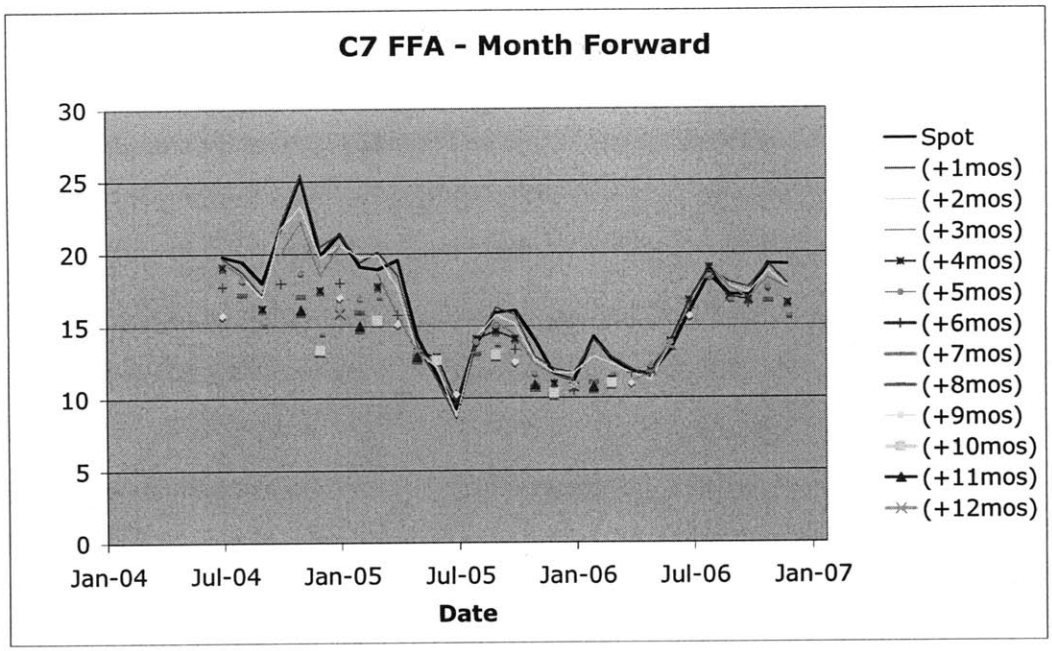


Fig. 2.8-18: The spot market and futures for C7 freight rates 1-12 months ahead – Using data from [FIS 2007]

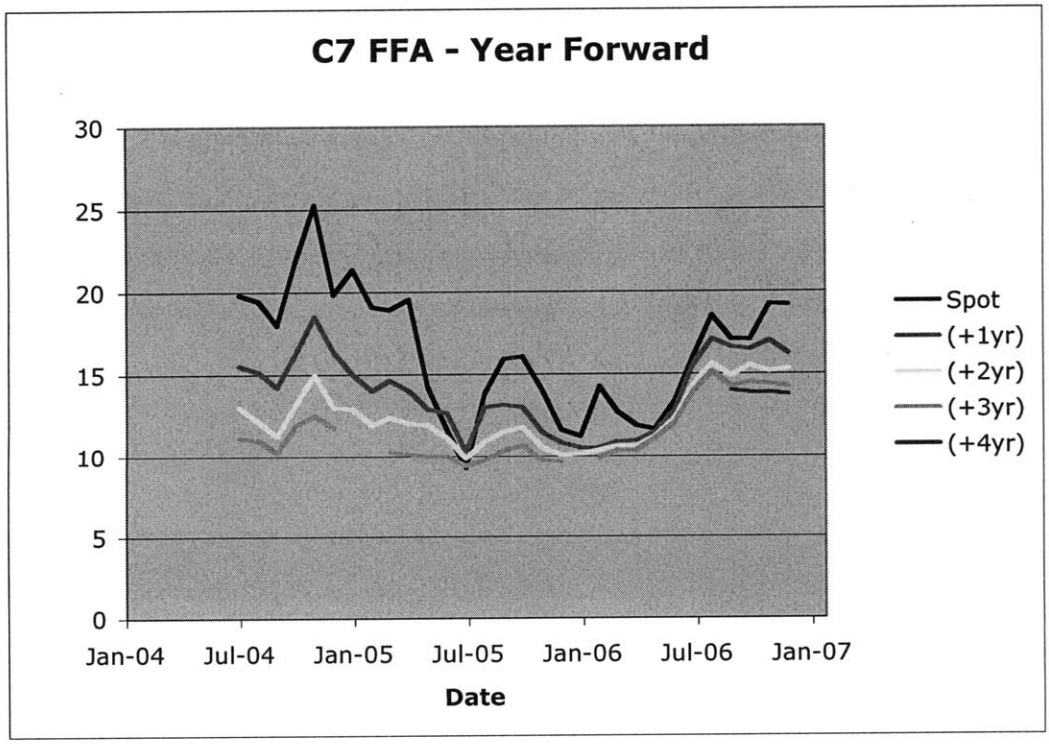


Fig. 2.8-19: The spot market and futures prices for C7 freight rates 1-4 years ahead – Using data from [FIS 2007]

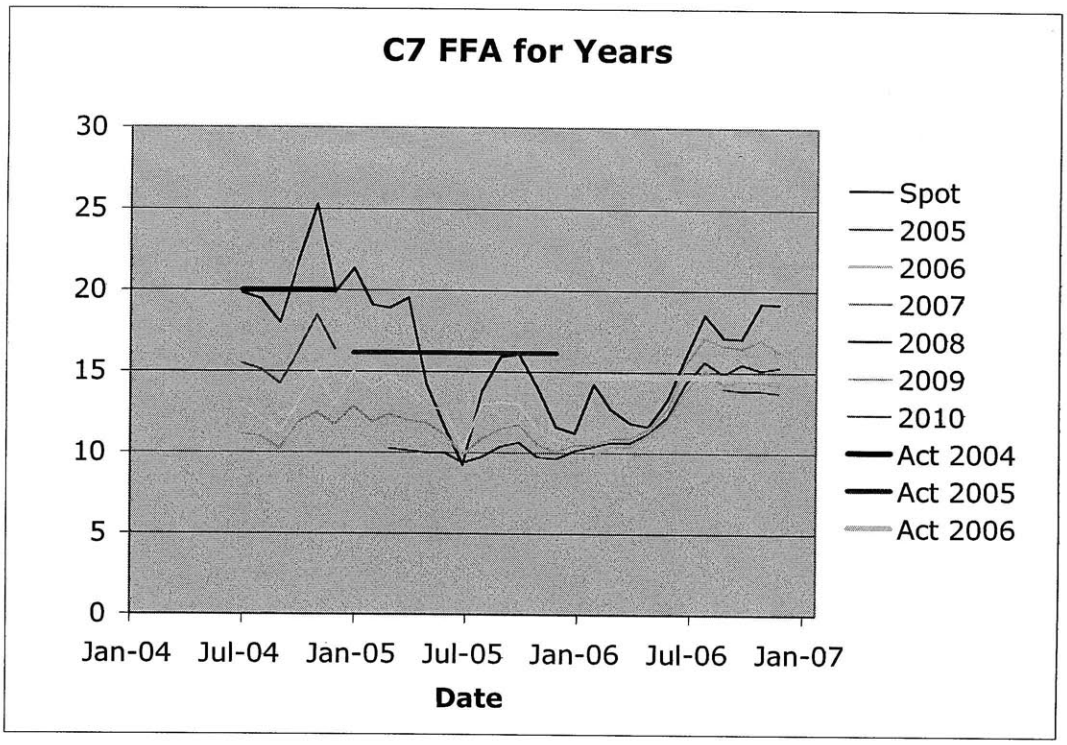


Fig. 2.8-20: The spot market, C7 futures prices for years and average annual values – Using data from [FIS 2007]

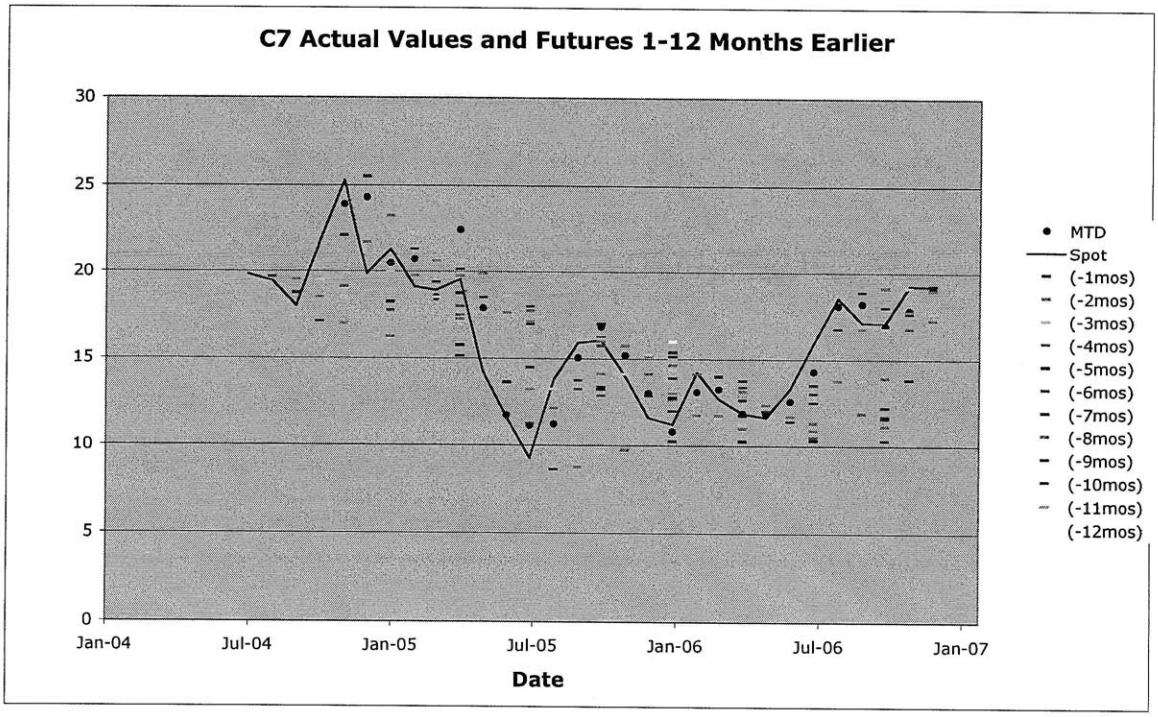


Fig. 2.8-21: The spot market and futures prices for C7 freight rates 1-12 months ahead – Using data from [FIS 2007]

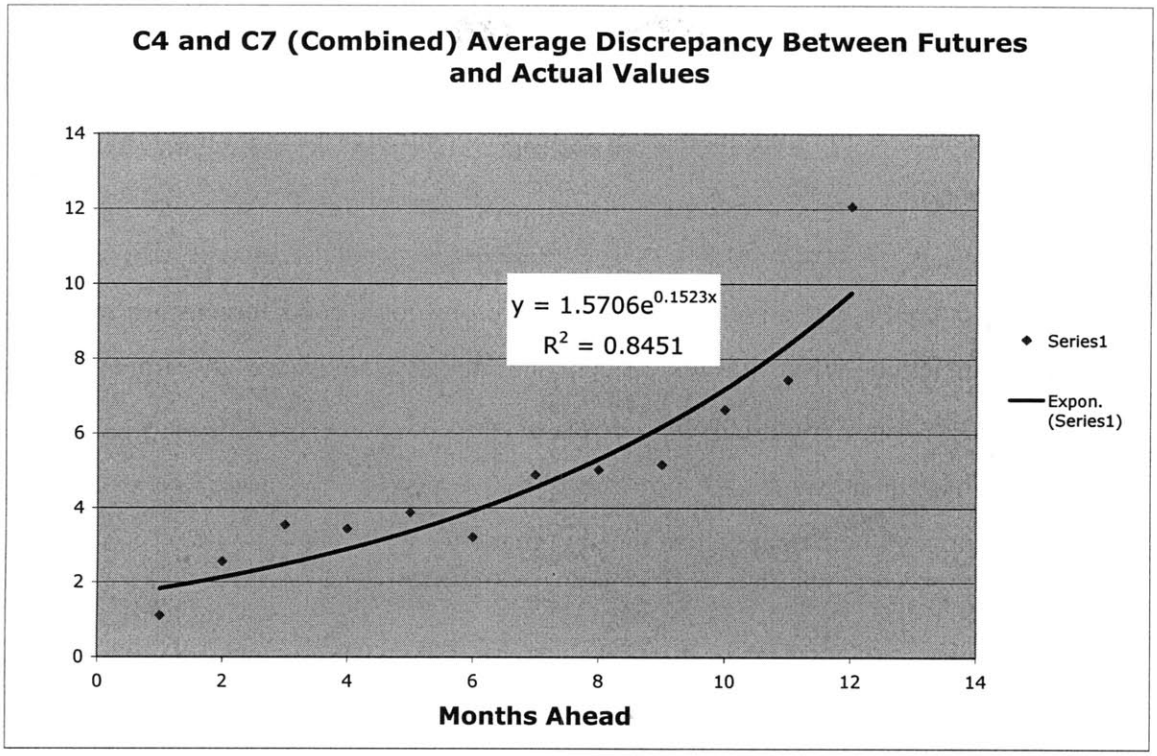


Fig. 2.8-22: Average difference between futures for freight rates and actual values – Using data from [FIS 2007]

2.8.5 Conclusions

After carrying out the above analysis on futures for capesize bulk carriers, the conclusions that can be derived are identical regarding futures for the t/c index and for trade routes C4 and C7. These can be summarized as follows:

- The futures and physical markets are separate but closely aligned and interrelated
- General opinion has consistently been that the market will gradually decline
- Futures prices are strongly affected by the current market and its direction

- Futures curves with different origins tend to converge into the future, showing that the influence of the current market is lower on futures prices for contract periods further ahead

- Futures curves are relatively "flat" and therefore not a good forecasting tool. Large discrepancies between futures prices and actual values are therefore common, creating potential for high profits/losses

- Futures prices fluctuate less than the spot market

- Futures prices fluctuate less, the longer the contract period (e.g. futures for years are on average more stable than futures for months). This leads to smaller absolute discrepancies but those represent a higher potential profit/loss

- Futures prices fluctuate less, the further ahead the contract period

- The average discrepancy between futures prices and actual values increases exponentially with time between the contract and the settlement date

2.9 2006 Investment Opportunities

2.9.1 Introduction

As discussed in the previous sections, the capesize bulk carrier market is highly cyclical both in terms of charter rates and ship values. This creates big investment opportunities with potential for high returns over relatively short periods of time. As shown earlier, the past cycle created opportunities that would yield a return of over 1000% in just 3-4 years.This section analyses the opportunities available in the current sale and purchase market both from a seller's and a buyer's perspective. A buyer is faced with the choice of asset to invest in and its employment. A seller is faced with the option of selling or chartering a vessel. Some representative vessel and charter combinations are chosen, covering the wide range that is available in the market. These are then evaluated and compared in order to provide recommendations to potential buyers and sellers. The analysis is carried out in a way so as to have long term significance and future reference value.

2.9.2 Deals Considered and Current Prices

Rather than considering actual ships that are for sale today, it is more appropriate for the purpose for this project to assume hypothetical deals of typical vessels based on recent transactions. This approach covers a wider range of ship ages and has greater long-term value, as the deals considered are more representative of those available in the market at any time.

The typical size of capes has increased significantly since the early 1970s when they were first introduced. In order to produce results that are relevant to what is most widely available; the typical size in the year that each cape was built is assumed. A few representative deals are chosen to analyze as summarized in Table 2.9-1.

Deals Considered			
Transaction	**Year Built**	**Age (years)**	**Size (DWT)**
Order	2010	0	180,000
Buy	2007	0	175,000
Buy	2002	5	175,000
Buy	1997	10	170,000
Buy	1992	15	150,000
Buy	1987	20	150,000
Sell	2007	0	175,000
Sell	2002	5	175,000
Sell	1997	10	170,000
Sell	1992	15	150,000
Sell	1987	20	150,000
Sell	1982	25	145,000

Table 2.9-1: S&P Deals Considered in the Current Project

Recent transactions have to be referenced for the current valuation of the vessels in Table 2.9-1. Table 2.9-2 shows secondhand transactions from January 1st and Table 2.9-3 shows the orders and resales since March 1st. Only those with reported prices are included.

Secondhand Deals Between 01/01/07 and 05/11/07					
Date	**Name**	**Built**	**Size**	**Notes**	**Price**
02/Jan	SPRING BRAVE	1995	151,066	Delivery in May	62.0
08/Jan	MONTEGO II	1993	149,391	T/C: 30k/d – Dec'08	50.0
08/Jan	CHS MOON	1990	151,227	-	45.0
10/Jan	BRILLIANT CORNERS	1981	105,496	-	8.7
26/Jan	LOWLANDS BEILUN	1999	170,162	T/C: 37.4k/d – Mar/Jun'10	72.5

05/Feb	YUE MAY	2007	175,000	-	99.0
14/Feb	DYNASTY	1982	132,082	-	15.0
14/Feb	PANTELIS SP	1999	169,883	T/C: 47.5k/d – Feb'08	83.0
22/Feb	THIOS COSTAS	1982	145,229	Delivery in May	18.0
02/Mar	CAPE PELICAN	2005	180,235	-	110.0
05/Mar	JOHNNY K	1994	174,770	POLAND BLT	63.5
12/Mar	ANANGEL WISDOM	2007	175,000	-	112.0
19/Mar	CAPE KASSOS	2004	171,480	Delivery in Sept	100.0
20/Mar	MARTHA VERITY	1995	157,991	-	62.0
Mar	AMERICANA	1987	148,982	-	33.0
30/Mar	IKARIA	1981	129,237	-	19.0
09/Apr	NAUTICAL DREAM	1994	151,439	-	63.5
09/Apr	Formosabulk CLEMENT	2001	170,085	Bareboat TC (10yrs)	95
09/Apr	Formosabulk BRAVE	2001	170,085	Bboat TC: 25k/d (10yrs)	95
12/Apr	ARIMATHIAN	1994	149,782	-	62.0
12/Apr	Formosabulk ALLSTAR	1995	150,393	BboatTC: 22,7k/d (10yrs)	67.0
16/Apr	GLOBAL PEACE	1982	132,049	-	19.5
16/Apr	BOSS	1985	139,816	-	31.0
22/Apr	WINNER	1985	174,004	-	37.5
04/May	AUSTRALIAN FAME I	1982	145,500	-	21.5

Table 2.9-2: Capesize Deals from January 1st to May 11th [Vafias 2007, Braemar 2007b, Tradewinds 2007]

Newbuilding Orders and Resales Between 03/01/07 and 05/11/07				
No of Ships	**Delivery (Start/Average)**	**Size (DWT)**	**Yard (Yard Country)**	**P ($m each)**
8 opt.4	2010/11 (start)	180,000	QINGDAO BEIHAI (China)	68.75
1	OCT 2008	170,000	KOREA	91
1	NOV 2007	175,000	SASEBO	102
1	NOV 2007	175,000	BOHAI	102
1	2010	170,000	KOREA	80

1	JAN 2010	181,000	STX (China)	76
2	MAY 2010 (av.)	181,000	STX (China)	76
3	JUN 2010 (av.)	181,000	STX (China)	76
2	NOV 2010 (av.)	180,000	DALIAN (China)	69
4	JAN 2010 (av.)	180,000	DAEWOO-MA. (Rumania)	78
2	NOV 2010 (av.)	180,000	DAEWOO (Korea)	81
1	SEPT 2010	180,000	DALIAN (China)	69
1	JAN 2011	300,000	NANTONG COSCO KSE (China)	90
2	DEC 2011 (av.)	250,000	NAMURA (Japan)	85
1	NOV 2009	177,000	SWS (China)	88
1	OCT 2009	177,000	SWS (China)	88
2 opt.4	2009 (starting)	170,000	DAEHAN (China)	72.5
2 opt.2	2009 (starting)	176,000	ZHOUSHAN JINHAIWAN (China)	75.75
3	2010 (starting)	180,000	QINGDAO BEIHAI (China)	69
2	2009 (starting)	180,000	DALIAN (China)	70
4	2011 (starting)	230,000	LONGXUE	90
1 opt.1	2010 (starting)	174,500	HANJIN SUBIC	80
2	2010/11	181,000	STX (China)	79.5
1	2007/10	177,000	SWS (China)	115.0
4	2010/11	176,000	NEW CENTURY (China)	69
4	2010	180,000	KOREA SHIPYARD CO.	77.7
2 opt.2	2010	170,000	DAEHAN	81
2 opt.4	2010	300,000	NANTONG COSCO (by COSCO)	80

Table 2.9-3: Capesize Newbuilding Orders and Resales Between March 1st 2007 and May 11th 2007

[Clarksons 2007c, Vafias 2007, Braemar 2007b, Tradewinds 2007]

The actual prices summarized in Table 2.9-2 and 2.9-3 have to be adjusted to estimate the prices of the hypothetical deals in Table 2.9-1. Parameters that have to be accounted for include age, size, delivery time, attached charters and the shipyard. For each hypothetical deal, the most similar ones from the recent transactions are chosen and adjusted.

When discounting for age, it is important to remember that linear depreciation in the current market is unrealistic as explained earlier. This is evident by comparing the *"Cape Pelican"* (built 2005) that was sold for $110m with the *"Anangel Wisdom"* (built 2007) that went for $112m in Table 2.9-2. Linear depreciation using a 25-year lifetime would result in a depreciation rate of about $4.5m/year whereas these two deals indicate a rate of $1m/year which is more realistic considering 20-year average capesize earnings.

The value of delivery time can be estimated by comparing deals that differ only in this aspect, and by considering potential earnings during the waiting period. The value of a time charter can be evaluated by comparing the charter rate to that of the current market for a similar period. This can be either negative or positive. The charter-free value of a ship can thereby be deduced by deducting the value of the charter from the ship's price.

Finally, it is evident from Table 2.9-3 that some shipbuilding yards and countries are preferred and produce more expensive ships than others. Japan and Korea are on average more expensive than Rumania, Poland and China, which has a wide range of prices. The chosen deals assume Korean built, charter-free vessels with prompt delivery, except for the newbuilding order that has a 3-year delivery time (current average). Using the deals in Table 2.9-2 and 2.9-3, and taking into account that rates have gone up by about 15% during April, the valuations for the hypothetical vessels are as shown in Table 2.9-4.

Valuation of Ships Considered				
Year Built	**Country Built**	**Age (Years)**	**Size (DWT)**	**Price ($M)**
2010	KOREA	0	180,000	80
2007	KOREA	0	175,000	115
2002	KOREA	5	175,000	100
1997	KOREA	10	170,000	85
1992	KOREA	15	150,000	63
1987	KOREA	20	150,000	41
1982	KOREA	25	145,000	25

Table 2.9-4: Valuation of the Hypothetical Cape Deals Considered in the Current Market as of April 30th 2007

2.9.3 Financing and Payments

Shipowners have access to many sources of capital in today's market. These include private reserves, partnerships, IPOs, leasing the ship, bonds etc. Very rarely however are any of these options better than a bank loan.

A leading Bank in ship finance provided some illustrative finance scenarios for capesize vessels in today's market. These are for a new building order, a newbuilding resale (prompt delivery), a ten year old and a fifteen years old vessel. As most banks, they have a policy of not financing vessels over 15 years old, though they consider them on a case by case basis and relate them to current scrap prices less a margin. For our purposes, we shall ignore the bank as a financer for vessels over 15 years old.

In order to minimize risk, the bank tries to keep the debt as low as possible compared to the ships value until the loan expires. In today's market therefore, the bank does not use a straight-line depreciation for the reasons discussed earlier. It typically finances 70% of the ship value, uses a margin of 1% over LIBOR, and frontloads the repayments as a requirement. It then relates the balloon payment with the last installment to the residual value (e.g. the scrap value in the case of the 15 year old).

The bank tries to relate to historical average values in order to account for the fact that we are currently at a very high peak in a cyclical market. 10-year average scrap values are about $220/ldt, which is equivalent to about $5.5m for a 25,000ldt cape. Table 2.9-5 summarizes the bank loan terms for the various deals considered while Table 2.9-6 provides the definitions to the abbreviations used in Table 2.9-5.

Bank Loan Terms							
Ship	**P**	**L**	**M**	**Q_t (yrs)**	**Q_f (%P)**	**Q_r (%P)**	**B (%P)**
Order	$78m	~70%	1%	40 (10)	8 (1.41)	32 (0.865)	30.9
Resale	$110m	~70%	1%	40 (10)	12 (2.59)	28 (0.682)	19.82
10-yr	$70m	~70%	1%	32 (8)	8 (4.5)	24 (1.13)	6.91
15-yr	$56m	~70%	1%	20 (5)	20 (3.05)	-	8.64

Table 2.9-5: Typical Bank Loan Terms for Capes in the Current Market

Nomenclature for Table 2.9-5 & 2.9-7	
Abbrev	**Definition**
P	Bank price based on Clarkson's valuations in March
L	Loan (the rest is down payment by the shipowner)
M	Margin over LIBOR
Q_t	Number of quarterly installments
Q_f	Number of frontloaded quarterly installments
Q_r	Remaining quarterly installments
B	Balloon payment with the last installment

Table 2.9-6: Definitions for the Abbreviations used in Table 2.9-5 and Table 2.9-7

Payment front-loading is adjusted to bring the loan down to the 10-year average price, while at the same time keeping the deal feasible from the shipowner's perspective based on current time charter rates. Once that is achieved taking advantage of the current market, payments assume linear depreciation until the balloon. Fig. 2.9-1 shows the 10-year average values along with the outstanding debt for the newbuilding and the resale vessel.

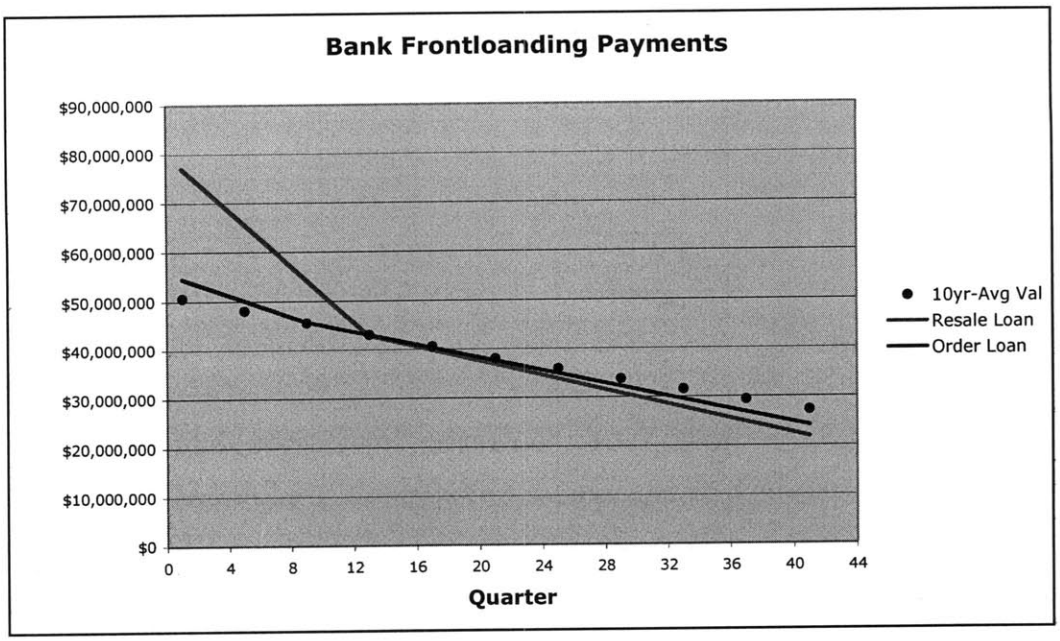


Fig. 2.9-1: Outstanding Loan Brought Down to 10-Year Average Prices through Frontloading Payments [Marsoft 2006a, Levine 2006, Vafias 2007, Braemar 2007a, Tradewinds 2007]

The financing terms assumed for the acquisition deals considered in Table 2.9-1 and Table 2.9-4 are based on the bank loan term indications of Table 2.9-5. Adjustments are made to account for price differences but the payments as a percentage of the price are kept constant. The loan terms for the 5-year old vessel are assumed to be the same as for the newbuilding resale. The 20-year old vessel is assumed to be self-financed from private reserves or through a partnership.

Table 2.9-7 summarizes the loan terms for the acquisition deals considered. The delivery, legal and initial financial cost is also included in brackets as part of the down payment. This is typically about $500,000 for a secondhand vessel and about $1,500,000 for a newbuilding, which includes supervision during construction etc.

Financing Terms for Acquisition Deals							
Ship	**PDown ($m)**	**L ($m)**	**M**	**Q_t (yrs)**	**Q_f ($m)**	**Q_r ($m)**	**B ($m)**
Order	24 (+1.5)	56	1%	40 (10)	8 (1.128)	32 (0.692)	24.832
Resale	35 (+0.5)	80	1%	40 (10)	12 (2.978)	28 (0.784)	22.312
5-yr	30 (+0.5)	70	1%	40 (10)	12 (2.590)	28 (0.680)	20.560
10-yr	25 (+0.5)	60	1%	32 (8)	8 (3.825)	24 (0.960)	6.360
15-yr	19 (+0.5)	44	1%	20 (5)	20 (1.922)	-	5.560
20-yr	41 (+0.5)	0	0	0	0	0	0

Table 2.9-7: Financing Terms for the Acquisition Deals Considered

It is assumed that LIBOR is hedged for each payment at the current futures rates, which are shown in Table 2.9-8.

Futures Price for LIBOR								
Period	2007 q2	2007 q3	2007 q4	2008 q1	2008q2-2013q1	2013q2-2014q1	2014q2-2015q1	2015 q2+
Price	5.35	5.34	5.3	5.25	4.9	4.97	5	5.02

Table 2.9-8: Current Futures Prices for LIBOR [Reuters 2007]

When ordering a newbuilding, payments are made to the yard at various stages before delivery. Typical payment terms are summarized in Table 2.9-9. It is assumed that these payments are made using the shipowner's reserves and only a post delivery loan is taken from the bank on the day of the delivery.

Newbuilding Payment Terms			
Stage	**Years from Now**	**% NB Price**	**Amount ($m)**
Signing	0	25%	16
Steel Cutting	2	25%	20
Keel Laying	2.75	20%	16
Delivery	3	30%	24

Table 2.9-9: Typical Newbuilding Payments

2.9.4 Cash Flow Analysis

Table 2.9-10 shows current period charter rates for a modern cape based on recent fixtures reported by [Braemar 2007b]. Table 2.9-11 indicates the factors used to adjust these rates for older vessels. These factors are only approximations based on fixtures that were reported since the beginning of 2007.

It was found that vessel size is an important factor in determining rates. A 25-year old 180,000 DWT vessel for example may be chartered at a higher rate than a typical 15-year old 150,000 DWT vessel. Table 2.9-1 assumes vessels of typical size for their year of built as shown in Table 2.9-4.

Current Rates for Modern Cape with Prompt Delivery	
Charter	**Rate**
Spot (Average of 4 TC roots)	$106,366/day
1 year	$90,000/day
2-years	$80,000/day
3-years	$70,000/day
5-years	$58,000/day
10-years	$40,000/day
10-years with delivery in 2010	$30,000/day

Table 2.9-10: Current Modern Capesize Rates for Prompt Delivery as of April 30th 2007 [Braemar 2007b]

Cape Rate Adjustment Factors for Age	
Vessel	**Rate as a % of Modern Vessel Rate**
Resale	100%
5-year old	95%
10-year old	90%
15-year old	80%
20-year old	70%
25-year old	50%

Table 2.9-11: Charter Rates for Capes of Various Ages as a Fraction of the Rates for a New Vessel

Some assumptions have to be made in order to get values for charter rates of the newbuilding order with delivery in 2010. The market is not very fluid so some crude approximations are needed based on the available data. These are summarized below:

1-year charter today is \$90,000/day so the 1st year is worth ~ \$90,000/day
2-year charter today is \$80,000/day so the 2nd year is worth ~ \$70,000/day
3-year charter today is \$70,000/day so the 3rd year is worth ~ \$50,000/day
5-year charter today is \$58,000/day so the 4th&5th year combined are worth ~\$40,000/day
Based on an average ratio of 1st yr: 2nd yr rates of ~1.1, the 4th year is worth ~41,905/day

These estimates are very close to the current futures prices for similar contract periods as of May 1st 2007. Table 2.9-12 shows a summary of both.

Forward Rate Estimates and Current Futures Prices			
Year	**Rate Estimate**	**Contract Period**	**Futures Price**
1st Year	$90,000/day	Remaining 2007	$91,000/day
2nd Year	$70,000/day	2008	$69,000/day
3rd Year	$50,000/day	2009	$51,000/day
4th Year	$41,905/day	2010	$42,000/day

Table 2.9-12: Charter Rate Estimates and Futures Prices for Similar Periods as of May 1st 2007 [FIS 2007]

So a 1-year time charter with delivery in 2010 (4th year) should be about $42,000/day. It can also be hedged at this value from now by buying the future to guarantee that rate so speculation is not required.

The rate for a 2-year charter with delivery in May 2010 (4th and 5th year combined) should be ~$40,000/day. From Table 2.9-10, a 10-year charter with delivery in 2010 is $30,000/day. Interpolation based on current period rates can be used to get approximate values for 3-year and 5-year rates for charters beginning in 2010 as follows:

Currently: 3 year rate = 2 year rate + ¾(2 year rate – 10 year rate)

For delivery in 2010: 3 year rate = 40,000 + ¾(40,000 – 30,000) = $37,500/day

Currently: 5 year rate = 2 year rate + 0.45(2 year rate – 10 year rate)

For delivery in 2010: 5 year rate = 40,000 + 0.45(40,000 – 30,000) = $34,500/day

The results for the deals considered are summarized in Table 2.9-13.

Charter Cases Considered		
Ship	**Charter Period (years)**	**Rate ($/day)**
Order	1	42,000
Order	3	37,500
Order	5	34,500
Order	10	30,000
Resale	3	70,000
Resale	5	58,000
Resale	10	40,000
5yr Old	3	66,500
5yr Old	5	55,000
5yr Old	10	38,000
10yr Old	3	63,000
10yr Old	5	52,000
10yr Old	10	36,000
15yr Old	1	72,000
15yr Old	2	64,000
15yr Old	3	56,000
15yr Old	5	46,500
20yr Old	1	63,000
20yr Old	2	56,000
20yr Old	3	49,000

Table 2.9-13: Charter Rates for the Acquisition Deals Considered

A 2.5% commission on the time charter earnings is typical so it is deducted in the calculation of quarterly earnings.

Since ships have to undergo repairs regularly, they are removed from service for a number of days each year. Classification requirements become more stringent as ships age and surveys become more regular and thorough. The number of days that a vessel is not earning money each year therefore increases with age. Since the bank requires quarterly

payments, a quarterly analysis overall is most convenient. Table 2.9-14 summarizes the earning days deducted from each quarter depending on the ship's age. These are approximate values based on experience.

Earning Days Deducted due to Repairs and Surveys		
Ship Age (years)	**Earning Days Deducted / Quarter**	**Earning Days / Year**
0 to 9	3	353
10 to 14	4	349
15+	5	345

Table 2.9-14: Number of Days Deducted per Quarter Depending on Ship Age to Account for Repairs

Running costs on the other hand are applied for the full 365 days in each year. These account for all operating and repair costs. As a ship gets older, maintenance becomes more expensive and running costs increase. More importantly, running costs increase every year due to inflation. Table 2.9-15 and 2.9-16 summarize running costs as a function of ship's age and time.

Running Costs as a Function of Ship Age and Time		
Ship Age (years)	**Running Costs Today**	**Annual Increase in Running Costs**
0 to 9	$5,000/day	2% per annum
10 to 14	$5,500/day	2% per annum
15 to 19	$6,000/day	2% per annum
20 to 30	$7,000/day	2% per annum

Table 2.9-15: Running Costs as a Function of Ship Age and Annual Increase due to Inflation

Daily Running Costs						
Year \ Ship	**New**	**5-Year**	**10-Year**	**15-Year**	**20-Year**	**25-Year**
0	$5,000	$5,000	$5,500	$6,000	$7,000	$7,000
1	$5,100	$5,100	$5,610	$6,120	$7,140	$7,140
2	$5,200	$5,200	$5,720	$6,240	$7,280	$7,280
3	$5,300	$5,300	$5,830	$6,360	$7,420	$7,420
4	$5,400	$5,400	$5,940	$6,480	$7,560	$7,560
5	$5,500	$6,050	$6,050	$7,700	$7,700	$7,700
6	$5,600	$6,160	$6,160	$7,840	$7,840	-
7	$5,700	$6,270	$6,270	$7,980	$7,980	-
8	$5,800	$6,380	$6,380	$8,120	$8,120	-
9	$5,900	$6,490	$6,490	$8,260	$8,260	-
10	$6,600	$7,200	$6,600	$8,400	$8,400	-
11	$6,710	$7,320	$6,710	$8,540	-	-
12	$6,820	$7,440	$6,820	$8,680	-	-
13	$6,930	$7,560	$6,930	$8,820	-	-
14	$7,040	$7,680	$7,040	$8,960	-	-
15	$7,800	$9,100	$7,150	$9,100	-	-
16	$7,920	$9,240	$7,260	-	-	-
17	$8,040	$9,380	$7,370	-	-	-
18	$8,160	$9,520	$7,480	-	-	-
19	$8,280	$9,660	$7,590	-	-	-
20	$9,800	$9,800	$7,700	-	-	-

Table 2.9-16: Running Costs as a Function of Ship Age and Time

2.9.5 Acquisition Deal Analysis

A quarterly analysis was carried out for each deal with each of the time charters indicated in Table 2.9-13. Payments are made on time with an interest rate of 1% over LIBOR, which is hedged at the prices indicated in Table 2.9-8. Quarterly revenues and running costs are applied half way through each quarter and bank payments are made at the end of each quarter. Fig. 2.9-2 shows the repayment of the loan from the day of the delivery for each ship according to the financing terms shown in Table 2.9-7.

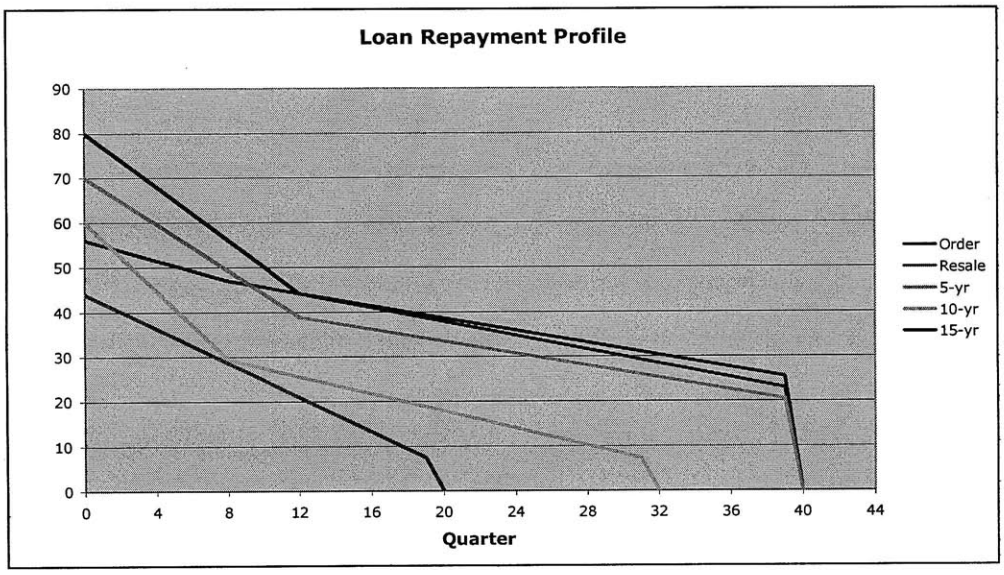


Fig 2.9-2: Loan Repayment Profile for the 5 Acquisition Deals using the Data from Table 2.9-7

Fig. 2.9-3 to 2.9-8 show the quarterly payments and profits of each ship for all the charters considered. Profits vary each quarter because running costs increase with age and time, earning days per quarter decrease with age, and because the number of days in each quarter varies. The quarterly payments vary because of the frontloading requirement and because interest is paid each time on the outstanding loan, which is reduced after each payment. Furthermore, LIBOR is hedged at a different price for each payment as shown in Table 2.9-8, so the interest rate also varies.

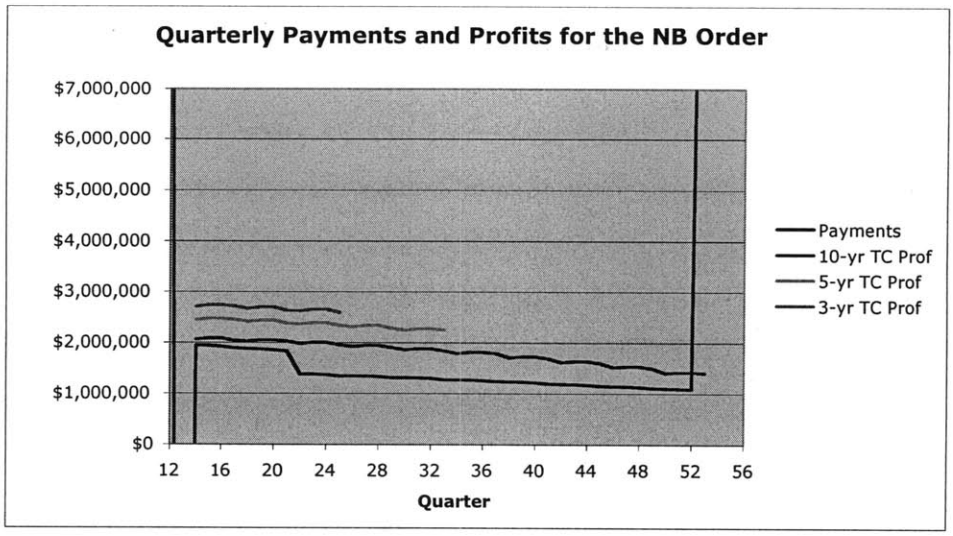


Fig 2.9-3: Quarterly Payments and Profits for the Newbuilding Order with the Time Charters Considered

The negative payment in at the end of Quarter 12 in Fig. 2.9-3 is the bank loan upon delivery of the vessel after a series of positive payments during construction.

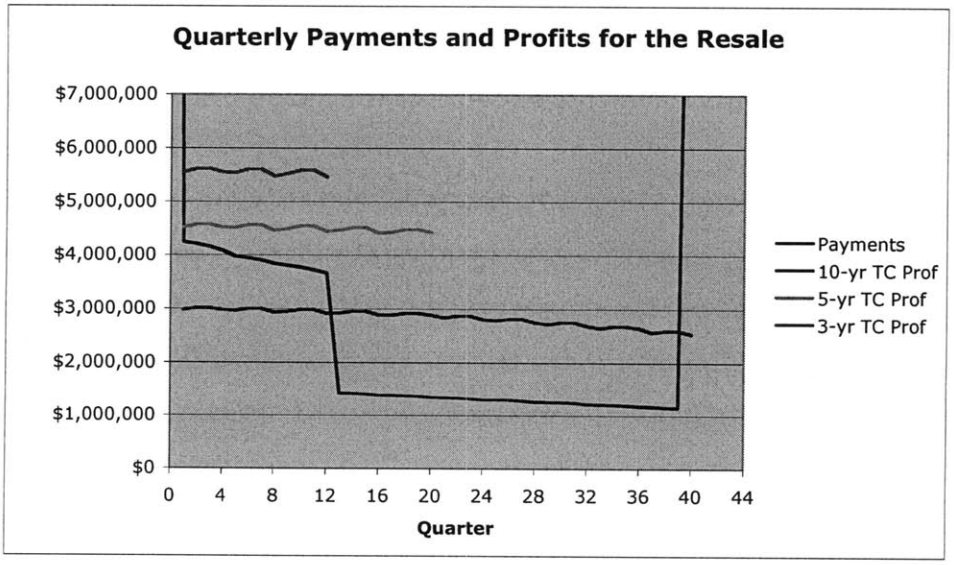


Fig 2.9-4: Quarterly Payments and Profits for the Resale with the Time Charters Considered

As shown in Fig. 2.9-4, the profits of the 10-year charter are not sufficient to cover the first bank installments for the Resale. This means that the vessel would be running at a loss during the first few years. Clearly therefore, this charter option is not feasible.

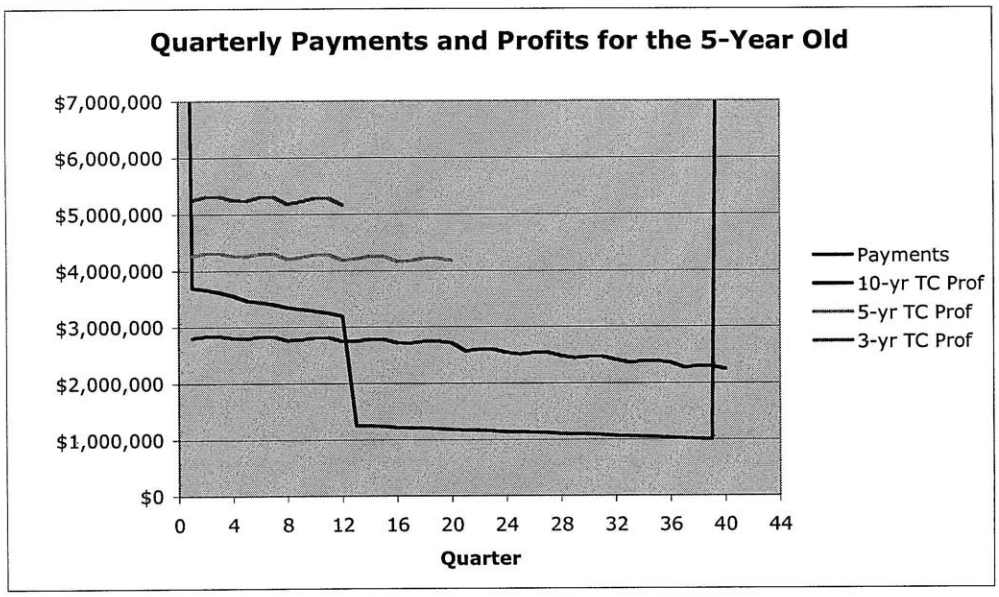


Fig 2.9-5: Quarterly Payments and Profits for the 5-Year Old with the Time Charters Considered

Again, as shown in Fig. 2.9-5, earnings from the 10-year charter do not cover the first installments so this charter option is not feasible for the 5-year old vessel either.

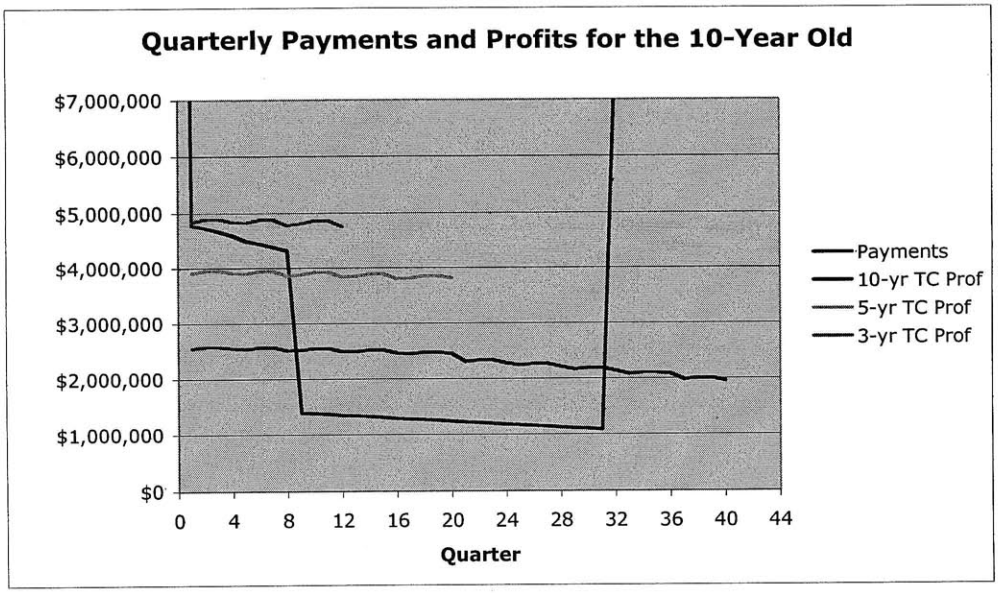


Fig 2.9-6: Quarterly Payments and Profits for the 10-Year Old with the Time Charters Considered

As shown in Fig. 2.9-6, earnings from the 3-year charter barely cover the first installments while 5-year and 10-year charter earnings are inadequate. Only a 3-year charter is therefore considered for the 10-year old vessel.

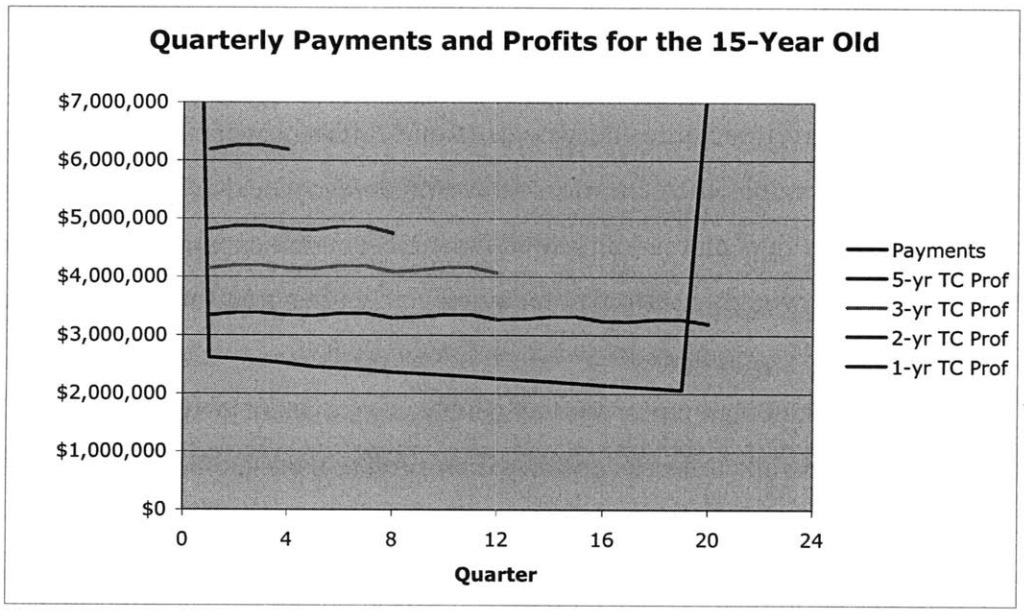


Fig 2.9-7: Quarterly Payments and Profits for the 15-Year Old with the Time Charters Considered

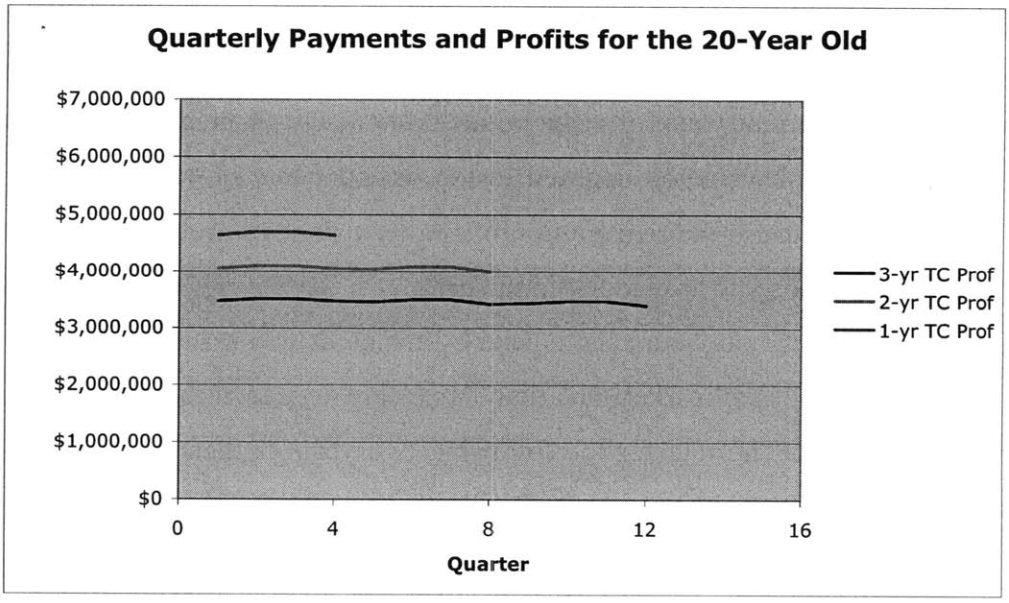


Fig 2.9-8: Quarterly Payments and Profits for the 20-Year Old with the Time Charters Considered

Fig. 2.9-7 and 2.9-8 show that all charter options considered are possible for the 15 and 20-year old vessels. All charter options from the above analysis that do not cover the full installment amount were eliminated before proceeding to the following comparisons.

The Net Present Value (NPV) and the vessel book value were calculated at the end of the charter for each option. Both these can be used to compare between the various options. The book value at the end of the loan is an indication of the equivalent amount one would have to pay on that day to acquire the vessel. If one thinks that the market value will be higher than the book value, then the deal is worth doing. The Net Present Value is an indication of today's value of the ship after the time charter ends. In other words, it is equivalent to what one would have to pay today for the charter-free ship with delivery when the charter ends.

The NPV calculation assumes that the bank loan repayments will be carried out in full meaning that the whole value of the loan (the benefit to the bank) is included. In reality, one would have the option of repaying the loan before the payments are due and thereby save on interest (the bank would normally request some kind of fee for this). The NPV of a deal at a date before the loan is repaid is therefore higher than the present value of the ship's book value at that point in time (when using the same discount rates). That is why the NPV of a deal with no charter is slightly higher than the price of the vessel.

The book value is equal to the outstanding loan plus the current value of all previous payments minus the current value of all previous profits (with interest). An interest rate of 5% is used for the book value as opposed to the discount rate of 10% used in the NPV calculations. This is because the remaining profits after payments are made are likely to be earning an interest of closer to around 5% in the bank.

As a check on the previous charter rate estimates, it was assumed that the resale is traded for 5 years on the spot market. The first 3 years are hedged at the current futures rates shown in Table 2.9-12. The rate for the following two years is then adjusted to bring the book value after five years to the same level as when the vessel is chartered for 5 years. This is provides an educated estimate based on the current market, of what the rates are going to be for the last two years (2010 and 2011). The result was $42,680/day, which is very close to our estimate of $42,000/day.

Table 2.9-17 shows the book value of each vessel after the time charter, using an interest rate of 5%, along with the vessel age and the time until the charter ends.

Book Value after TC for Each Deal										
Book Value ($m)		**Years Until TC Ends**								
Vessel (charter)	**Age**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**13**
NBOrder (0yrs)	0				85.8					
NBOrder (1yr)	1					80.9				
NBOrder (3yrs)	3							68.6		
NBOrder (5yrs)	5								60.1	
NBOrder (10yrs)	10									51.1
Resale (0yrs)	0	115.5								
Resale (3yrs)	3				64.3					
Resale (5yrs)	5						48.9			
5yrOld (0yrs)	5	100.5								
5yrOld (3yrs)	8				50.5					
5yrOld (5yrs)	10						35.2			
10yrOld (0yrs)	10	85.5								
10yrOld (3yrs)	13				49.5					
15yrOld (0yrs)	15	63.5								
15yrOld (1yr)	16		44.6							
15yrOld (2yrs)	17			30.3						
15yrOld (3yrs)	18				21.1					
15yrOld (5yrs)	20						7.6			
20yrOld (0yrs)	20	41.5								
20yrOld (1yr)	21		24.4							
20yrOld (2yrs)	22			11.6						
20yrOld (3yrs)	23				3.2					

Table 2.9-17: Book Value for Each Deal After the Time Charter using an Interest Rate of 5%

The book value can be viewed as the amount one would pay for a charter-free vessel of that age in the indicated number of years. To compare amongst the deals in Table 2.9-17, one has to look down a single column. Taking the column of 3 years until the charter ends for example, there are 6 options to compare. Each option is equivalent to buying the vessel in 3 years at the indicated price while the age of the ship in 3 years is read from the column "age". Hence the choice (in 3 years) is between a new vessel for $85.8m, a 3-year old vessel $64.3m, an 8-year old vessel for $50.5m, a 13-year old vessel for $49.5m, an 18-year old vessel for $21.1m and a 23-year old vessel for $3.2m. By making such comparisons, some options can clearly be eliminated. The 8-year old vessel for $50.5m for example is clearly better than a 13-year old vessel for $49.5m.

Based on historical average prices, the most reasonable deals in the current market appear to be that of buying a 15-year old vessel and chartering it out for 5 years to write it off at $7.6m, and buying a 20-year old vessel and chartering it out for 3 years to bring write it off at $3.2m. 10-year average scrap prices are about $220/ldt, equivalent to about $5.5m for a cape with a lightship of 25,000ldt. These two deals therefore involve the lowest risk and rely the least on speculation of the market beyond 2010.

Table 2.9-18 shows the NPV for each ship after each time charter using a discount rate of 10%. This can be viewed as the equivalent amount one would pay today to acquire the charter-free vessel of the indicated age with delivery after so many years. With a discount rate of 10%, no option appears reasonable. The best ones are the same as in Table 2.9-17.

Net Present Value for Each Deals After TC										
NPV ($m)		**Years Until TC Ends**								
Vessel	**Age**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**13**
NBOrder (0yrs)	0				60.6					
NBOrder (1yr)	1					51.7				
NBOrder (3yrs)	3							39.6		
NBOrder (5yrs)	5								32.2	
NBOrder (10yrs)	10									24.7

Resale (0yrs)	0	104.7								
Resale (3yrs)	3				46.6					
Resale (5yrs)	5						33.0			
5yrOld (0yrs)	5	91.0								
5yrOld (3yrs)	8				36.1					
10yrOld (0yrs)	10	89.8								
10yrOld (3yrs)	13				39.2					
15yrOld (0yrs)	15	59.6								
15yrOld (1yr)	16		38.6							
15yrOld (2yrs)	17			24.4						
15yrOld (3yrs)	18				16.3					
15yrOld (5yrs)	20						6.9			
20yrOld (0yrs)	20	41.5								
20yrOld (1yr)	21		23.7							
20yrOld (2yrs)	22			11.9						
20yrOld (3yrs)	23				5.3					

Table 2.9-18: Net Present Value for Each Deal After the Time Charter using a Discount Rate of 10

2.9.6 Sell or Charter Analysis

A similar analysis was carried out from the point of view of the seller who is faced with the option of time chartering at current rates, or selling at current prices. The same scenarios of ship age and time charter combination were considered with the addition of a 25-year old cape instead of the newbuilding order.

An annual analysis was carried out as opposed to a quarterly analysis for simplicity. Charter rates for each case were based on Tables 12, 13 and 15. A commission of 2.5% was applied again as in the previous analysis. Average running costs were taken for each charter based on Table 2.9-15 and Table 2.9-16. The average number of earning days per year for

each case was taken from Table 2.9-14. An end value was calculated for each scenario based on the profits and current prices as follows:

$$EndVal = \left(P - NPV_{prof}\right)(1+I)^{n} \tag{2.9-1}$$

$$NPV_{prof} = (\text{Pr}of \times a)(1+I)^{1/2} \tag{2.9-2}$$

$$a = \frac{1-\left[(1+I)^{-n}\right]}{I} \tag{2.9-3}$$

Where: Prof: average annual profits
n: number of years of the time-charter
I: interest rate = 5%

If one believes that their vessel will be worth more than "End Value" after the charter, then it is best to charter the vessel. Otherwise, it is better to sell at the current price. Table 2.9-19 provides a summary of the analysis for each scenario along with the resulting "End Value".

Sell or Charter Analysis							
Ship (tc)	**R ($/day)**	**RC ($/day)**	**Days/Yr**	**a**	**NPVprof ($m)**	**Price ($m)**	**EndVal ($m)**
0-yr (3)	70,000	5,100	353	2.723	62.0	115	**$61.3**
0-yr (5)	58,000	5,250	353	4.329	80.1	115	**$44.6**
0-yr (10)	40,000	5,450	353	7.722	93.2	115	**$35.5**
5-yr (3)	66,500	5,100	353	2.723	58.7	100	**$47.8**
5-yr (5)	55,000	5,342	353	4.329	75.3	100	**$31.5**
5-yr (10)	38,000	5,735	351	7.722	86.3	100	**$22.3**

10-yr (3)	63,000	5,610	349	2.723	54.1	85	**$35.8**
10-yr (5)	52,000	5,775	349	4.329	69.1	85	**$20.2**
10-yr (10)	36,000	5,995	347	7.722	79.1	85	**$9.7**
15-yr (1)	72,000	6,000	345	0.952	21.5	63	**$43.6**
15-yr (2)	64,000	6,060	345	1.859	36.8	63	**$28.9**
15-yr (3)	56,000	6,120	345	2.723	46.3	63	**$19.3**
15-yr (5)	46,500	6,483	345	4.329	58.9	63	**$5.2**
20-yr (1)	63,000	7,000	345	0.952	18.2	41	**$24.0**
20-yr (2)	56,000	7,070	345	1.859	31.0	41	**$11.1**
20-yr (3)	49,000	7,140	345	2.723	38.7	41	**$2.6**
20-yr (5)	40,500	7,350	345	4.329	48.5	41	**-$9.6**
25-yr (1)	45,000	7,000	345	0.952	12.3	25	**$13.4**
25-yr (2)	40,000	7,070	345	1.859	20.7	25	**$4.7**
25-yr (3)	35,000	7,140	355	2.723	26.5	25	**-$1.8**

Table 2.9-19: Sell or Charter Comparison for the Various Scenarios Using an Interest Rate of 5%

The age of each vessel after the charter is equal to the initial vessel age (shown in the left column) plus the length of the charter (shown in brackets). In the first row, the decision is between selling the vessel today for $115m, or chartering it out for 3-years if the owner expects that the value of a 3-year old vessel in 3 years will exceed $61.3m.

Some decisions are very clear. One for example should definitely choose to charter a 20-year old vessel for 5 years as opposed to selling it because the negative "End Value" shows that it will make more money during the charter than it is now worth even of the residual value of the vessel is ignored. Similarly, it is definitely worth chartering the 25-year old vessel for 3 years as opposed to selling it.

It is important to note that these decisions rely on the fact that the charterer will continue to pay the agreed rate if the market goes down. Since the risk varies depending on the integrity of the charterer and the probability of the market declining, it is not quantifiable and therefore not incorporated in the analysis. In real life, one may base their decision on their interpretation of the risk involved in a given situation.

Assuming low risk charters, the most sensible option for each ship was chosen from Table 2.9-19. The choices are based on historical average values and personal opinion. They are summarized along with a brief explanation in Table 2.9-20.

Summary of Best Options		
Ship	**Best Option**	**Comments**
0-yrs	Sell or 5-yr charter	A 5-year old vessel in 2010 should be worth more than $44.6m if orders are made at above $80m for delivery in 2010
5-yrs	Sell	High risk involved in all other options
10-yrs	Sell	10-yr charter: A 20-yr old ship in 20 years may be worth slightly more than $9.7m but it is not worthwhile
15-yrs	5-yr charter	$5.2m is less that the 10-yr average scrap value of ~$5.5m
20-yrs	5-yr charter	Profit of $9.6m plus the residual value of a 25-yr old vessel
25-yrs	3-yr charter	Profit of $1.8m plus the residual value of a 28-yr old vessel

Table 2.9-20: Best Chartering or Selling option for each Vessel Based on Current Rates and Prices

1-year and 10-year charters seem to be bad options compared to intermediate periods. 10-year charters allow very little room for significant profits, while 1-year charters rely heavily on a strong market thereafter. If one wants to avoid relying on a strong market for many years, the best option for vessels of age 15 years or older, is the longest time charter available.

2.9.7 Conclusions

- We are currently at a very high peak of a highly cyclical market. The following few years are therefore valued significantly higher value than remaining ship's life

- Banks respond to this by frontloading loan repayments to bring a high loan down to 10-year average values. This makes some charter options unfeasible because the earnings are inadequate to cover the first payments

- Out of the possible options from a buyer's point of view, only older vessels seem to make sense as they involve lower risk and rely the least on speculation of the market beyond 2010

- From a seller's point of view, 1-year and 10-year charters appear to be redundant options in general while 3-year and 5-year charters or selling are chosen for all vessel ages

- If one does not want to rely on the market staying strong, it is generally worth selling newer vessels and chartering old vessels (15+ years) for as long as possible

2.10 Overall Comments and Conclusion

Since the development of capes in the late 1960s, their market has been closely correlated with that of the dry bulk fleet. China's recent economic expansion and huge increase in demand for iron ore, has created a boom for capes that account for the great majority of iron ore transportation.

China's steel production industry is expanding rapidly and this drives the demand for iron ore imports. Furthermore, China has gradually become a net coal importer, causing its previous importers to go to Australia. This has led to a heavy increase in tonne-miles and to record-high delays and queue lengths in Australian ports, driving freight rates extremely high. Demand is also affected by the high oil prices, which not only boost the economies of oil producing countries, but also cause many factories and power plants around the world to convert to steam coal, creating more employment for capes.

The global supply of capes is inelastic in the short run due to the limited capacity of yards and ports and the length of delivery times. The high increase in demand, combined with the inelasticity of supply has led to exceedingly high spot and t/c rates. Record-breaking newbuilding, second hand and demolition prices have followed. The weak US $ has also helped boost trade and the freight market.

Most people do not expect the market to last at the current levels for long so the next few years are valued much higher than the remaining ship's life. This has made the second-hand more expensive than the newbuilding that has an average delivery time of 3 years. A modern resale today with prompt delivery is worth about 150% the price of a newbuilding order. This has also narrowed the gap in prices between older and newer vessels. Spot rates are also significantly higher than t/c rates and the difference increases with t/c period length. Since the crisis of 1986 when a 9-year-old cape was of scrap value, the market has moved to the opposite extreme with a 13-year old cape today worth as much as a newbuilding order.

Supply will increase by about 30% by 2011 on the basis of the current newbuilding orderbook. However, China's imports/exports are expected to keep increasing and there is a corresponding optimism on the demand side. Hence there may be a tight balance between supply and demand until then and this will determine the outcome of the market.

There has been minimal scrapping over the past few years leading to an increasing scrapping pool. A decline in rates will force old ships out of the market, thereby counteracting the decline. The resolution of the congestion problem will effectively increase supply and will have an imminent impact on the freight market. If China's demand drops significantly, the increase in supply over the coming years will lead to a shipping crisis. This could make the next decade one of the worst in the history of shipping. Even if that happens however, ship values are unlikely to drop for a relatively long time because of cash reserves and optimism that has been built up during the current boom.

The market is cyclical and very volatile both in terms of ship earnings and ship values, particularly for capes. This cyclicality leads to huge losses but also provides big investment opportunities particularly with older vessels. The latest cycle has created opportunities, which in instances yield return on investment of over 1000% in just 3-4 years. Today we are probably near the peak of the market with average daily earnings of about $115K/day and a modern resale worth in excess of $115m. Such high returns are therefore unlikely to be repeated in the near future. The less risky investments today are in older ships and rely the least on speculation of the market beyond 2010. From a seller's point of view, it is generally worth selling newer vessels and chartering out older ones for as long as possible.

The futures (FFA) market provides good investment opportunities to those that wish to hedge or speculate. The FFA market and the physical market are not identical but one affects the other and they are closely aligned. Large discrepancies between actual values and futures prices are very common creating opportunities for high profits. The average difference between futures prices and physical values in fact increases exponentially with the time between the contract and the settlement date. Future prices are strongly affected by the current market and its direction and they are relatively flat. They are therefore a relatively bad forecasting tool and create a risk for big losses. One therefore has to adopt a more scientific approach to forecasting the market and to hedge accordingly.

CHAPTER 3
Technical Review

3.1 Bulk Carrier Losses

About 10 ships and 50 lives are lost every year from bulk carrier losses alone since the beginning of the 1980s [Intercargo 2004, O'Mahony 2004a, Terry Macalister 2004, Intercargo 2002, MER 2002c, Naval Architect 1996, Byrne et al 1998, Mortensen 1998]. A recent study of total losses between 1997 and 2006, by the International Union of Marine Insurance IUMI, found that hull damage is one of the leading causes for total loss [Wang et al 2009].

Human error has consistently been a dominant factor accounting for about 90% of all maritime accidents [Lloyd's 2003]. Approximately half are directly initiated by human error while about a third result from the failure of human performance to avoid or mitigate the consequences [Baker et al 2004]. Fig. 3.1-1 shows the trend in bulk carrier losses and the resulting losses of life between 1995 and 2004.

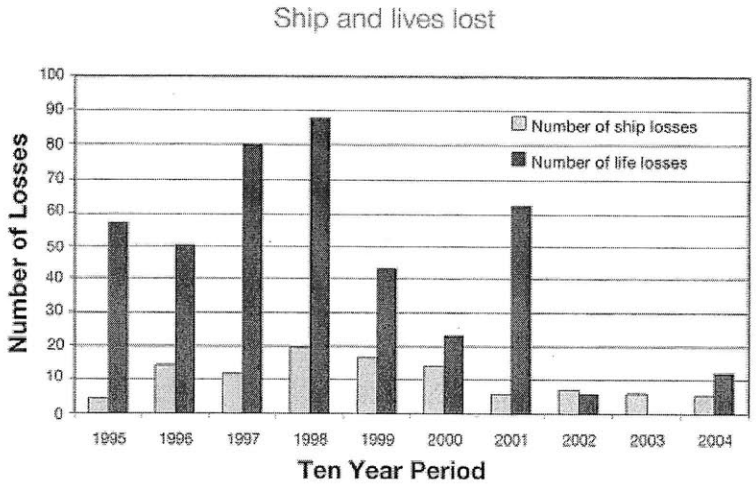


Fig. 3.1-1: Ships and Lives Lost due to Bulk Carrier Losses since 1995 [Intercargo 2004]

In an analysis of bulk carrier losses, ABS suggests that they seem to follow the fluctuations of the freight market [ABS 1997]. A contributing factor is that during a high freight market, repairs are more likely to be postponed. This emphasizes the influence of repairs and structural integrity on ship casualties.

According to the chairman of Intercargo, Frederick Tsao, "Structural failure remains a consistent and significant cause of loss, while the presence of heavy cargos features in many of the losses" [MER 2002a]. The 11 largest out of the 12 capes which were lost due to known or suspected structural failures between 1990 and 1997 were carrying iron ore. Furthermore, while capes comprised only about 9 percent of the bulker fleet, they accounted for 48% of the casualties [Mortensen 1998]

[Thayamballi et al 1996] suggest that the loss rate from all cape causes is approximately 3 times greater than that of Panamaxes. Fig. 3.1-2 compares the normalized casualty rates due to side shell failure, which is a common failure cause, and due to collision, between the various bulk carrier size groups.

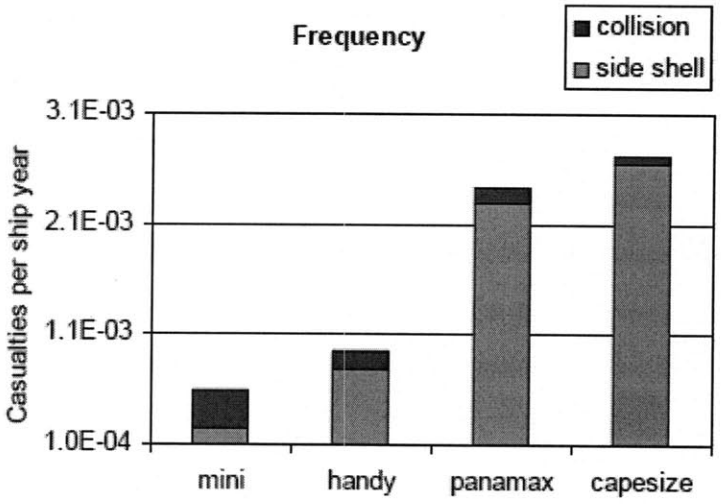


Fig. 3.1-2: Casualties per ship year for the various bulk carrier size groups [Vassalos et al 2004]

The prevalence of iron ore cargos in bulk carrier losses is demonstrated in Fig. 3.1-3. The reasons for this are mainly associated with the cargo's high density. The implications of loading iron ore on the hull stresses are analyzed in greater depth in Section 3.9.2.

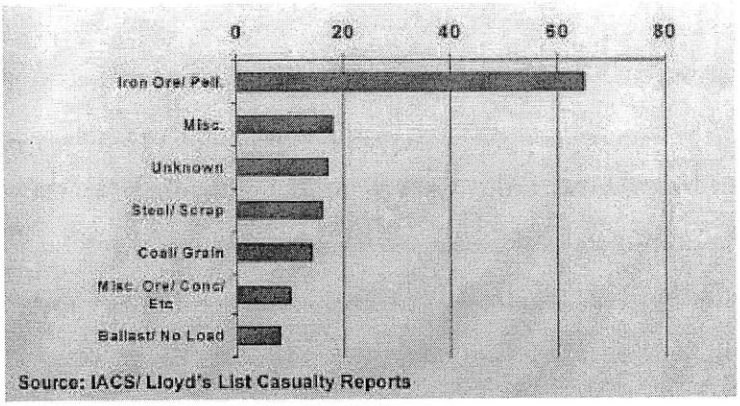


Fig. 3.1-3: Bulk Carrier Casualties (>2000dwt), where Hull Failure may have been a Factor [DNV 1997]

Even though bulk carrier losses have stemmed from a variety of causes, fatigue cracking is a recurring one. Significant research was carried out on the effect of fatigue in tankers [Bea 1994, Rolfe et al 1993, ABS 1992], but bulk carriers suffer more because of the larger number of discontinuities in their structure. Fig. 3.1-4 shows the trend in the total and hull related casualties between the periods of 1980 and 1994.

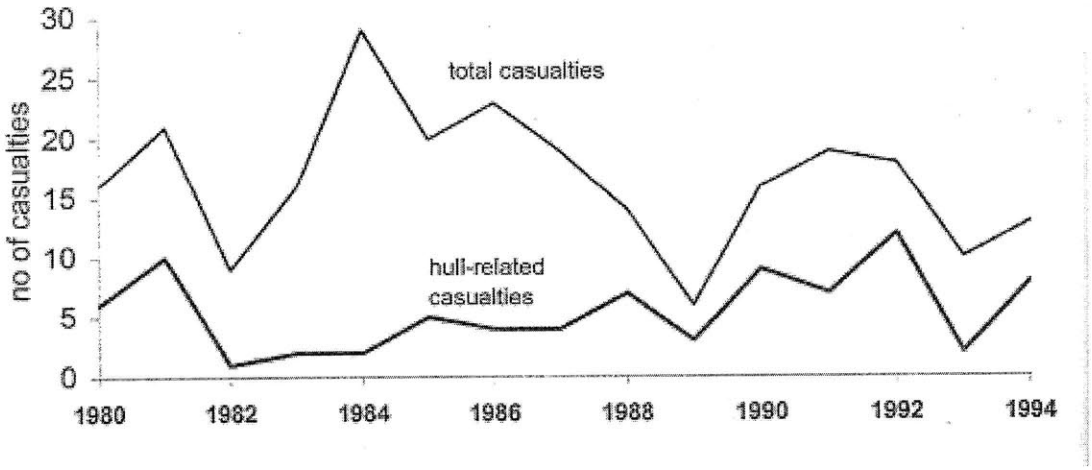


Fig. 3.1-4: Total and Hull-Related Casualties [LR 1996]

Both corrosion and fatigue cracking, particularly on the side shell, appear to be a prime cause of failure [Intercargo 2002, Plaza 1998, IACS 1992, LR 1995, Robinson 1991, Anon 1991]. According to a study of the IMO, cracked or damaged side shell is the leading

cause of bulk carrier losses, while flooding of the first cargo hold accounts for ~40% of bulk carrier casualties [ABS 2002c]. For capes, side shell failure accounts for 58.3% of the total losses, while hatch cover failures account for 13.3% [ABS 2002c]. Typically, fatigue cracks on shell frame connections propagate towards the shell as a result of cyclic loading. This causes leakage and ultimately flooding of a cargo hold. Excessive loads consequently lead to the progressive collapse of bulkheads, which may also have fatigue cracks and corrosion. Progressive flooding of an iron ore loaded ship, which is usually only designed for the flooding of one cargo hold, ultimately leads to rapid sinking.

This is a typical way by which many capes are lost [Braidwood et al 1998, Kim et al 1996a, Naval Architect 1996, Liu et al 1995, Ferguson et al 1993, Richardson 1986, IMO 1993, Adam et al 1991, Foy 1983]. About 20 ships disappeared as such without warning in the 1980s and early 1990s [Paik et al 1998c]. These include the two major cape incidences "Giga 2" (140,000dwt built in 1981) and "Pos Challenger" (149,000 built in 1992). Other examples include the ore bulk oil carrier (OBO) *MV Derbyshire* in 1980, the Capes *Alexandre P., Pasithea* and *Algarrobo* all of which disappeared virtually without trace in 1990 while loaded with iron ore [LR, Peckham, Ferguson 1991a], the *Mineral Diamond* in 1991 again loaded with iron ore [NK 1992] the OBO and the capes *MV Christopher* in 2001 and *Alexandros T* in 2006. Naturally, this has attracted public attention and it has caused great concern about fractures particularly in capes. Studies have shown that ships with alternately loaded holds are more susceptible to failure this way [Hibbert 1997, Somerville 1996].

Fig. 3.1-5 shows the number of capesize bulk carrier losses per year and the fleet size since 1980. There are also a few cases where Capes were saved just in time following quick and decisive action by an alert crew after discovering dangerous cracks while at sea. Examples include the 170,000 dwt Cape *Setsuyo Star* in 2006 [Corbett 2006b] and *Hebei Wisdom* in 2008 [Corbett 2008].

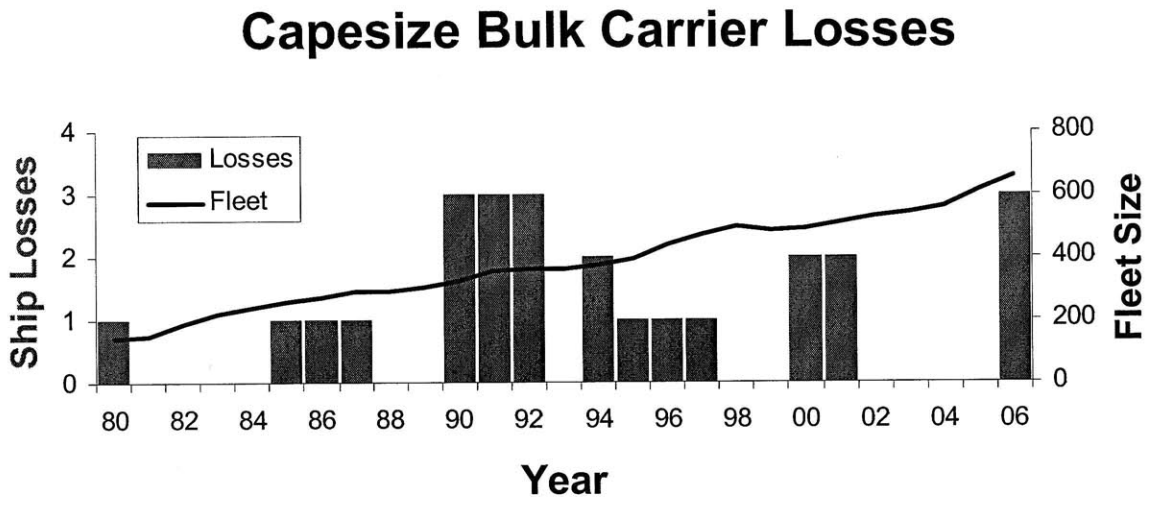


Fig. 3.1-5: Cape Losses Since 1980 [Intercargo 2007, Clarksons 2007a]

The average loss rate has been on average 1 cape per year or approximately 0.3% of the world fleet. Many of these failures have given rise to the commonly used term of "disappearing capes". The failure sequence described above is most common in capes because of their frequent transportation iron ore, which has a density of 2600kg/m^3. At 175,000tons, only 67,308m^3, or a third of the cargo hold space of a typical 175,000dwt cape is occupied. If the rest becomes filled with sea water, the weight in the cargo holds increases to approximately 310,000 tones or 177% of the dwt capacity, making it sink like a rock.

3.2 Maritime Organizations

3.2.1 Overview

The maritime industry includes a large number of parties who have a vested interest in the ship at any point in time. Fig. 3.2-1 provides a summary of some of the most important constituents.

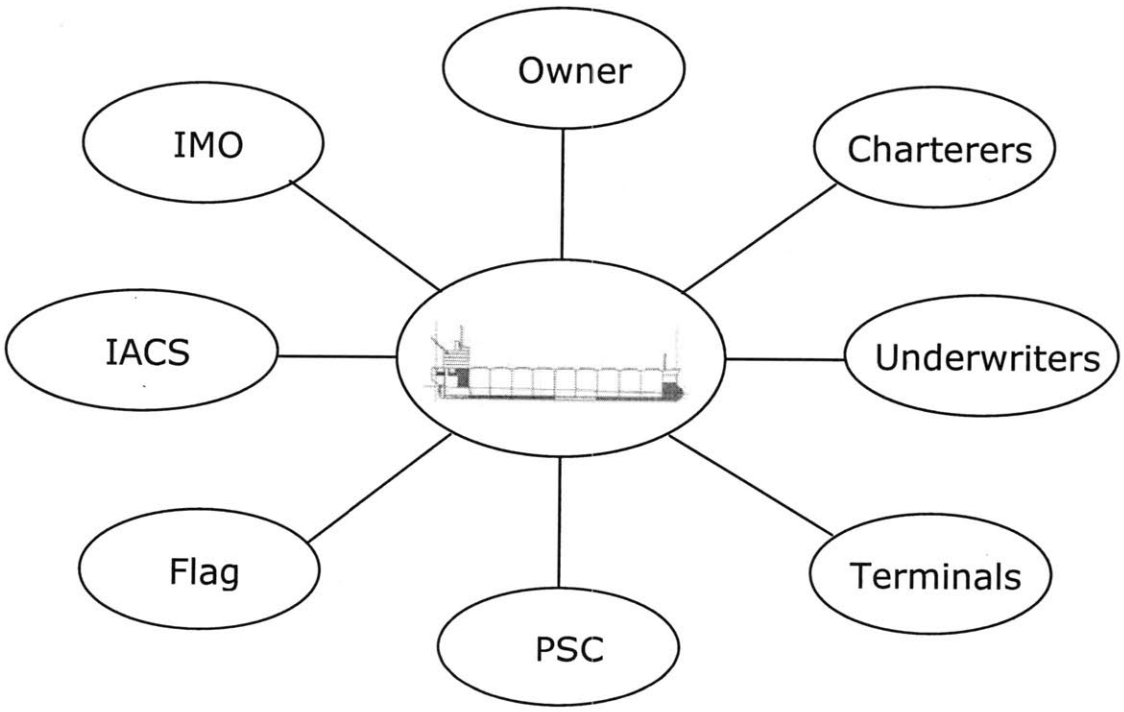


Fig. 3.2-1: Parties Involved in the Shipping Industry

Maritime societies which are directly concerned with the safety of ships include Classification Societies, the International Maritime Organisation (IMO), and the Flag Administrations. They try to ensure safety through the introduction of rules/ regulations and minimum requirements. Additional inspections may also be carried out by other parties who may be concerned with the safety of ships, such as the Port State Control when a ship enters or leaves from a port.

3.2.2 The IMO

The *International Maritime Organisation (IMO)* was established in 1959. Its main purposes are "*to provide machinery for cooperation among Governments in the field of governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade; to encourage and facilitate the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships*". The IMO is also authorized to deal with administrative and legal matters related to these purposes [IMO 2009a].

The most important of the Conventions adopted by the IMO are the International Convention for the Safety of Life at Sea (SOLAS) 1974, and the International Convention for the Prevention of Pollution from ships (MARPOL 73/78). Others include the International Convention on Standards of Training Certification and Watch-keeping for Seafarer (STCW), Load Lines (LL), Convention on the International Regulations for Preventing Collisions at Sea (COLREG) and International Labour Organization Convention No. 147 Merchant Shipping (Minimum Standards) (ILO 147).

The first version of SOLAS was adopted in 1914 in response to the *Titanic* disaster and successive versions followed in 1929, 1948, 1960 and 1974. The 1974 version has been updated and amended several times and today it is referred to as SOLAS 1974, as amended [IMO 2009b]. This is now generally regarded as the most important international treaty concerning the safety of merchant ships.

In the 1994 SOLAS amendments, the International Safety Management (ISM) code was introduced, which was enforced to all bulk carriers from 1 July 1998. The ISM code requires every company to implement a safety management system in compliance with the mandatory rules and regulations.

3.2.3 IACS and Classification Societies

Classification Societies are the certification agents which provide their classification and statutory services for the operation of the maritime community. They are independent, self regulated organizations which have no commercial interests related to ship design, construction or operation. Their purpose is to establish and apply technical standards relating to the design, construction and survey of marine structures.

Primary clients of classification societies include ship-owners, flag states, designers, shipyards and manufacturers but there are also others who do not relate directly but depend upon the quality of services provided by classification societies. These include port states, underwriters, financiers, charterers, cargo interests etc.

Classification societies are responsible for the design approval and inspections throughout a ship's life. As such, they publish rules and regulations that are principally concerned with the strength and reliability of the ship structure, its machinery and all systems which are required to maintain essential services on board. The rules and standards are developed by the Bureau staff and passed upon by committees made of naval architects, marine engineers, shipbuilders, engine builders, steel makers and other technical operating and scientific personnel associated with the maritime industry. Theoretical research and development, established engineering disciplines and service experience are all used in their development. A certificate of classification may be issued for a ship which meets the requirements upon application after the completion of the relevant surveys. This certifies that the class requirements are met by the ship but does not guarantee sea worthiness or safety.

There are over 50 classification societies worldwide but the ten major ones cooperate through the International Association of Classification Societies (IACS) and, therefore, have many common requirements. It is estimated that IACS, including the additional societies that have been accorded associate status, collectively classifies about 94 percent of all commercial tonnage involved in international trade worldwide [IACS 2006] and over 95% of the bulker fleet [IACS 1998].

IACS adopts Common Structural Rules and ensures minimum standards between its members but there are often significant differences between them as a result of the differences in experience or policy. This can have a great impact on the ship's quality. An example is with GL which has a great experience particularly with containerships and whose philosophy is to extend the minimum IACS requirements by introducing all the relative developments from the strength analysis and experience of containerships, to the design and classification of bulk carriers. This is why GL-classed bulk carriers are generally known to experience fewer structural problems.

The classification society carries out regular surveys throughout the ship's life to check her conformity and ascertain that she remains up to standard. Inspections are scheduled so as to ensure safe operation between surveys subject to proper maintenance. The classification society, however, is not responsible for maintenance. The Flag Administration is responsible for overseeing that the safety requirements are maintained. The ship owner is required to inform the society without delay if any defects affecting class become apparent, or if damages are sustained between surveys.

The surveyor may give a recommendation (condition of class) for any minor details which are observed. Under more serious circumstances, class may be suspended temporarily or withdrawn permanently. After a ship is assigned and registered under a classification, it is maintained in class as long as it meets the requirements and surveys are carried out in accordance with the class rules.

3.2.4 Flag States & Statutory Certification

The United Nations Convention on the Law of the Sea (UNCLOS) is an umbrella convention concerned with several maritime aspects, including the granting of registration of a ship by a State. Among the duties of the *Flag State* laid out in UNCLOS is to take enough measures for all ships flying its flag in order to ensure safety.

Uniform standards have been established through international conventions in order to allow ships registered in one port to travel to waters of other countries. These are known as

"statutory requirements" and cover aspects of design, safety, accident prevention and the situation after an accident.

There are approximately 100 administrations that are parties to SOLAS. According to SOLAS Ch II-1, Reg 3-1, a ship must comply by the standards of a classification society which is recognised by the administration according to regulation XI/1, or with standards of the Administration which ensure an equivalent level of safety [IACS 2006]. All ships are obliged to meet both statutory and class requirements. If a ship is suspended or withdrawn from class, IACS publishes this information on its website and notifies the flag administration which then usually invalidates the statutory certificates.

3.2.5 Recognised Organisations (RO)

ROs carry out inspections and surveys on behalf of the flag administration in order to ensure that a ship is in compliance with the applicable requirements. They are thus responsible to the flag administration and are authorised to require repairs and invalidate the ship's certificates if the necessary actions are not taken. The details of inspections and surveys regarding safety and pollution are established by international conventions and the Government is a signatory. Minimum standards for ROs are set by the IMO Resolution A 739(18) [IACS 2006].

3.2.6 Port State Control (PSC)

Port state control (PSC) is the inspection of ships when they enter ports in order to ensure that IMO requirements are met. Although this is strictly the responsibility of the Flag States, Port State control is complementary to Flag State Control and is used as a safety net to catch substandard ships as they enter ports.

The Port State is thus entitled to inspect vessels as soon as they enter the port. It usually takes action when ship owners, classification societies and Flag Administrations fail to enforce IMO requirements. In such circumstances, it usually requests an occasional survey to be carried out by the society and withholds permission to sail until any deficiencies are rectified.

The Memorandum of Understanding on Port State Control (MOU on PSC) has been in effect since July 1982 [Isbester 1991]. Organizing inspections on a regional basis is very effective as it allows for cooperation of port state authorities in consecutive ports of call. Inspections are closely coordinated to enforce effective control while mitigating unnecessary inspections. IMO has encouraged the establishment of regional PSC organizations and agreements (MOUs) have been signed covering all oceans [IMO 2009a].

3.3 History of Fractures and Fracture Mechanics

Introduction

The problem of fractures is as old as structures themselves. An 1982 study estimated the cost of fractures in 1978 in the US alone at $119bn in 1982 $ (4% of GNP) and that this could be reduced by $35bn with current technology and a further 28bn with further fracture mechanics research [Anderson 1995, Eischen 2008, Roylance 2001]. Substantial progress has been made in fracture mechanics over time, particularly during the 20th century but it will never be known exactly how many lives were saved and how much damage has been avoided.

One of the most famous brittle fracture problems was that of the Liberty ships during WW2. Those were among the first to have an all-welded hull allowing for much faster construction than riveted ships. The fracture problem of these ships, and particularly that of the T2 Tanker *Schenectady* was arguably the birth of the field of fracture mechanics. Today, virtually all steel ships are welded as opposed to riveted and this is possible partly due to knowledge gained from the Liberty ships. What follows is a brief history of the discoveries in fracture mechanics and their application in the maritime industry along with some of the major fracture disasters.

Ancient times (B.C.)

In ancient times, designing against fractures was done by trial and error. Understanding of fracture mechanics was very vague and structures often failed below the predicted loads. Therefore, safety factors greater than 10 were common. It can be seen that the Romans soon discovered that compressive stresses are safer than tensile stresses by the way they built their bridges. They actually tested them by requiring the design engineer to stand underneath while chariots drove over it. This put the right incentives in place and

resulted in a Darwinian natural selection whereby only the best engineers survived [Anderson 1995]. Similarly today, the highest ranked officials are required to go in the first dive of a submarine which is done to stress relieve the welds.

15th Century

Leonardo da Vinci performed experiments on iron wire and found that longer wires failed at lower loads than shorter wires. He showed that the strength of iron wires was inversely proportional to their length thus drawing a connection between flaws and strength for the first time (longer wires had a higher probability of containing a larger flaw).

17th Century

In 1638, Galileo investigated the strength of a column under tension and referred to it as resistance to fracture [Eischen 2008].

18th and 19th Century

In 1843, Rankin first talked about fatigue in railroad axles [Eischen 2008]. The increase in heavy industry during the Industrial Revolution resulted in many accidents related to brittle fracture. This stimulated a lot of interest in understanding fracture mechanics and a number of papers were published before the 20th century [Kobayashi and Onoue 1943].

1910s

In 1912, Charpy clarified the ductile to brittle transition and developed the Charpy Impact Test to evaluate it by measuring the absorption energy and ductile to brittle transition temperature [Kobayashi and Onoue 1943]. The study of crack-like defects began by professor of Naval Architecture, C E Inglis who in 1913 formulated the stress analysis equations of a crack-like elliptical hole in a stressed infinite elastic plate [Inglis, 1913].

In 1912, the *Titanic* sank with 1,523 passengers and crew after hitting an iceberg on its maiden voyage to the U.S. [Deitz 1998]. The steel had very large grains and high sulfur content and the temperature was -2degC. The ductile to brittle transition temperature was found to be 20degC on one direction and 30degC on the other compared to -15degC for a reference sample of modern A 36 steel [Baumgartner 2006]. It is believed that tougher steel could have delayed the sinking allowing more passengers to board the life boats.

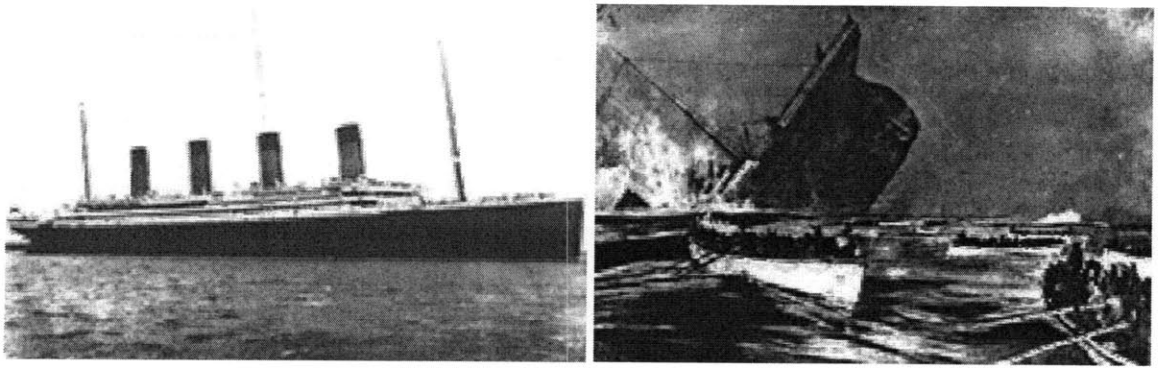


Fig. 3.3-1: The *Titanic* [Deitz 1998]

Another famous examples is the tragic rupture of a molasses tank in 1919 in Boston which resulted in 12 deaths and 40 injuries [Shank 1953, Love 1944, NHML 2004]. Half a century later, it was determined that as with the *Titanic* and the Liberty Ships, the steel was below the ductile/brittle transition temperature [NHML 2004].

1920s

In 1920, Griffith modified the equations of Inglis and applied the first law of Thermodynamics to formulate a theory based on an energy balance [Griffith, 1920]. Fracture occurs when the strain energy change due to an increment of crack growth exceeds the material surface energy. The theory correctly predicted fracture in glass specimens but was only valid for "ideally brittle materials".

1930s

Dislocation theory which explained how metals deform at the crack tip started in the early 1930s and was a hot topic in the 1950s [NHML 2004]. They are the primary reason why materials fail at stresses much lower than those predicted using inter-atomic force arguments – something which troubled engineers for centuries. In 1938, Westergaard developed a technique for analyzing stresses and strains at the crack tip [Westergaard 1939].

1940s

The Liberty ships were the reason why fracture mechanics became an engineering discipline. They were supplied by the U.S. to Britain during WW2 under the Lend-Lease Act. The Nazis were sinking British cargo ships at three times the replacement rate so the famous construction engineer, Henry Kaiser developed a revolutionary procedure to increase the fabrication speed. 37 shipyards produced 5,777 ships (2708 Liberty ships) totaling 56million DWT between 1939 and 1946 [Kobayashi and Onoue 1943]. Under another account, the Kaiser program produced 2580 liberty ships, 414 Victory Ships and 530 T2 Tankers [TWI 2000].

T2 tankers were being produced at an average time of about 70 days [Wright 2005]. In November 1942, the Liberty ship Robert E Peary was launched only 4 days and 15 hours after keel laying as a propaganda effort to show that ships could be built faster than they

were destroyed [Thompson 2001]. Fig. 3.3-2 shows a plot of the days from keel laying to delivery for keel-laying dates of Liberty ships between Jan-41 and Nov-44.

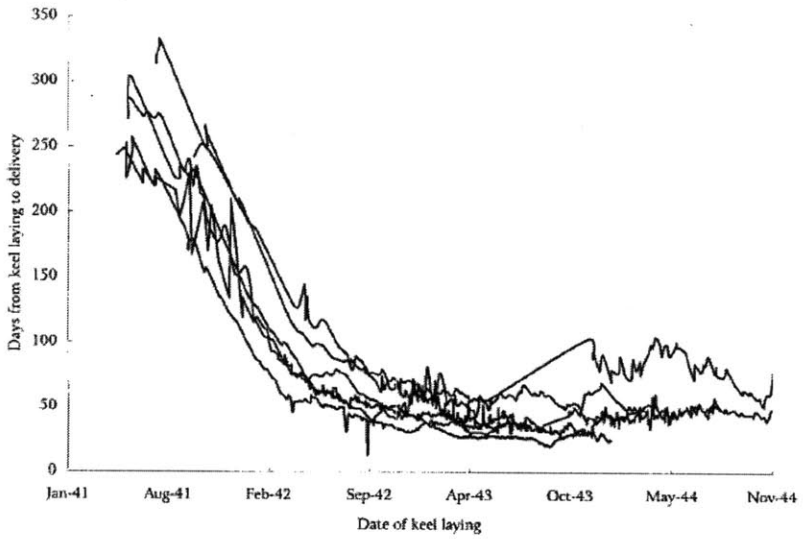


Fig. 3.3-2: Liberty Ship Construction Time of Shipyards [Thompson 2001]

They were considered a great success until they started breaking in two. One of the most tragic failures was the T2 tanker *Schenectady* in Jan 1943 in Portland, Oregon. This was one of at least 9 T-2 tankers that broke in two between 1942 and 1952 [Barsom & Rolfe 1987]. The failure was due to poor weld quality combined with stress concentration at a water temperature of 4degC and air temperature of -3 degC [Hayes 1996]. The ship was only 24 hours old and even though 8 Liberty ships had fractured earlier, this attracted the most attention because it was in full view of the population of a major city [Thompson 2001]. This showed the importance of fracture toughness which marked the birth of fracture mechanics [Kobayashi and Onoue 1943].

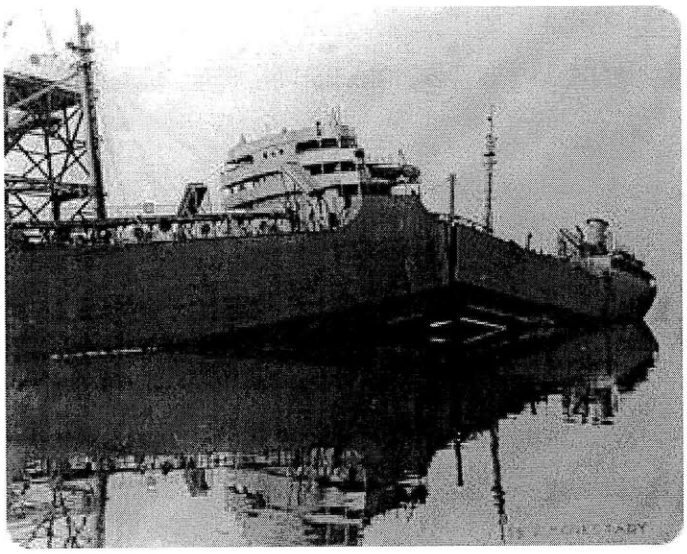


Fig. 3.3-3: *Schenectady* T2 Tanker Failure [TWI 2000]

1031 damages or accidents due to brittle fracture on Liberty ships were reported by April 1st 1946 and more than 200 Liberty ships were sank or damaged beyond repair [Kobayashi and Onoue 1943]. Under another account, of the 2751 liberty ships built during WWII, about 400 had brittle fractures of which 145 were catastrophic failures [Banks-Sills 2003]. 19 ships broke completely in two but fractures often occurred luckily before the ships were floated [NHML 2004]. Reasons were the ~600,000 feet of welded joints [Statistics and Reports Unit 1944] on each ship which were made by semi-skilled workers, stress concentrations at hatch corners and the low toughness steel that was being used. Welded construction did not provide crack arrest sites where a fracture would terminate. Steel, however, was not a problem in the riveted Canadian Liberty ships.

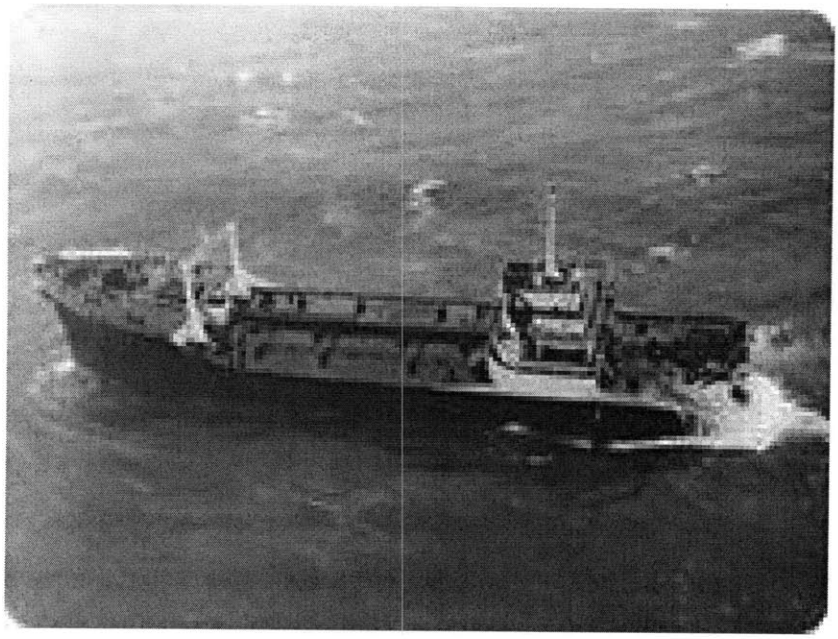


Fig. 3.3-4: Liberty Failure [Cambridge, 2000]

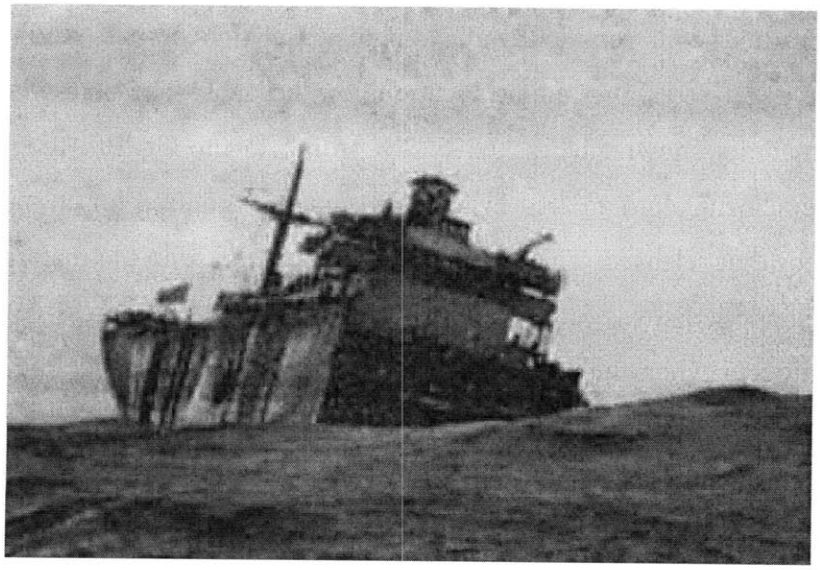


Fig. 3.3-5: Liberty *John P Gaines* [Wright 2005]

[Thompson 2001] showed that the quality of Liberty ships (in terms of fracture occurrences) declines with labor productivity and production speed. This is an important lesson we learnt from these ships.

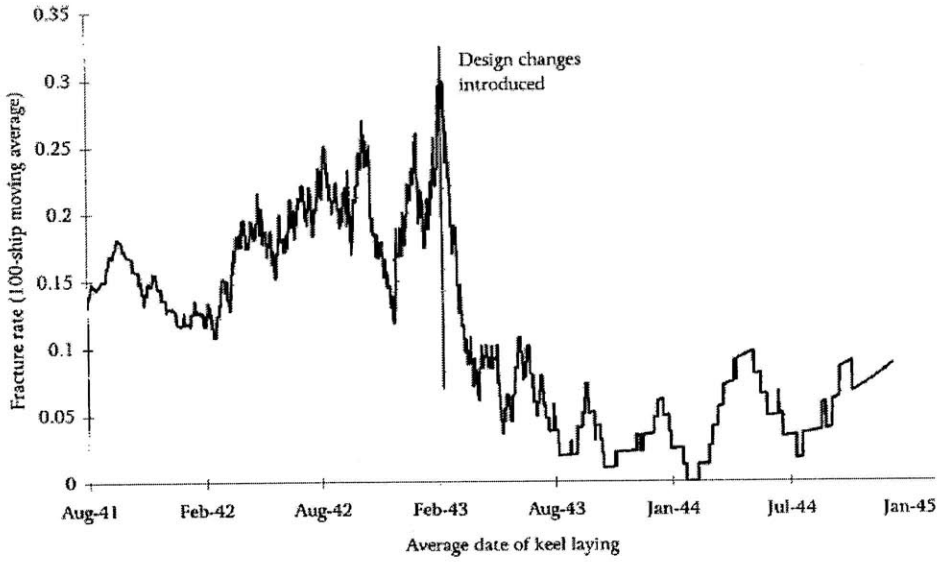


Fig. 3.3-6: Fracture rate (100-ship average) vs. Average Date of Keel Laying [Thompson 2001]

Following these failures, square cut-outs in the sheer strake were removed and the ships were retrofitted with rounded and strengthened hatch corners and high toughness riveted crack arrester plates at strategic locations on the deck. The date when these design changes were made is shown in Fig. 3.3-6. According to the Griffith theory, crack arrest occurs when a crack runs into an area in which the energy required for an incremental crack extension exceeds that released. This may be due to an increase in the material toughness or a decrease in the applied stress (e.g. if a tensile stress becomes compressive). Alternatively, crack arrest can occur when the crack reaches the end of a plate (hence the riveted arrester plates). As a result of the design modifications, many of the ships, which were initially designed to last for a single voyage (until they were sunk by the Nazis), were in service up until the 1970s. Two of those ships were still afloat in 2000 [TWI 2000, Wright 2005]

Fracture mechanics, as we know it today was born from studies associated with the Liberty ships over the next few years after WW II. Constance Tipper investigated the Liberty ship failures and demonstrated the temperature below which the steel turns brittle. She wrote a book titled "The Brittle Fracture Story" published in 1962 and developed the "Tipper Test" for determining brittleness in steel [Cambridge, 2000]. She laid the foundation for studying the effect of low temperatures on steel.

All the WW2 ship failures occurred at temperatures below 15degC(60F) and steel was improved by adjusting the C-Mn ratio to decrease the Nil Ductility Temperature (NDT) by about 20degC(30F) [Pellini 1986]. A lot of work has been done in the area since then and the toughness of steels has improved a lot. The NDT+Δt procedure for fracture arrest design (using fracture arrest properties at Δt above the NDT) was first applied to naval structures in 1955 and there are no cases of brittle fracture in structures that were conservatively designed on this basis [Pellini 1986]. Crack arrestability is still an important topic that is being researched for application in ships [Inoue et al 2007]. Even today however, there are occasionally brittle fractures due to low temperatures. An example is the 21.5foot crack on the side shell of the "Lake Carling" which occurred in the Gulf at St Lawrence in 2002 at a water temperature of 0 degC and air temperature of 06degC [Drouin 2006].

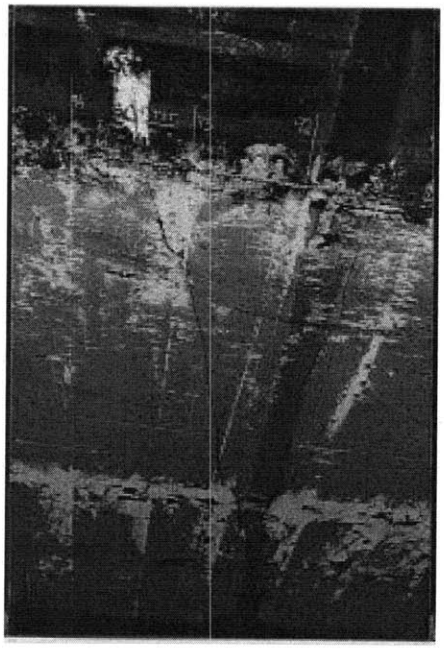


Fig. 3.3-7: Stress Fracture on the bulker Lake Carling [Professional Mariner 2004]

Another famous fracture of the 1940s was that of the Cleveland LNG storage tank which destroyed 79 houses, 2 factories and 217 cars while heavily damaging a further 35 houses and 13 factories totaling $6m to $7m in 1944. The failure was from a crack starting at a weld defect, which grew due to the vibration of passing trains [Eischen 2008]

Following the war, [Irwin 1948] and [Orowan 1948] independently extended the work of Griffith and Inglis to metals by including the energy dissipated by local plastic flow while [Mott 1948] extended the theory to rapidly propagating cracks. The electron microscope also came from RCA in 1948 allowing us to see what was happening [NHML 2004].

1950s - LEFM

After the Liberty ship disaster, at least 4 ships split in two between 1945 and 1956 [Hodgson et al 1958] including two young cargo ships and a tanker between 1951 and 1953 [Barsom & Rolfe 1987] and the tanker *World Concord* in 1954. The first jet powered pressurized passenger plane, the 1952 DeHavilland Comet airplane, was also a fracture disaster of the 1950s (due to fatigue). Three aircraft suffered in–flight breakup due to fatigue cracks near stress risers at window openings [Eischen 2008, Bishop 1955]

In 1956, [Irwin 1956] developed the strain energy release rate concept stemming from Griffith's theory. He then used Westergaard's technique from the 1930s, to describe the stress-strain field at the crack tip by the stress intensity factor, which is related to the strain energy release rate via the Young's modulus and Poison's ratio [Irwin 1957]. This was the beginning of Linear Elastic Fracture Mechanics (LEFM). At around the same time, [Williams 1957] also arrived at the same crack tip solutions and stress intensity factor via a different approach.

Energy Criterion

$$G = -\frac{\partial \Pi}{\partial a} \tag{3.3-1}$$

$$\Pi = \int_V W dV - \int_S T_i u_i dS \tag{3.3-2}$$

For an crack of length 2a in an infinite plate:

$$G_c = \frac{\pi \sigma_c^{\,2} a}{E} \tag{3.3-3}$$

Fracture occurs when: $G = G_c$. Rearranging, we can see that:

$$\sigma_c \sim \frac{1}{\sqrt{a}} \tag{3.3-4}$$

Where: G: strain energy release rate (change in potential energy with crack area)

Π: Potential Energy

α: Crack Length (of half crack length for a center crack)

W: Strain Energy Density

V: Volume

T: Traction

u: displacement vector

S: Surface

σ: Applied Stress

E: Young's Modulus

G_c : Critical energy release rate of the material

Stress Intensity Approach

Even though the stress range, mean stress, stress ratio and amount of damage are the main parameters contributing to crack growth [Schijve 2001, Blake 1996, Broek 1986, Chell 1979], as Irwin concluded, all the stress components around the crack tip are proportional to the stress intensity factor K. At the crack tip K is given by:

$$K = F\sigma\sqrt{\pi a} \tag{3.3-5}$$

Where F is a correction factor and σ is the crack opening stress. Fracture occurs when K is equal to the fracture toughness of the material $K = K_C$. The correction factor F can be decomposed into particular factors as follows [Zettlemoyer and Fisher 1978]:

$$F = F_e * F_s * F_w * F_g * F_t \tag{3.3-6}$$

Where: F_e: Joint Geometry Factor

F_s: Front Free Surface Correction (accounts for the load distribution on the crack surface where stress is zero on the free boundary)

F_w: Back Free Correction (accounts for the free surface ahead of the crack)

F_g: Stress Gradient (accounts for non-uniform applied stress e.g. in bending)

F_t: Finite Thickness Factor (applies to surface cracks) [Albrecht & Yamada 1977]

Another form of the equation which makes explicit differentiation between membrane and bending stresses is:

$$K = \sqrt{\pi a}\left(\sigma_m Y_m M_{k,m} + \sigma_b Y_b M_{k,b}\right) \tag{3.3-7}$$

Where the Y's are geometry factors and the M_k's are correction factors for the stress concentration due to the weld profile [Shine and Nair 2008]. For Simple crack geometries, K is given by the expressions presented in Fig. 3.3-8.

Type of Crack	Stress Intensity Factor, K_I
Center crack, length $2a$, in an infinite plate	$\sigma_\infty \sqrt{\pi a}$
Edge crack, length a, in a semi-infinite plate	$1.12\ \sigma_\infty \sqrt{\pi a}$
Central penny-shaped crack, radius a, in in infinite body	$2\ \sigma_\infty \sqrt{\frac{a}{\pi}}$
Center crack, length $2a$ in plate of width W	$\sigma_\infty \sqrt{W \tan\left(\frac{\pi a}{W}\right)}$
2 symmetrical edge cracks, each length a, in plate of total width W	$\sigma_\infty \sqrt{W\left[\tan\left(\frac{\pi a}{W}\right) + 0.1 \sin\left(\frac{2\pi a}{W}\right)\right]}$

Fig. 3.3-8: Stress Intensity Factors for Common Geometries [Roylance 2001]

Factors that can lower the fracture toughness of the material include intergranular fractures, quench-age embrittlement, blue brittleness, temper embrittlement, intermetallic compound embrittlement, hydrogen embrittlement and order-disorder reactions [NHML 2004].

A ductile fracture can be distinguished from a brittle fracture by examining the cracked surfaces. Ductile fracture is slow and stable and involves extensive plastic deformation whereas brittle fracture is characterized by very rapid, unstable crack growth with almost no plastic deformation.

There are 3 modes of fracture as shown in Fig. 3.3-9. The mode is usually noted by K subscript I, II or III. Mode I is the crack opening mode, mode II is the shearing mode and mode III is the out of plane shear or tearing mode. We are primarily concerned with mode I fracture as it is the most severe.

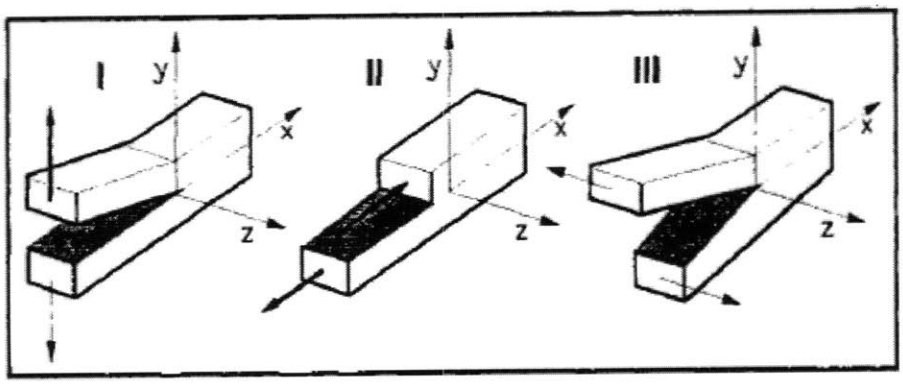


Fig. 3.3-9: The Three Fracture Modes [Kozak 2002]

For a center crack of length 2a in an infinite plate under mode 1, the parameter Y is equal to 1, yielding:

$$G = \frac{K^2}{E} \text{ and } G_C = \frac{K_C{}^2}{E} \tag{3.3-8}$$

In other words, the strain energy and stress intensity approaches are equivalent. The corresponding equation under plane strain is

$$G_C = \frac{K_C{}^2}{E\left(1-\nu^2\right)}. \tag{3.3-9}$$

Paris-Erdogan Law

The late 1950s was a difficult time period as research in fracture mechanics was openly discouraged and design engineers were not ready to replace their cumulative damage approach. Paris and his co-workers found it difficult to publish their work at first in 1959 [Paris et al 1961, Paris and Sih 1965]. The Paris-Erdogan law is as follows:

$$\frac{\partial a}{\partial N} = A\Delta K^n \quad \text{[Paris and Erdogan 1963]} \qquad (3.3\text{-}10)$$

Where N is the number of stress cycles and A and n are material constants (which may vary with medium (e.g. salt water) and with time.

This can be integrated from the initial crack length to give the final crack length or the number of cycles to failure:

$$N_f = \int_{a_0}^{a_c} \frac{da}{A\Delta K^n}, \qquad (3.3\text{-}11)$$

where the critical crack length is obtained from the fracture toughness:

$$a_c = \frac{1}{\pi}\left[\frac{K_c}{Y\sigma}\right]^2 \qquad (3.3\text{-}12)$$

There is a threshold ΔK_{th} below which cracks will not propagate, and fast fracture will occur at K_c. So $\frac{\partial a}{\partial N}$ must approach zero as ΔK approaches ΔK_{th} and must shoot to infinity when $\Delta K = (1\text{-}R)\, K_c$ where R is the stress ratio. The Paris-Erdogan law can be written as:

$$\frac{\partial a}{\partial N} = A\Delta K^n \left(\frac{\Delta K - \Delta K_{th}}{(1-R)K_c - \Delta K}\right) \quad \text{[Liu 1998].} \qquad (3.3\text{-}12)$$

1960s - EPFM

Linear elastic fracture mechanics is not valid when significant plastic yielding precedes fracture. It assumes that the plastic zone occurring at the crack tip is too small to significantly affect the stress distribution. Research was carried out to account for plasticity at the crack tip by [Irwin 1961] who proposed a simple extension of LEFM introducing the effective stress intensity factor (including the plastic zone) K_{eff}, by [Dugdale 1962] and [Barenblatt 1962] with new models and by Wells who developed the Crack Tip Opening Displacement approach (CTOD) to account for significant plasticity. Fracture occurs when $\delta = \delta_c$ where δ is the opening of crack surfaces where they are intersected by 45° lines from the tip, and δ_c is the critical crack tip opening displacement.

In 1968, [Rice 1968] developed the J Integral which expresses the non-linear (plastic) energy release rate evaluated along an arbitrary contour around the crack tip. Eshelby had already published conservation integrals including one equivalent to the J Integral but did not apply them to cracks. Soon after, Hutchinson, Rice and Rosengren related the J integral to the crack tip stress fields in nonlinear materials allowing J to be used both as a nonlinear stress intensity parameter as well as an energy release rate [Hutchinson 1968, Rice and Rosengren 1968]. Since then, the M integral has also been developed for mixed modes and interface cracks. The J integral is given by:

$$J = \int_{\Gamma} W dy + T_i \frac{\partial u_i}{\partial x} ds \qquad (3.3\text{-}13)$$

Γ: a path independent contour enclosing the crack tip
s: the distance along Γ

Once J is evaluated, K can easily be determined from its elastic component and is then usually quoted as K_{JIC}. Under pure mode I loading:

$$K_{JIC} = \sqrt{J_e E'} \qquad (3.3\text{-}14)$$

In 1962, the Kings Bridge in Melbourne failed at brittle fracture at 40F and in December 15th 1967, the Pleasant Bridge at Point Pleasant, West Virginia fractured unexpectedly claiming 46 lives [Barsom & Rolfe 1987]. A series of other brittle fractures of steel bridges have occurred since then [Fisher 1984]. [Boyd 1969] describes 10 brittle ship failures that occurred between 1960 and 1965.

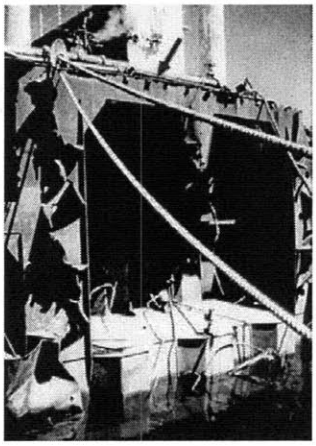


Fig. 3.3-10: The 29,000 Liberian Tanker ***SS Bridgewater*** broke in two in early 1962 [Wright 2005]

1970s

In January 1972, the 584ft tank barge *I.O.S. 3301* and the 1-year old ship *Martha R Ingram* involved broke almost completely in half while in port at calm seas [MCR 1974]. In 1979, the six year old tanker *Kurdistan* broke in two while sailing in the North Atlantic, full details of which can be found in [HMSO 1982, Corlett et al 1987]. The warm oil inside and cold water outside resulted in high thermal stresses and the crack initiated from a stress concentration at an improperly welded bilge keel. In the same year in Chicago, there was an AA DC-10 crash with 271 deaths after an engine pylon fracture [Eischen 2008].

Design analysis based on J integrals became possible after the Electric Power Research Institute (EPRI) published a fracture design handbook based on a methodology of Hutchinson and Shih developed in 1976 [Shih and Hutchinson 1976, Kumar et al 1981]. Shih related the US J integral to the UK CTOD, showing that both are equally valid [Shih 1981]. Both are used today. Research using finite elements also took off in the 1970s with the

advent of computers. Special crack tip elements were developed. Examples of quarter point elements include quadrilateral elements by Henshell and Shaw in 1975 and triangular elements by Barsoum in 1974 and 1976. Others include the eight noded isoparametric element and the square root singular element developed by Banks-Sills and Bortman in 1984 [Banks-Sills 2003].

1980s and Onwards

One of the most notable fractures of the century was the Aloha Airline stress fracture in April 28th 1988 where one third of the roof was lost at 24,000 feet altitude. Failure was caused by fatigue under a corrosive environment after 19 years in service [Bastawros 2006, Banks-Sills 2003, Roylance 2001].

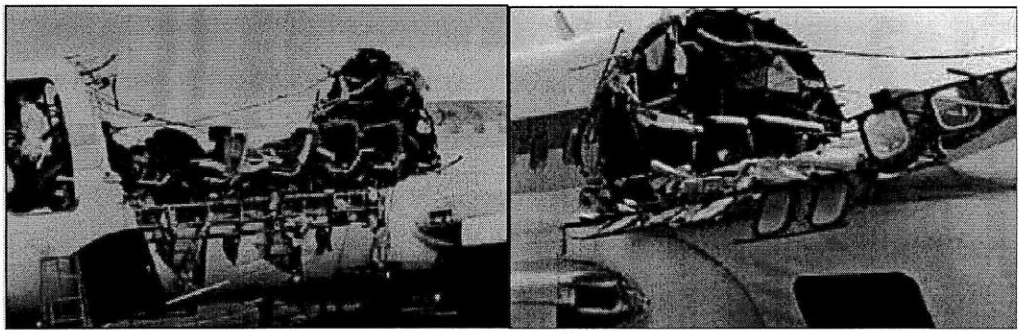


Fig. 3.3-11: Aloha Airline Stress Fracture [airdisaster.com 2009]

Other 1980s aircraft fracture disasters include the 1989 United Sioux city crash (due to a hard phase inclusion) [Bastawros 2006] and the 1985 JAL B-747 crash in Japan with over 500 fatalities due to aft pressure bulkhead fatigue [Eischen 2008].

Most work since the 1980s has been incremental. There has been focus on composites and ceramics, dynamic fracture, fracture of thin films and interfaces, molecular simulations etc. Sophisticated models have been developed for material behavior, incorporating time dependent nonlinear behavior, such as viscoelasticity and viscoplasticity, and others to relate local and global fracture material behavior. Along these lines, influence

functions are promising in predicting fatigue life. This may solve many problems if proven to be reliable. The concept is:

$$\sigma_L = A\sigma_A + B\sigma_B \qquad (3.3\text{-}15)$$

Where: σ_L = a local stress in a critical area which is to be determined

σ_A, σ_B = stresses or other measurements at two convenient locations

A, B = Influence Functions

Similarly to stress concentration factors, Influence Functions can be used to obtain the effect of Global actions such as longitudinal stresses on the deck, on a critical area which may not be accessible for measurements. [Braidwood et al 1998, Braidwood et al 1997] have carried out research showing how well influence functions can predict fatigue life of typical components using response amplitude operators from finite element modeling along with fatigue analysis programs.

Today, interest in fracture mechanics for ships is low because brittle fractures have become rare, following steady design and steel improvements since the Liberties. Brittle fracture casualty rates have decreased from one in ten ship-years in the 1940s to about one in ten thousand ship-years [Sumpter and Kent 2006]. This trend is directly linked to the increase in toughness of the basic (grade A) shipbuilding steel [Sumpter and Kent 2004]. Some notable recent examples of ships splitting in two include the *Corazon* in 1990 [NK 1992], *Mineral Diamond* in 1991, *Karadeniz S* in 1992 *Flare* in 1998, *Lassia* in 1999 and *Selendang Ayu* on December 2004.

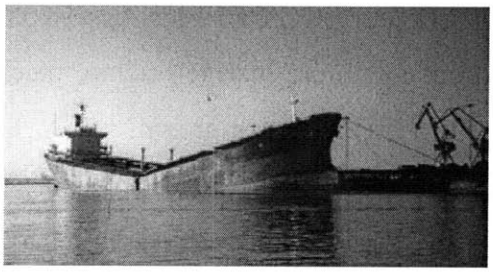


Fig. 3.3-12: OBO *Lassia* during discharge in Italy

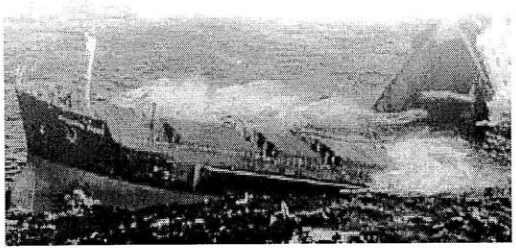


Fig. 3.3-13: Sinking after Brittle Fracture [ABS 1999]

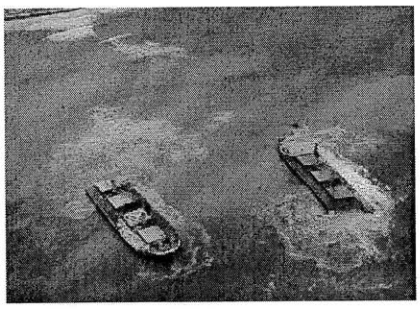


Fig. 3.3-14: The PMX *Selendang Ayu* on Dec 9th 2004, by United States Coast Guard (USCG) [ENS 2009]

Most classification societies prefer cumulative damage methods in designing their rules. Their fracture control strategy relies on Charpy energy indices. They require repair of all identified cracks immediately, which is often too conservative and expensive. A more rigorous analysis could show that the repair of some cracks can safely be delayed until the next scheduled dry dock. Progress towards developing a crack management approach has been made by [Kent and Sumpter 2006]. Major shortcomings of the linear damage accumulation approach include the neglect of loading sequence and crack blunting, the effect of the surrounding structure and stress redistribution, and the lack of distinct qualitative differences on the basis of damage ratio. A notable exception of fracture mechanics in ships is the *Leak Before Break* criterion of LNG Carrier tanks [Kokarakis and Taylor 2009]

Research is carried out for future marine fracture mechanics application. The Paris-Erdogan law is widely used to predict crack growth in a wide range of structures. Studies based on lab tests are carried out on ship building steel specimens for the purpose of calibrating the constants of the Paris-Erdogan law in order to be used in the design of ship structures [Shine and Nair 2008]. Some, however, have found it to be conservative in

complicated structures like ships. Forman, Newman and de Konig developed the FNK (or ESACRACK) equation which is applied by [Shehu et al 2006] on shipbuilding steel:

$$\frac{da}{dN} = C\left[\left(\frac{1-f}{1-R}\right)\Delta K\right]^n \frac{\left(1-\frac{\Delta K_{th}}{\Delta K}\right)^p}{\left(1-\frac{K_{\max}}{K_c}\right)^q} \tag{3.3-16}$$

Where: f: Crack opening function: $f = A_0 + A_1 R + A_2 R^2 + A_3 R^3$ (3.3-17)

A_0, A_1, A_2, A_3: functions of material properties and the peak stress

K_{max}: Maximum stress Intensity Factor

C, p, q, n: Empirical Constants

Some materials exhibit a very small stress ratio effect and the effect of crack closure can be neglected. The equation can then be reduced to the following expression:

$$\frac{da}{dN} = C\left[\Delta K\right]^n \frac{\left(1-\frac{\Delta K_{th}}{\Delta K}\right)^p}{\left(1-\frac{K_{\max}}{K_c}\right)^q} \tag{3.3-18}$$

From this form, it can be seen that setting the parameters p and q to zero, we get the Paris-Erdogan Law. The modified Forman crack growth Eq. 3.3-19 [Forman 1986], , has been applied by [Kokarakis and Taylor 2009] in Bureau Veritas (BV) to structural details for developing a fracture mechanics based ship design method.

$$\frac{da}{dN} = C\left[\Delta K\right]^n \frac{\left(\Delta K - (1-2R/3)\Delta K_{th}\right)^p}{\left((1-R)K_c - \Delta K\right)^q} \tag{3.3-19}$$

Some have also tried to combine the S-N curve approach with fracture mechanics to carry out fatigue assessment of cracked ships [Xu & Bea 1998]

Summary

Fracture mechanics has been of great interest to engineers for many centuries. Research in the field had been carried out as early as the 15th century by Leonardo da Vinci but we only had a quantified understanding after the works of Charpy, Inglis and Griffith at the beginning of the 20th century. It really became an engineering discipline after the Liberty ship failures in WW2. The particular ship which signaled its birth was the T2 Tanker Schenectady. We have learnt a lot since then but ships have continued to break in two in some rare circumstances. Today, fracture mechanics has limited application in ships as engineers tend to favor a more conservative approach and the use of the simpler cumulative damage rules. Fracture mechanics can potentially be much more accurate than these cumulative damage models and research is currently being carried out for increased application in ships.

3.4 Recent Research in Aircraft Fatigue

A significant amount of research has been carried out on fatigue and fracture in aircraft. Recent research has primarily been focused on predicting and improving fatigue strength and fatigue life; predicting crack initiation, propagation (trajectories and growth rates) and effects on structural integrity; developing new designs and materials; performance of adhesives; and non-destructive testing (NDT).

Fatigue life prediction is carried out primarily using cumulative damage models, such as Palmgren-Miner Damage Summation [Wu et al 2008] and Wohler Curves (S-N curves) with Miner's rule [Braccesi et al 2008]. [Aruajo et al 2008] predict fatigue strength using the theory of critical distances, the hot spot approach and Modified Wohler Curves (MWC). Methods have also been developed for estimating the cumulative fatigue damage based on surface deformation near the stress concentration [Karuskevich et al 2008] and using the inverse power law [Allegri & Zhang 2008]. A new damage parameter has also recently been introduced, based on the maximum strain on the critical plane [Sun et al 2008].

Besides damage accumulation models, crack growth models, based on stress concentrations and energy criteria [Fomichev 2008], are also widely used. Paris Law is often applied and experiments are carried out to determine the required material properties "A", "n" and fracture toughness K_c of various alloys [Farahmand & Nikbin 2008]. Stress intensity factors are calculated using Boundary Element Methods (BEM) [Yang & Mall 2008] or 3-D finite elements [Srikant & Arakere 2008] while [Ren & Lu 2008] uses FEA to calculate stress intensity factors for the case of three-dimensional cracks.

Crack growth rates and trajectories have also been studied using FEA and experimental methods. Finite element modeling is used to predict crack growth rates and direction [Srikant &Arakere 2008] and to examine crack closure due to repeated overloads [Singh et al 2008]. Experimental methods have been applied to measure crack growth rates under different stress concentrations [Huynh et al 2008], while crack trajectories have been examined with respect to material orientation and loading mode [Hosseini-Toudeshky et al 2008].

Crack initiation has been studied experimentally by [Rashed et al 2008], with regards to the stress-strain state by [Hurley et al 2008] or by assuming that it follows a Weibull or Log-Normal distribution by [He et al 2008], who also consider the effects of corrosion.

Other common approaches to determining fatigue life include the application of Coffin-Manson Law for thermal cyclic fatigue, Basquin's equation $t \sim (\Delta\sigma)^{\alpha}$ and the Ramberg-Osgood relation:

$$\varepsilon = \frac{\sigma}{E} + k\left(\frac{\sigma}{E}\right)^{n} \quad \text{[Begum et al 2008]} \qquad (3.4\text{-}1)$$

New ways of evaluating the Manson-Coffin-Basquin and Ramberg-Osgood equations have also been developed [Niesloni et al 2008]. Finally, some employ a probabilistic approach on life distribution, based on the Monte-Carlo technique [Liao et al 2008a].

Understanding and quantifying the effects of several parameters on the fatigue strength and fatigue life has been the focus of several recent papers for various materials, alloys and composites. Examined parameters include temperature [Harbour et al 2008] (also specifically on titanium alloys [Majidi 2008] and on composites [Shimokawa et al 2008]), corrosion [Bian et al 2008], environmental effects [Ruggles-Wrenn et al 2008], grain size [Tsushida et al 2008], loading frequency [Ruggles-Wrenn et al 2008], load sequence [Matikas et al 2008], fiber properties, component shape and size, crack orientation, coating, geometric effects such as weld toe radius [Nykanen et al 2009] etc. The effect of interacting surface cracks has been studied experimentally and using FEA [Kamaya 2008a, Kamaya 2008b]. Analysis has also been done under various loading conditions including oblique, dynamic, random and static loads, high and low cycle fatigue, repeated overloads and creep fatigue.

Various methods have been examined for increasing fatigue resistance and extending fatigue life. These include heat treatments [Deodati et al 2009], bake hardening [Robertson et al 2008], pre-straining [Robertson et al 2008, Park et al 2009, Froustey and Lataillade 2008], shot peening [Oguri et al 2008], ultrasonic impact treatment [Liao et al 2008b], improved adhesive bonding and replacing mechanical fasteners with adhesives [Kwakernaak &

Hofstede 2008]. To aid these attempts, studies have also focused specifically on the crack resistance of adhesives [Levesque & Arakere 2008] and the impact resistance of adhesives [Silberschmidt et al 2008] and coatings [Bouzakis et al 2008].

The effect of crack propagation on the structure has been studied with regard to shaft deflections [Bachschmid et al 2008] and structural stiffness [Gaidai et al 2008], while work on NDT and fatigue monitoring has been carried out [Safizadeh et al 2008, Aubele & Keown 2008]. A new NDT technique based on linear acoustics has also recently been developed [Matikas et al 2008].

A significant portion of the work is focused on material developments and understanding. This includes the development of stronger and lighter composites [Zwaban 2008] as well as research on fatigue and crack propagation in various alloys [Xu et al 2008, Fadag et al 2008, Underhill & Duquesnay 2008]. Research has been carried out to optimize the number of experiments required for alloy characterization [Farahmand & Nikbin 2008].

3.5 Crack Growth Mechanisms

3.5.1 Overview

Cracks in ships develop and propagate mainly due to corrosion or fatigue. Corrosion cracks manifest by the mechanism of stress corrosion cracking, while the structure is fatigued by alternate loading due to sea waves and cargo operations with rates of up to 18,000t/hr. Overstressing of the hull during loading and damage often caused during discharging may further intensify the problem.

Cracks may initiate in gas cut notches, at geometrical discontinuities, in defects, or in other high stress concentration sites which often arise due to poor design. Defects are very common in welds, of which there are several miles on a cape. Cracks also often occur during repairs, when steel plates are welded at a 90 degree angle to the direction is which they have been hardened. This typically occurs in regions of large surface area, such as deck plates, the tank top, the shell plate, hoppers, sloping plates, bulk heads etc.

Cracks can also occur through careless handling, for example by the impact of excavators during discharge or as iron ore strikes the tank top plate during loading. These and other factors may result in denting and the formation of high stress concentration sites which give rise to cracks.

Cracks tend to propagate along preferred paths such as along the grooves parallel to the weld seams because of the lower thickness of the material. This is because contraction on cooling locks in high residual tensile stresses along the weld line. The preferred crack path generally depends on the material, geometrical considerations such as the thickness and the mode of loading i.e. the direction of stresses relative to the crack.

A number of criteria have been developed to predict the crack path when subjected to mixed mode loading. Some of the most common ones include the stress based criterion which predicts crack propagation in the direction of the maximum hoop stress, the critical shear stress criterion (propagation in the direction of maximum shear stress), the Griffith criterion in which the crack propagates in the direction of maximum energy release rate, and

the $k_{II} = 0$ criterion which predicts crack growth in the direction of local zero mode II loading.

The hoop stress field ahead of the crack tip is given by:

$$\sigma_\theta = \frac{K_I}{\sqrt{2\pi r}}\cos^3\left(\frac{\theta}{2}\right) + \frac{K_{II}}{\sqrt{2\pi r}}\left[-3\sin\left(\frac{\theta}{2}\right)\cos^2\left(\frac{\theta}{2}\right)\right] \qquad (3.5\text{-}1)$$

Where: K_I = mode I (crack opening mode) stress intensity factor

K_{II} = mode II (shearing mode) stress intensity factor

σ_θ = hoop stress distance r and angle θ

r = distance from crack tip

θ = angle measured anticlockwise from the crack plane.

By employing the maximum hoop stress criterion and setting $\frac{\partial \sigma_{\theta\theta}}{\partial \theta} = 0$, the crack branching angle $\hat{\theta}$ satisfies:

$$\frac{\sin\hat{\theta}}{1-3\cos\hat{\theta}} = \frac{K_{II}}{K_I} \qquad (3.5\text{-}2)$$

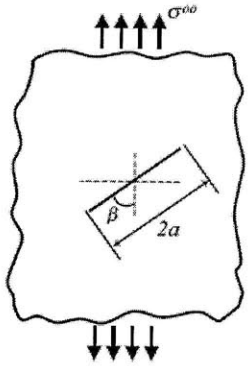
For $K_{II} \neq 0$, this results in:

$$\tan\left(\frac{\hat{\theta}}{2}\right) = \frac{1}{4}\left[\frac{K_I}{K_{II}} - \sqrt{\left(\frac{K_I}{K_{II}}\right)^2 + 8}\right] \qquad (3.5\text{-}3)$$

Using this result, the crack branching angle of an inclined crack in a plate under tension loading is given by:

$$\hat{\theta} = 2\tan^{-1}\left(\frac{\tan\beta - \sqrt{\tan^2\beta + 8}}{4}\right) \qquad (3.5\text{-}4)$$

Fig. 3.5-1 shows the crack branching angle $\hat{\theta}$ as a function of applied load angle β (both measured from the crack centerline).



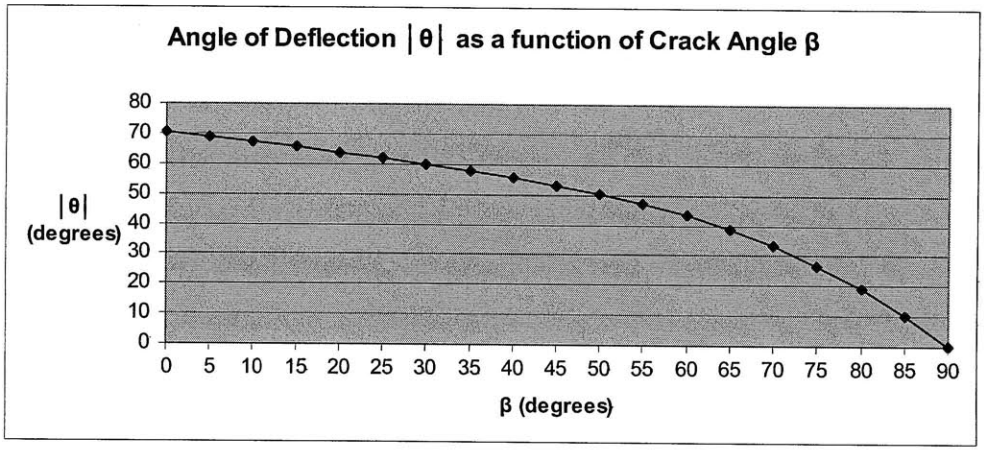


Fig. 3.5-1: Crack branching angle vs. applied load direction using the maximum σ_θ criterion

Though curved crack paths are predicted during mixed mode loading and are also observed in bi-axially loaded welded structures, fatigue life predictions in ships are based on a one dimensional crack path. A finite element model has been established in order to investigate fatigue crack growth under mixed loading conditions [Pedersen et al 1996].

3.5.2 Vulnerable Areas

The areas most vulnerable to cracks are known to be the side shell, bulk heads, longitudinal frames, hatch coamings' connections to main deck, hatch covers, welds and other stress concentration sites. Fractures tend to initiate at the beginning or the end of a weld

or a stiffener, at corners, intersections with other welds, at undercuts, or at the abrupt edges of bad quality welds. Fig. 3.5-2 shows some typical defects which occur within the cargo hold region.

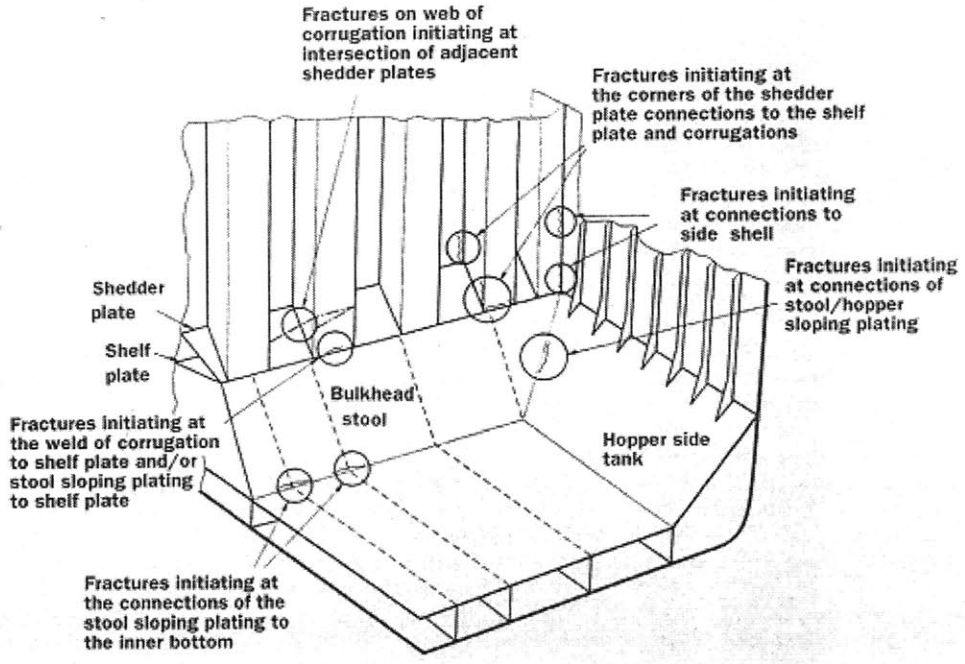


Fig. 3.5-2: Typical defects within the cargo hold region [The Motor Ship 1994]

The main frames and end brackets are also very vulnerable to cracking. A few examples are illustrated in Fig. 3.5-3.

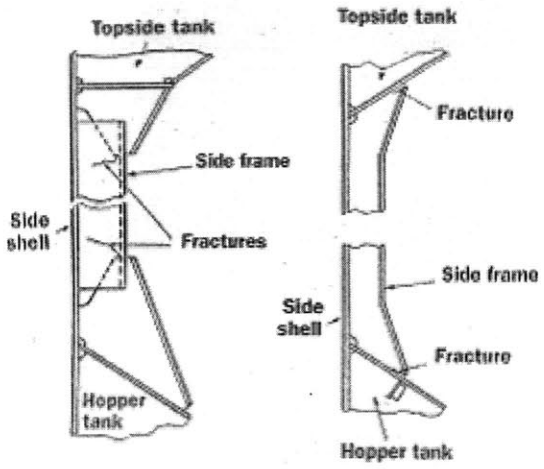


Fig. 3.5-3: Potential Problem Areas in Main Frames [The Motor Ship 1994]

It is important to realize that cracks in some locations are more dangerous than in others. This may either be because some cracks can more readily cause serious failure or because the critical stress for brittle fracture is more likely to be exceeded in certain cracks due to their location and size.

The side shell is arguably the most critical part of a bulk carrier when it comes to cracks. Apart from the static loads, it is also fatigued by the continuously changing pressure loads from the sea. Its failure may lead to immediate flooding of the hull and total loss. Fig. 3.5-4 summarizes a few of the factors which Lloyd's Register cites as contributory to bulk carrier structural failure and losses.

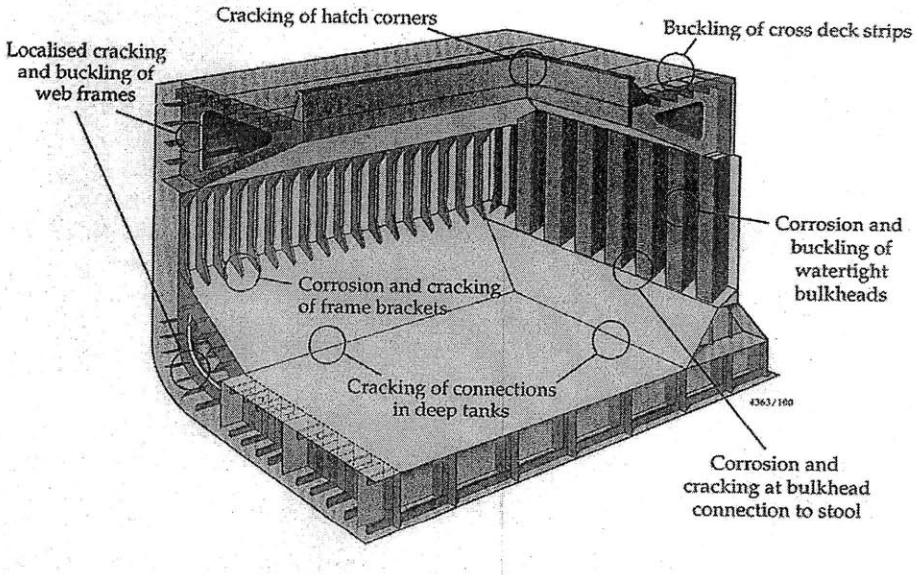


Fig. 3.5-4: Structural Failure and Loss Contributory Causes for Bulk Carriers as cited by LR [MER 1997]

3.5.3 Fatigue and Brittle Fracture

Creep is generally not a major concern in ships, so there are essentially two types of fractures, fatigue and brittle fractures.

Fatigue is a process by which cracks propagate through a structure when it is subjected under cyclic stresses that are below the yielding point. The stress cycles may be of

relatively high frequency, such as those induced by the engine or propeller vibrations, moderate frequency due to waves, or low frequency due to loading and discharging in consecutive ports.

Crack propagation can be affected by several parameters including the initial crack size and geometry, mode of loading, applied stress range, stress concentration at the crack tip, sequence of the applied stresses, history of local nominal stresses, crack retardation, crack closure, crack growth threshold etc. Crack initiation and propagation in a steel structure due to fatigue, is illustrated in Fig. 3.5-5. This is shown in conjunction with the critical crack size for fast fracture, which also varies with time. Failure occurs when the two lines intersect.

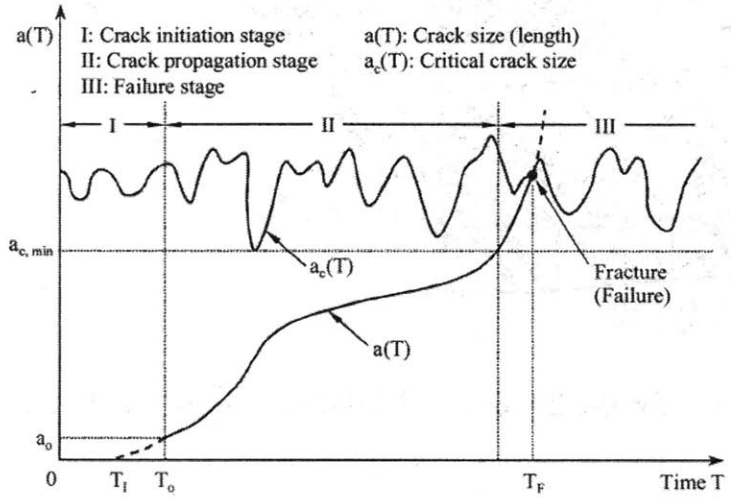


Fig. 3.5-5: Variation of crack size and crack critical size with time [Paik et al 2003b]

Brittle fracture is a failure mechanism in which a crack suddenly becomes unstable. When critical combinations of crack size α and stress σ are exceeded, fast fracture occurs, resulting in sudden catastrophic failure. This happens when the toughness of the material is exceeded.

Parameters used to quantify the toughness of the steel include the elastic-plastic crack tip parameter $J = J_c$, the strain energy release rate $G = G_c$, the crack tip opening displacement $\delta = \delta_c$ and the elastic stress intensity factor $K = K_c$. These are defined as follows:

δ = opening of crack surfaces where they are intersected by 45° lines from the tip

$$J = \oint_{\Gamma} W dy + t_i \frac{\partial u_i}{\partial x} ds \tag{3.5-5}$$

$$G = -\frac{1}{B}\frac{\partial U}{\partial a} \tag{3.5-6}$$

$$K = Y\sigma\sqrt{\pi a} \tag{3.5-7}$$

Where: Γ = path independent contour enclosing the crack tip

W = Strain energy density

t = traction vector (normal to the contour)

u = displacement

s = distance along Γ

U = potential energy

B = Specimen breadth

a = Crack size (assumed elliptical)

Y = Tabulated geometry factor (for centre crack ~1, edge crack ~1.12)

σ = Applied stress

E = Material Young's Modulus

These parameters are interrelated as follows:

Under the HRR field (J-dominance zone), $\delta = d_n \frac{J}{\sigma_y}$ (3.5-8)

For a Linear Elastic Material, $J = G = \frac{K_I^{\,2} + K_{II}^{\,2}}{E'} + \frac{K_{III}^{\,2}}{2G'}$ (3.5-9)

Where $d_n \sim 1$ for plane stress, $d_n \sim 0.5$ for plain strain

$E' = E$ for plane stress, $E' = \frac{E}{(1-\nu^2)}$ for plane strain

G' = Material Shear Modulus

Subscripts I, II & III refer to Mode I, II & III respectively.

J can be evaluated by several methods e.g. the η approach or the GE-EPRI scheme. In both cases, J is composed by elastic and a plastic component. Using the η approach for example, J is defined as follows:

$$J = J_e + J_p = \frac{\eta}{B(W'-a)}\int_0^{\Delta} P d\Delta = \frac{\eta}{B(W'-a)}A = \frac{\eta_e}{B(W'-a)}A_e + \frac{\eta_p}{B(W'-a)}A_p = \frac{K^2}{E'} + \frac{\eta_p}{B(W'-a)}A_p$$

(3.5-10)

Where: K = elastically calculated stress intensity factor (defined as above)

η = Tabulated geometry factor (For tension ~ 0.5, bending ~ 1)

W' = Specimen width (along direction of crack)

P = Load

Δ = displacement

A = area under stress/strain curve

Subscript e = elastic component

Subscript p = plastic component

The Y factor, used in the evaluation of the elastic stress intensity factor K, comprises of a crack shape factor, a crack surface factor, a finite width factor and a non-uniform stress factor [Dexter et al 2004]. The stress intensity factor K has also been tabulated for various geometry configurations and loadings [Tada 1985, Rooke et al 1976] and can also be evaluated by FEA.

The K approach is the easiest method to apply but K is only valid if plasticity is localized to the crack tip. The K dominance zone is lost near or far away from the crack tip. The near tip fields are better characterized by the HRR field (J-dominance zone) as the zone of plastic strains becomes significant. Furthermore, the HRR field will always be conservative if J-dominance is lost. Therefore, K_C is often estimated from J_C in order to account for the plasticity at the crack tip of ductile metals. Once J is evaluated, K can easily

be determined from its elastic component and is then usually quoted as K_{JIC}. Under pure mode I loading:

$$K_{JIC} = \sqrt{J_e E'} \qquad (3.5\text{-}11)$$

For ship steels, fracture toughness is controlled using "Charpy" impact tests and its value varies significantly between steels from grade A to E used in ship construction.

Factors affecting brittle fracture include the toughness of the material, the applied elastic stress intensity K loading rates, weld metal and quality, welding sequence and technique, plate thickness and microstructure etc. The toughness of the material can in turn be affected by environmental factors including temperature and the presence of hydrogen.

The elastic stress intensity applied depends on the defects present, the applied stress levels, residual stresses and stress concentrations. Residual tensile stresses in welds can be of yield stress magnitude. These are superimposed with global stresses and increase the chances of fracture in weld defects. Stress relief of welds occurs due to "shake out" during operation. It can also be applied thermally or mechanically during repairs. Heating blankets may be used for thermal stress relief. However, hammer peening (mechanical stress relief) is not so common these days. Experimental data [Torii et al 1989, Galambos 1988, Bjorhovde 1972, Tall et al 1969] suggests that the initial residual stresses in welds and rolled sections, are highly dependent on the fabrication process and can vary significantly.

Mild steel is very sensitive to strain rate. During normal operation, significant strain rates can be generated by slam impact or wave loads. The freezing point of sea water is -2degC, while the air temperature above sea level can be as low as -15degC without the sea freezing. However, operating temperatures will always be higher due to insulation from the sea on the submerged hull, and icing on the exposed hull.

The use of thicker plates in repairs to reduce stress levels may introduce less uniform properties and larger grains which promote brittle fracture. Furthermore, brittle fracture is favored by plain strain conditions (thick components). It is less likely in thinner plates for a given microstructure. Therefore, increasing thickness is not always a good practice.

Bearing these factors in mind and considering the typical conditions during normal ship operation, brittle fracture is generally not a favorable mode of failure. A storm, however,

may occasionally be encountered in which wave slamming, typically at low temperatures, results in significantly high loading rates of the hull. If in such a case large defects are present, and if the steel is of poor quality, brittle fracture may be around the corner.

Brittle fracture can either be post-yield, or true (classical). Post-yield brittle fracture is more common and results from local overloading. True brittle fracture develops from existing defects at relatively low stresses and low temperatures. In today's ships, crack arrest is probable, as a crack enters an area of low stress or residual compression, particularly during post-yield brittle fracture [Faulkner 1999].

Crack arrest occurs when the crack arrest toughness of the material K_{ca} exceeds the stress intensity generated at the tip of the propagating crack. Fig. 3.5-6 shows the static and dynamic stress intensity analysis for the Robertson test at an applied stress of 200MPa for various crack velocities as obtained by Curr and Turner.

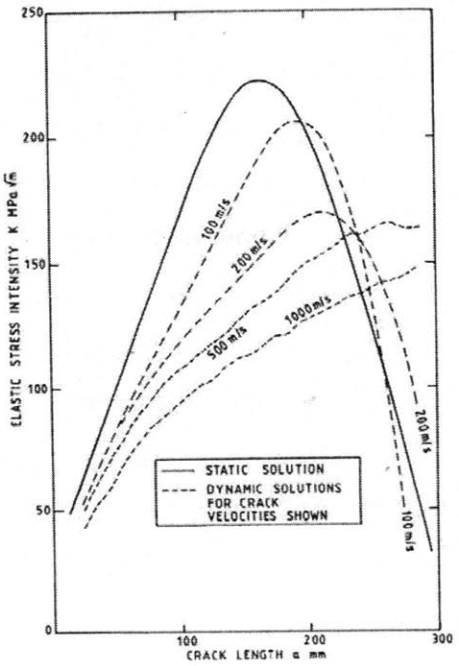


Fig. 3.5-6: Static and dynamic Stress intensity solutions for the Robertson Crack Arrest Specimen at an applied stress of 200MPa [Curr et al 1987]

Fatigue cracking is more common in ships but it is also far less dangerous than brittle fracture, which has been the cause of some of the most disastrous accidents in the history of shipping. Brittle fracture can result in propagation rates so high that a crack may propagate

across the ship beam in less than a tenth of a second [Faulkner 1999]. This has resulted in a number of ships splitting in two, including several Liberty and T2 ships around WW2, another 4 ships between 1945 and 1956 [Hodgson et al 1958] including the tanker *World Concord* in 1954, the six year old tanker *Kurdistan* in 1979 full details of which are contained in [HMSO 1982, Corlett et al 1987], the cement loaded bulker *Corazon* in 1990 [NK 1992, 2], the capes *Mineral Diamond* in 1991 and *Karadeniz S* in 1992 [2], the bulker *Flare* in 1998 or the panamax *Selendang Ayu* on December 2004.

Fatigue cracks occasionally also have the potential of ultimately leading to serious damage. An example is when a crack propagates from a frame to the outer shell and affects the watertight integrity of the hull, which can then lead to flooding and ultimately sinking, in extreme weather conditions. This, however, is rare and fatigue cracking is generally viewed as being much safer than brittle fracture. According to [Dexter et al 2000], fatigue cracks may propagate to lengths as great as 8m before the ship's structural integrity is compromised. An example where this has been demonstrated was the 15m crack which propagated across the deck of the Ro-Ro *Great Land* during a storm without brittle fracture of the section [MDTN 1998]. Fatigue cracks in some cases can even prove to be beneficial as they may serve to transfer the crack tip away from a dangerous area such as the heat affected zone, to an area less prone to brittle fracture [Nibbering et al 1970].

There are significant differences in the factors influencing the two mechanisms. Fatigue cracks, for example, usually initiate at the surface while brittle fracture can often initiate at a subsurface defect. Time is an important factor in fatigue cracks since a large number of stress cycles are required before a fatigue crack initiates, while temperature is more important in brittle fracture as it affects the ductility of the steel. The quality of steel on the other hand plays a minor role in fatigue cracking but is critical in brittle fractures [Antoniou 1977, Hollister et al 1948].

A lot of work has been carried out to investigate the effect of residual stresses, which can be of critical importance in brittle fracture, on ductile fracture and fatigue crack growth rates [Almer et al 1997, Torii et al 1989, Torii et al 1988, Bucci 1981, Formby et al 1977]. The effect of residual stresses on ship hulls has been investigated by [Osgood 1954]. The effective stress range and hence ΔK (the range of applied stress intensity factor), which

controls the crack propagation rate may be affected by residual stresses but the influence is minor compared to that over brittle fracture.

The effect of salt water on crack growth rates has also been examined [Dexter et al 1990]. It has been concluded that saltwater increases growth rate at high ΔK ranges and reduces it at low ΔK. An explanation for this could be that corrosion, which accumulates at the crack tip at low ΔK, retards crack growth. Corrosion at high ΔK weakens the structure without being able to accumulate corrosion because of the high flexing. Such environmental effects can be incorporated into the Paris-Erdogan law by adjusting the material coefficients "A" and "n".

Significant improvements in fracture resistant steels were made following the losses of the Liberty ships during and after WW2 [Barltrop et al 1992]. A lot of experience was gained from research in warship steels. The British Admiralty, whose work continued into the 1960s, played a leading role in the investigations of brittle fracture [Sumpeter et al 1988]. There has also been an increased use of crack arrest plates made from tougher steels in ship structures. Catastrophic brittle failures have become extremely rare. Therefore, we are primarily concerned with fatigue cracks.

3.5.4 Stress Corrosion Cracking

3.5.4.1 Outline of Mechanism

Stress corrosion cracking is a very common phenomenon in ships. Corrosion results in degradation and loss of structural strength locally and globally. This leads to fatigue and the development of cracks throughout the hull. Corrosion is known to bring down the fatigue threshold stress intensity K_{th}, bellow which, there is no crack growth. This means that fatigue occurs under lower stresses than those required in the absence of corrosion. The mechanism is known as *corrosion fatigue.* Corrosion can also affect material properties such as fracture toughness, making the material more susceptible to fast fracture after a crack reaches a

certain length. An example of this is through hydrogen embrittlement, a form of corrosion that leads to hydrogen cracking.

Corrosion can progress by several millimeters per year. Fig. 3.5-7 shows typical stress corrosion cracks at the repair of a capesize bulk carrier, while Fig. 3.5-8 presents a schematic diagram of the crack growth rate with respect to crack length.

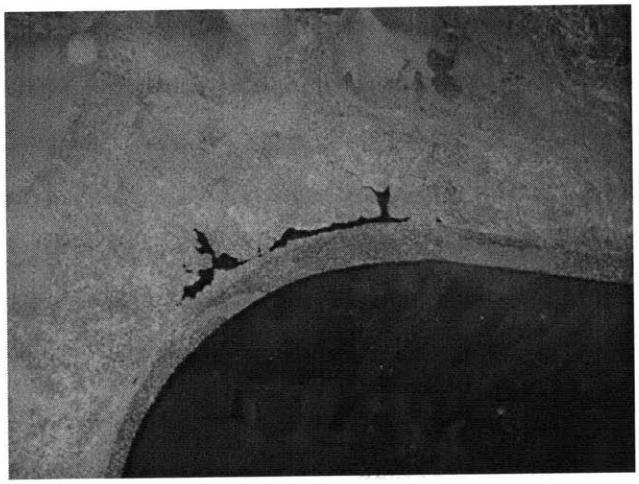


Fig. 3.5-7: Stress Corrosion Cracks at Web Frame in Top Side Tank of *Cape Cosmos* - 2006

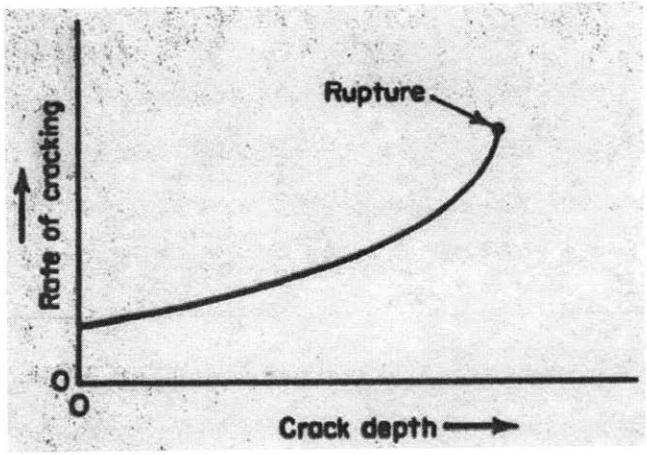


Fig. 3.5-8: Crack Growth Rate of a Stress Corrosion Crack [Fontana 1986]

While loss of material and large diameter holes are common, corrosion in the past has also resulted in deck cracks across almost the entire ship width [ABS 2001]. This has been a major contributing factor to the loss of structural integrity of bulk carriers [Tong, 1995, IACS

1984]. Statistics have shown that it is the leading cause for casualties in older ships [Harada et al 2001].

In his famous book on Corrosion Engineering in 1967, Mars G. Fontana talks about eight types of corrosion. These are "uniform attack", "crevice corrosion", "pitting", "intergranular corrosion", "selective leaching", "erosion corrosion", "stress corrosion", "hydrogen damage" [Fontana 1986]. There is significant overlap between those and they have been described under different names by various authors ever since. However, it has become a convention to describe corrosion under eight types.

Pitting corrosion, which can progress by up to 3 or 4 millimeters per year, can be resisted by high-grade alloy steels, but their use is economically unfeasible [Burton, 2004]. Careful coating, used in combination with strategically placed sacrificial anodes, is the best alternative which is generally adopted.

The process begins from coating breakdown. Corrosion starts as the metal is exposed to the atmosphere, leading to material wear and a reduction in cross section. Holes in the material may result and the structural component becomes more prone to fractures. Cracks begin to form due to the stresses acting on the corroded component.

Both corrosion and the mechanisms of coating breakdown are electrochemical in nature. Large flat sites are usually the cathodes that drive the anodic sites including welds, edges and/or sacrificial anodes. Corrosion current is focused on weak areas of non-uniformity. These areas are therefore more prone to stress-corrosion cracks.

Ballast tanks are the most vulnerable area regarding stress corrosion cracking and they are generally protected by anodes. They are vulnerable because of the harsh conditions resulting from the frequent sea water ballasting operations and because of the difficulty associated with inspection in that area.

3.5.4.2 Coating Lifetime

Unlike corrosion, there is only limited research, available in the open literature, on the modeling of coating deterioration [Murakami et al 2007]. Coating life follows a normal distribution and usually has a mean value of 5 to 10 years, with a Coefficient of Variation (CoV) of about 0.4 [Paik et al 1998c]. Fig. 3.5-9 provides an outline of the various phases during the coating lifetime in ballast tanks.

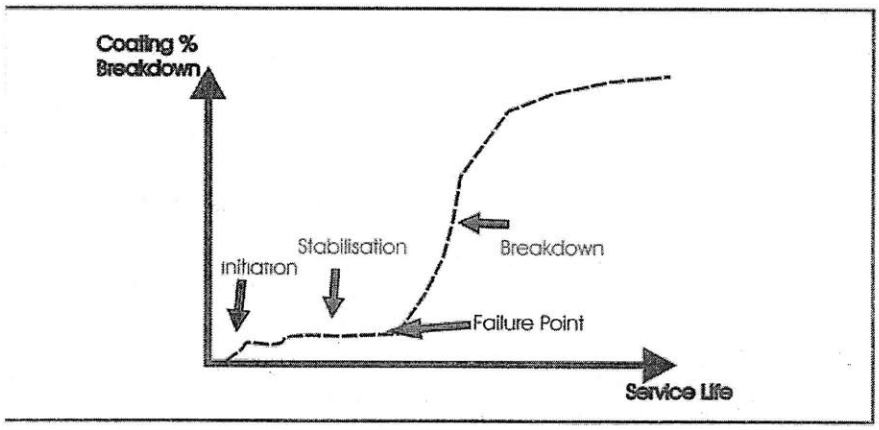


Fig. 3.5-9: Ballast Tank Coating Breakdown vs. Service Life [Callow 2004]

The coating barrier properties increase during the initiation stage which lasts between half to two and a half years. Then, they slowly decline over a number of years, during the stabilization stage, until failure. A great increase in the electrochemical loading of the ballast tank then follows and corrosion sets in.

Coating lifetime depends on several factors, including the type of coating system, the environment, damage during operation, but also very importantly, the details of its application. Humidity and salinity control during painting, the number of stripes, the film thickness and pre-surface preparation can have a significant effect. Taking an extreme case, coating over a corroded surface is no use at all, as there is nothing to stop corrosion from continuing beneath the new layer. Improper removal of the previous layer before painting is also ineffective as it leads to an abrupt surface, which is very prone to coating breakdown. Entrapment of air in the coating layer also must be prevented as much as possible. Another

determining factor in the coating lifetime is the film thickness. A film too thin may give insufficient protection but excessive thickness can also result in sagging and cracking of the coating.

Inventories made by the TNO Institute of Industrial Technology (the Netherlands), have shown that the majority of coating breakdown is caused by human error. Both repair and maintenance costs can be saved if more attention is paid during the design of painting specifications and by more rigorous inspection during coating application [Shipping World & Shipbuilder 1997c].

Fig. 3.5-10 shows the connection of a the sloping plate with the bulk head in a capesize bulk carrier. This is near the top of the cargo hold, where flexing is more pronounced, and doesn't allow a film of corrosion to accumulate and protect the base metal.

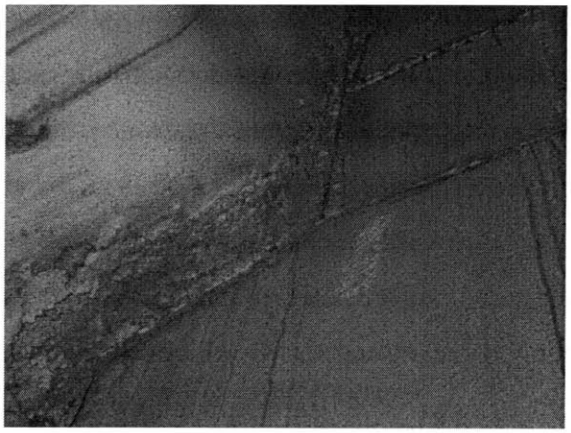


Fig. 3.5-10: Connection of Top Side Tank Sloping Plate with Bulkhead in *Cape Cosmos* - 2006

Coating breakdown is evident, along with pitting corrosion, and leaks of ballast water into the cargo hold. The main cause was improper coating application in the previous repair. After sand blasting, the weld seams should be stripe coated before spray painting the cargo hold. This ensures that no parts of the weld seams are left unprotected.

A new green and efficient coating removal method has been developed by ice blasting. Small dry ice pellets are blasted with air at a speed of 300m/s onto the hull, and then sublimate upon impact. This provides good surface preparation and cleaning of both the surface and the surroundings. Dust accumulation can be reduced by as much as 70% [Reuss 2001].

The color of the coating plays a role in the operating temperatures of the structure. This affects both the rate of corrosion and also thermal fatigue. An all-white color scheme above the water line, as chosen by Hellespont in their Korean built 2001-2 series of VLCCs and ULCCs, may reduce peak deck temperatures by 20-25°C in warm countries [Van Dyck 2002b, Ryle 2000]. A pale color may also ease the work of painters and inspectors in dark, restricted spaces such as the ballast tanks [The Motor Ship 1993]. Another reason why Hellespont chose a white color is for marketing purposes, since it takes a lot of confidence in one's ability to maintain it clean of corrosion and dirt.

3.5.4.3 Basics of Ship Corrosion

Various types of corrosion are identified in ships, namely general corrosion, pitting, grooving, weld metal and microbial corrosion. Other mechanisms include galvanic corrosion and erosion corrosion, while cracks arise from stress corrosion cracking and corrosion fatigue etc. (Boon et al 1997)

Metals are thermodynamically unstable and have a tendency to revert to their natural ore. This is the driving force of corrosion which consists of an anodic and a cathodic reaction. The electrolyte provides the medium for these electrochemical reactions. Three important factors are the temperature, oxygen supply and humidity. These vary significantly in bulkers depending on a number of factors. Corrosion protection is mainly through coating and sacrificial anodes in the ballast tanks and the outer immersed hull. However, sacrificial anodes in ballast tanks are only effective when the ship is ballasted so they only provide protection for about half of the time.

3.5.4.4 Factors Affecting Corrosion

The rate of corrosion varies with time [Melchers 1995] and one important cause of this is the variation of surface exposure with time. Several factors have been found to influence the rate of corrosion and these can be summarized under a few categories. They include the type of corrosion; the quality and damage of the protection such as the coating and anodes; the age and type of ship as well as the quality of steel used in its construction; the ship operation including handling procedures and the amount and frequency of repair; the ship location being considered and whether it is immersed in sea water; trading factors including the type of cargo, the loading and ballasting condition and the trading route followed; environmental conditions such as humidity or temperature and salinity of the water and atmosphere. Moisture is the primary factor affecting corrosion rates of steel covered by coal and iron ore, with the critical moisture level being between 60 and 80% of the theoretical Maximum Water Holding Capacity (MWHC) [Gardiner and Melchers 2001].

Corrosion is often not uniform throughout the ship because it is affected by different factors in different parts of the hull. Corrosion of areas immersed in sea water, for example, depends mostly on sea water salinity, temperature, oxygen content and the velocity of the ship (for the outer hull) [Melchers 1997c]. The corrosion rate is governed by accessibility of oxygen to the surface. Corrosion rates of areas exposed to the atmosphere depend on the relative humidity, air temperature, time of wetness, chloride deposition and sulphur dioxide pollution [Evans et al 1972]. In the cargo holds and deck, mechanical damage and wear increase the likelihood of corrosion. In ballast tanks, the time and duration of ballasting dictates when (and for how long) the anodes are effective. It thereby affects the time over which corrosion take place. Furthermore, different temperatures are attained at the various sections of the hull during operation. As a rule of thumb, corrosion rate doubles for every 10°C increase in temperature [DNV 2002]

The trading pattern is one of the most important parameters because it controls a variety of factors which affect corrosion. Environmental factors, including atmospheric and sea water conditions, depend on the trade route. The weather encountered is also determined by the trading route. It affects temperature and atmospheric composition as well as water and humidity exposure of the hull. It also dictates whether the ship will be sailing on light or

heavy ballast (with an additional hold ballasted) and the number of storms, large waves and rains that are encountered.

The trading pattern also determines the frequency of loading and ballasting. The frequency of loading has a major effect on coating breakdown, and also dictates the frequency of washing. The frequency of ballasting operations determines the supply of new oxygenated water to the tank surfaces. Exposure to moisture is also affected by the loading condition, since this determines the number of holds that require washing after discharge.

The cargo is also a determining factor, particularly in capes, which mainly carry coal and iron ore. The type and origin of coal is important because some coals are more corrosive than others and because it affects the amount of moisture in the cargo holds. Sulphate concentrations can vary vastly between the coals while corrosion has been shown to be a linear function of sulphate concentration [Johansson et al 1995]. This is one of the reasons why corrosion rates vary significantly between bulk carriers. Iron ore is not corrosive but it is very abrasive so it accelerates coating breakdown. The usual practice of carrying coal and iron ore alternatively in capes, therefore, is one of the worst trading patterns in terms of corrosion.

3.5.4.5 Critical Areas for Corrosion

The ballast tanks are the most vulnerable area and the most difficult to inspect. When ballast tanks are empty, anodes are not effective, so protection is provided by the coating alone. Therefore, extra care is given to the type and application of ballast tank coatings, both in ship building and during repairs. Coating usually breaks down at the edges and around corners but also randomly due to the impacts from grabs in the holds during discharge. Therefore, coating flexibility is critical. The rate of corrosion when the ballast tanks are empty depends on the previous ballasting water temperature [Melchers 1997d] and salinity.

Fig. 3.5-11 shows corroded longitudinals under the tank top in the double bottom of a 25 year old cape (a ballast area).

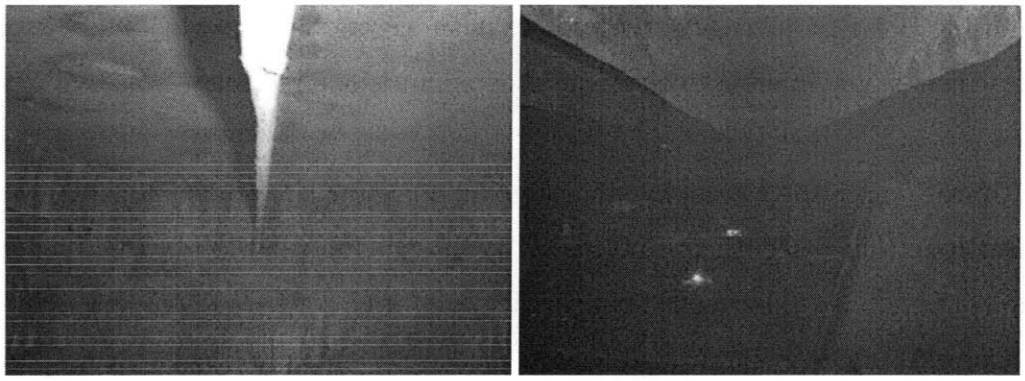


Fig. 3.5-11: Tank Top Longitudinals in Double Bottom of *Cape Cosmos* - 2006

These are flat bars by design, which weigh approximately 100kg/m. The double bottom is a very inaccessible area in which repairs are difficult. In old ships, therefore, it is common to convert them into an unequal angle-bar by adding a flange. This gives it a shape with a higher modulus to weight ratio, thereby maintaining the section modulus while compensating for the wear due to corrosion. A lot of time and money is thereby saved during repairs since the heavy corroded flat bars do not have to be replaced. The exact same situation applies in longitudinals in other ballast areas. Fig. 3.5-12 shows the modified under-deck-longitudinals of the same ship in the top side tank, just before welding, and after the first coating.

Fig. 3.5-12: Under-Deck Longitudinals in Top Side Tank of *Cape Cosmos* - 2006

Since sand blasting is also difficult and expensive in ballast tanks, it is more practical to burn the surface with an oxygen flame in order to prepare the surface for the two filet welds (one on each side of the flange connection). The prepared surface is shown on the left

picture of Fig. 3.5-12. The right picture shows the area after the repair with the first layer of coating, which is grey in order to distinguish it from the final, red coating that will be applied on top.

Corrosion is also very common in cargo hold bulk heads, which until a few years ago, were usually left uncoated. [Yamamoto et al 1996] developed a probabilistic model for the corrosion of transverse bulkheads in bulk carriers.

Corrosion rates in cargo hold tend to increase with depth, partly because protection also decreases the lower you go. There is full coating on the upper stools and frames, just a corrosion product layer on the hoppers, and no protection at all on the tank top. Another reason is that the likeliness of damage or coating breakdown also increases with depth. This is due to the impact of iron ore on the hoppers and particularly the tank top during loading, the likelihood of mechanical damage in the lower regions during discharge, and the increased exposure to cargo when holds are partly loaded. Finally, moisture levels also increase with depth within the cargo holds. This is due to the temperature difference across the sea immersed hull being greater and also because moisture accumulates in the lower regions due to gravity.

3.5.4.6 Corrosion Models

Having realized the consequences of corrosion, it is very important to understand its mechanisms and most importantly to accurately predict it. This is critical during initial design, during maintenance and also when planning for inspections and setting the corrosion allowances. Though our understanding of corrosion mechanisms is generally improving, prediction is a very difficult task due to all the determining factors which vary dramatically between different ships.

Therefore, there has been an effort to develop probabilistic models to describe corrosion and predict corrosion rates [Guo et al 2008, Garbatov and Soares 2007, Wang et al 2007, Moatsos et al 2005, Gao et al 2005, Melchers 1997a, Melchers 1995, White et al 1991], and some are focused specifically on bulk carriers [Paik et al 1998a, Yamamoto et al

1996]. Statistical means have also been used to estimate the rates of corrosion on ship structural members from observational data [Loseth et al 1994, Yamamoto et al 1994, Okamoto et al 1993].

As our understanding of corrosion mechanisms improves, there are incentives to move from a statistical approach to a physically based probabilistic model, in which all the contributing factors can be incorporated. Physical models have been developed in the past for predicting corrosion [Gardiner et al 2001, Melchers 2001]. The problem, however, is that they are often limited to defined conditions and thereby render themselves inappropriate for application is ships which are exposed to great variety of conditions.

Several studies on corrosion wastage have been carried out over the past few years based on thickness measurements. Such studies are difficult to perform as there is only limited corrosion wastage measurement data reported to the public. Furthermore, the size of the database is important to ensure an accurate representation of the ships in service. Some of the available literature conducted so far and the databases used are summarized in Table 3.5-1.

DIRECT MEASUREMENT BASED CORROSION LITERATURE		
Author	Ships/Type	Measurements
Wang et al 2003b,a	140 Tankers	110,082
Paik et al 2003b,a	>100 Tankers	33,820
Harada et al 2001	197 Tankers + 98 Bulk Carriers	>250,000
Yamamoto et al 1998	50 Bulk Carriers	?
Paik et al 1998a	44 Bulk Carriers	?
Paik et al 1997a	40 Tankers	?
TSFC 1992	52 Tankers	?

Table 3.5-1: Corrosion Wastage Surveys

Probabilistic representations, corrosion models and measurement databases are often combined to evaluate corrosion.

The most frequently used distributions for corrosion wastage i.e. to calculate the probability that a plate thickness will meet the requirements at a given ship's age, are the Weibull, Normal, truncated normal and log-normal distributions. According to [Ivanov et al 2004b], the Normal and truncated normal distributions produce slightly more optimistic results than the Weibull distribution by about 2-3%.

In addition to wastage, other types of corrosion exist such as pitting, grooving/necking etc. but unfortunately no such data is being collected, so no quantitative analysis can be performed. Three general models for corrosion progress are published so far as shown in Fig. 3.5-13.

All assume that there is no corrosion during the first stage, during which the coating is still intact. Corrosion initiates at some point as a result of coating breakdown. As shown in Fig. 3.5-8, the corrosion rate may (a) remain constant, (c) gradually decrease until corrosion stabilizes due to corroded material which accumulates over the plate providing a protective layer, or (b) increase if this film is removed due to impacts or as the structure flexes due to waves [Saidarasamoot et al 2003, TSFC 1992].

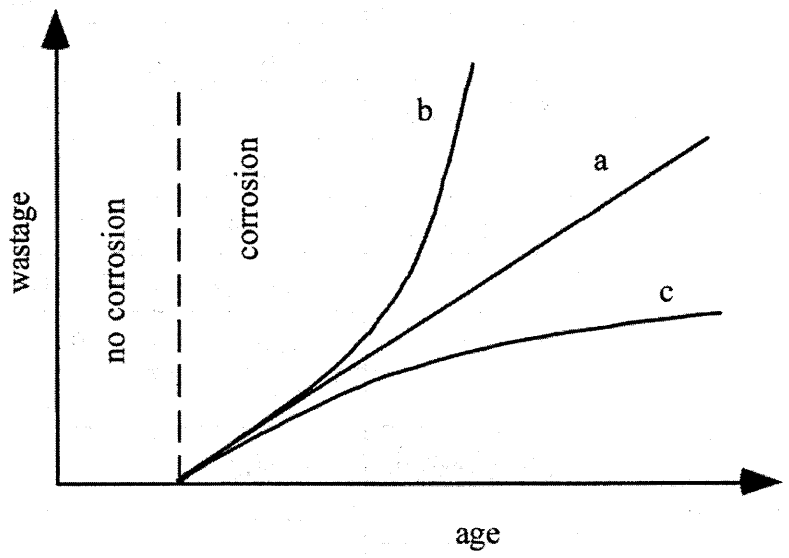


Fig. 3.5-13: Corrosion models [Wang et al 2003a]

[Wang et al 2003a] and [Vassalos et al 2004] assume 5 years for the first stage and they conclude that corrosion rates can be described by a Weibull distribution function. [Paik et al 2003b] adopt a model of type (a) which appears to be the most common. They suggest

the inclusion of a transition period after coating breakdown and before corrosion initiates over a large enough area to be measurable. Their findings suggest that the relative frequency of corrosion depth tends to follow a Gaussian distribution for younger ships and a log-normal or Weibull distribution for older ships. They also assume that the coating life of a cape lasts 7.5 years except for the tank-top and the hopper plates where 5 years are assumed instead. As they suggest, however, a more realistic structural assessment should account for both general and pitting (localized) corrosion, which is more likely to occur in bottom plates.

A three stage model, which seems to be more accurate and flexible has also often been adopted as shown in Fig. 3.5-14. Coating breakdown initiates at the end of the first phase. The corrosion rate is assumed to increase linearly during the second phase as the coating gradually breaks down exposing new material. This continues until a maximum rate is reached when the coating is completely broken down at the end of the second phase. The corrosion rate may then stabilize at this value as assumed by [Ivanov et al 2004a, Ivanov et al 2003], or it may decrease to zero again as a result of the accumulated protective corrosion layer [Soares et al 1999].

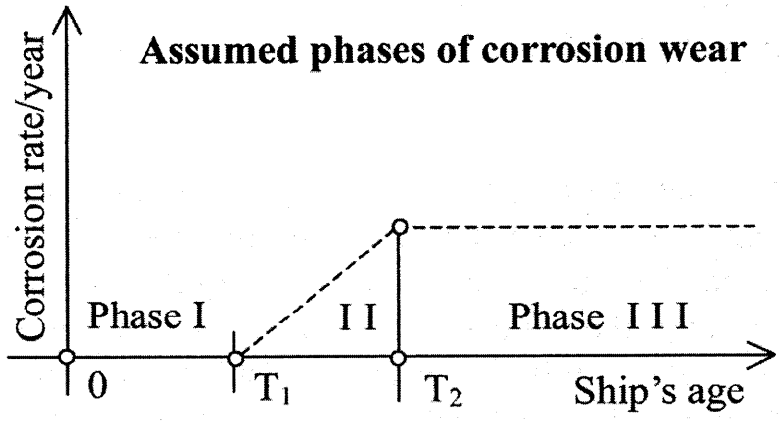


Fig. 3.5-14: The Three Assumed Phases of Corrosion [Ivanov et al 2003, pp. 332]

Whichever assumption is made, the total corrosion wastage accumulated over time can be obtained from

$$W = \int_0^T r(t)dt \qquad (3.5\text{-}12)$$

Where: W = Corrosion wastage in millimeters at time T

r(t) = Corrosion rate in millimeters per year

T = Time in years

[Ivanov et al 2003] assume three years for the coating lifetime (first phase) and three years for the second phase. Their findings suggest that the effect of the 2nd phase is slightly greater than that of the 1st phase in the probability of meeting renewal criteria at a given time.

[Vassalos et al 2004] adopt a model of the form:

$$t_r = C_1 T_e^{C_2} \qquad (3.5\text{-}13)$$

Where t_r = corrosion wastage (mm)

T_e = time in years (after corrosion starts)

C_1 = coefficient defining the corrosion rate

C_2 = coefficient determining the corrosion progress

The use of thickness measurements by [Paik et al 2003a] to estimate C_1 and C_2 revealed that C_1 is a random Weibull distributed variable while C_2 is equal to unity [Vassalos et al 2004]. [Paik et al 2006] and [Paik and Thayamballi 2002] use the same approach but break down the time in various components, as shown in Fig. 3.5-15.

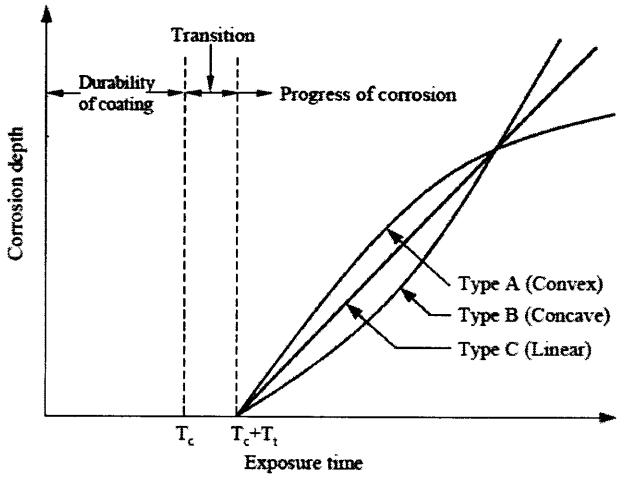


Fig. 3.5-15: Corrosion Depth with Respect to Time [Paik et al 2006]

The equation is $t_r = C_1 (T - T_c - T_t)^{C_2}$ (3.5-14)

Where T_c = Life of coating in years

T_t = Transition time

Many methods of estimating corrosion have been proposed but the most important aspect to be analyzed is the effect on ship. [Andreassen et al 1998] present a probabilistic analysis method to assess the strength of the hull girder as corrosion progresses. The influence of adopting the various corrosion models on the predicted reliability of ship structures has also been investigated [Ivanov et al 2003].

3.5.5 Fatigue Life Estimation

Fatigue life is defined as the time required in service for a structure to experience enough stress cycles for a fatigue crack to initiate. Ship hulls were known to be subject to localized fatigue since the 19th century [Bishop et al 1985]. Fatigue assessment as part of a ship's design, however, was not required until about 10 years ago [Wang et al 2004]. As it has become of increasing importance, several methods have been developed and documented in the literature [Bea et al 1995, DNV 1995, ABS 1992, Wirsching et al 1987, Munse et al 1983, Thayamballi 1983, Wirsching 1983]. Examples include the "Simplified" method which is most common, or the "Spectral" and "Deterministic" methods [ABS 2003].

Depending on which stress is used in the calculations, the analysis can be categorized as a "nominal", "hot spot" or "notch" stress approach. The hot spot stress approach is the most commonly used in complicated ship details where a hot spot stress is defined as a local stress at a hot spot such as the toe of a weld which is prone to crack initiation [Wang et al 2004]. The hot spot stress concentration factor is defined as the ratio of the hot spot stress to the nominal stress applied. This can be established by several methods but FEA is most commonly used [ABS 2004, ABS 2003]. Linear elastic quadrilateral plate or shell elements

are typically used while triangular elements are avoided, particularly in the hot spot region [Wang et al 2004]. A "structural stress method" which uses an "equivalent structural stress" has also been introduced by Dong and is said to be mesh size and type insensitive [Dong 2003]. Case studies by [Wang et al 2004], however, have established that this is not always the case and that both the hot spot and the structural stress methods are mesh sensitive and they both tend to under-predict fatigue life compared to experimental test results.

The "Simplified" method of estimating ship fatigue life involves the combination of Palmgren-Miners's rule of cumulative damage with S-N curves where a Weibull probability distribution parameter is used to characterize the long-term stress ranges on a detail [Wang et al 2003c]. Miner's law of Cumulative Damage [Miner 1945] predicts failure when the damage ratio "D" reaches 1. The damage ratio is given by $D = \sum_i \frac{n_i}{N_i}$, where n_i are the number of stress cycles of stress amplitude s_i, and N_i are the number of cycles to failure at stress amplitude s_i.

The use of S-N curves and the cumulative damage approach is far more common in assessing ship fatigue life as opposed to the application of fracture mechanics. Different S-N curves are proposed by various sources because there are numerous ways which can be used to incorporate the effects of corrosion, plate thickness, welding procedures and other relevant factors. Differences in results when using the various S-N curves are illustrated by [Wang et al 2003c]. [Wang et al 2006] also use Miner's rule and derive an S-N curve for predicting cyclic plasticity (low cycle fatigue) of welded joints.

The procedure of using S-N curves with Palmgren-Miner's rule to predict cracking is relatively simple. The rule is as follows [Mansour and Liu 2008]:

$$\log(N) = \log(K) - m\log(S)$$
$$or \qquad (3.5\text{-}15)$$
$$N = K(S^{-m})$$

Where: $\log(K) = \log(K_1) - 2\sigma$

S = Stress range

N = Number of cycles to failure under stress range S

K_1 = Constant relating to the mean S-N curve

σ = standard deviation of log(N)

m = inverse slope of S-N curve

The histogram of cyclic stresses is first defined, and then the cumulative damage is calculated from the chosen S-N curves to predict crack initiation. This can be applied to all structural members of a ship for which the loads have been pre-estimated. Ship fatigue life estimations can thus be obtained.

However, estimation of the loads to which a ship will be subjected throughout its service life is not a simple task. These include wave induced dynamic, vertical, and horizontal bending moments; hydrostatic loads and still water bending moments; external wave pressure and internal tank pressure etc.

Therefore, a probabilistic approach has often been adopted to carry out fatigue life assessments for various types of applications including ships [Lambrigger 1997, Soares et al 1996b, Columbi et al 1995,]. The wave-induced loads throughout a ship's service life and the ocean surface are often modeled using Gaussian random variables. However, waves of extreme height have been witnessed, on a number of occasions, which could not occur if the wave statistics followed Gaussian assumptions [Doneal 1991, Bascom 1980]. Such waves have been the cause of many ship losses in the past [Faulkner 2001, Corlett et al 1992] and there have been many studies to explain the phenomenon [Smith et al 2002, Kim et al 2001, Clauss 1999, Chaplin 1996, Zou et al 1995]. It is important to consider these extreme waves in the design and fatigue analysis of ships.

The proper combination of the various stress components is critical in order to derive the total stress values to be used in the calculations. Various methods have been developed for this [Shin et al 2004, Baarholm et al 2002, Chen et al 1997, Mansour 1995].

[Shin et al 2004] propose a method where the total stress σ_T at a structural location is expressed as a linear summation of the component stresses σ_i multiplied with the corresponding stress combination factors C_i as follows:

$$\sigma_T = \sum C_i \times \sigma_i \qquad (3.5\text{-}16)$$

The combination factors strongly depend on structural location, cargo loading condition, wave heading angle and the period under each sea state. A load transfer function is obtained from the ship motion prediction program. This is a function of the wave heading angle and frequency. By multiplying this with the stress combination factors C_i, the corresponding component stress (σ_i) distribution factors are obtained. These can then be summed to give the total stress transfer function. The total stress (σ_T) can thereby be translated to any location in the hull.

Since the long term environment is characterized by a wave scatter diagram, which gives the different sea states that might be experienced over a ship's service life, this analysis has to be carried out for all the sea states. The long term distribution of dynamic stresses is then obtained by summing the distributions for the various sea states. [Shin et al 2004]

The influence function method also shows a promise in predicting fatigue life and may solve many problems if it proves to be reliable. The basic theory is summarized as follows:

$$\sigma_L = A\sigma_A + B\sigma_B \qquad (3.5\text{-}17)$$

Where: σ_L = a local stress in a critical area which is to be determined

σ_A, σ_B = stresses or other measurements at two convenient locations

A, B = Influence Functions

Similarly to stress concentration factors, Influence Functions can be used to obtain the effect of Global actions such as longitudinal stresses on the deck or at a critical area which may not be accessible for measurements. As such they can be combined with the stress history of the convenient locations using FEA, to predict fatigue life at critical inaccessible areas. Influence Functions combined with FEA, stress predictions (anticipated voyages), and fatigue analysis (Palmgren-Miner's rule), at the design stage can be used to estimate fatigue life at those critical locations.

[Braidwood et al 1998, Braidwood et al 1997] have carried out research in showing how well influence functions can predict fatigue life of typical components using response amplitude operators from finite element modeling along with fatigue analysis programs. They evaluate their results by taking full scale measurements with strain gauges and

accelerometers on a cape on homogeneous loading and heavy ballasting conditions. Some of their experiments were successful, showing accurate results on a long term basis.

As with corrosion predictions, due to the difficulty associated with predicting stresses, there is a trend in moving towards probabilistic methods in performing strength analysis in ships. Our understanding of structural failure modes has improved over the past few years and probabilistic presentations of loads and stresses have been developed. This has led to improvement of the reliability approach and its application in the shipping industry [Melchers 1997b, Mansour 1997, Wang et al 1996, Soares et al 1989]. Further progress has led to the development and use of the Time Variant Reliability (TVR) approach which incorporates structural deterioration with age and is much more accurate with reference to ships [Ivanov et al 2003, Paik et al 2003b, Qin et al 2002, Sun et al 2001, Wirsching et al 1997, Soares et al 1996a].

A statistical approach is common in evaluating the uncertainty of a ship's strength over time, based on the probability of experiencing excessive bending moments. [Ivanov et al 2004] have extended this by incorporating the corrosion wastage over time and the consequent change in section modulus. Hence, by using the still water and wave induced bending loads and geometric properties, the bending stress is expressed in the form of time dependent distribution laws. The probability of exceeding the classification society's permissible value at different ship ages can thus be calculated. Their analysis shows that there is no change in the permissible bending stresses as a ship ages, provided that all parameters determining the ship's strength are calculated in probabilistic terms as for a new design.

It is common practice in the shipping industry to perform fatigue life calculations using S-N curves and Palmgren-Miner's rule of cumulative damage without the application of fracture mechanics. According to [Nibbering et al 1973], one of the reasons for this is that the influence of crack length on fracture strength is less important than temperature and speed of loading.

According to [Rizzo 2007], a fracture mechanics approach is required for the proper assessment of the remaining life of a cracked member. Recent developments have been made, enabling the rapid calculation of stress intensity factors for complex structural details,

thereby, making LEFM more applicable [Chahardehi and Brennan 2008, Brennan and Love 2006, Brennan and Teh 2004].

[Kinoshita et al 1973] demonstrated the applicability of Paris's Law in ship structural plates. One of the few examples where fracture mechanics is currently used in shipping is in the analysis of Liquefied Natural Gas (LNG) Carriers membrane tanks where the concept of "leak before break" is applied. This refers to the thickness of the membrane being smaller than the critical crack size for fast fracture so that in the event of a crack, the tank leaks instead of suddenly breaking. The reason for this is that the membrane tanks carry liquefied gas at high pressures and at temperatures around 160degC. An explosion of a membrane tank would thus have very serious consequences extending far beyond the ship structure if it is near a port at the time.

Research based on fracture mechanics in ships has been carried out extensively since WWII. Using the fracture toughness of the given steel, and by estimating the loads applied throughout the hull, the critical crack lengths for brittle fracture in each location can be determined. This provides very useful information regarding the danger of particular cracks. Furthermore, fracture mechanics can be used to calculate the remaining time until a particular crack grows to critical length. The time when a crack needs to be repaired can then be determined. However, classification societies are currently too conservative to allow the existence of any cracks at any location in the hull.

The Paris-Erdogan Law is integrated over a period of time to give the final crack length after a number of stress cycles. It is roughly considered that the period of wave load cycles in ships is about 6-10s [Paik et al 2003b]. Consequently, the number of cycles can by estimated over a period of time giving the crack length. This method, however, is based on the assumption that the local stress levels don't change as the crack propagates. It therefore underestimates fatigue life. Stress concentration factors for typical joints in ships can be found at [ABS 2002a]. Fig. 3.5-16 shows the predicted values of stress ranges at some critical points in a cape, and the associated crack growth rates after initiation at the age of 5 years.

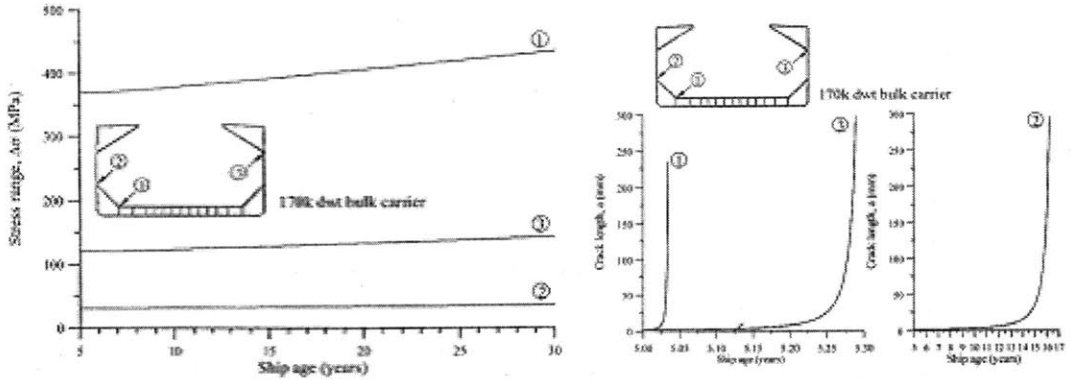


Fig. 3.5-16: Time dependent hull girder stress at some critical points in a cape (left), and the associated crack growth characteristics (right) [Paik et al 2003b]

As shown in Fig. 3.5-17, [Brennan and DeLeeuw 2008] demonstrate how inspection results can be used to infer remaining crack sizes, and thereby refine fatigue life predictions. The ship's life prediction depends on the size of the largest defect which is unknown. The probability distribution of this value defines the range of possible values for the life prediction. By considering the detected cracks of a repair and assuming a typical POS 90/95% inspection, one can narrow down the range of possible values for the size of the largest remaining crack. This yields a more precise prediction of the fatigue life. The maximum size crack that can escape a POS 90/95% inspection, $\alpha_{90/95}$ has a 90% probability of detection at a 95% confidence level.

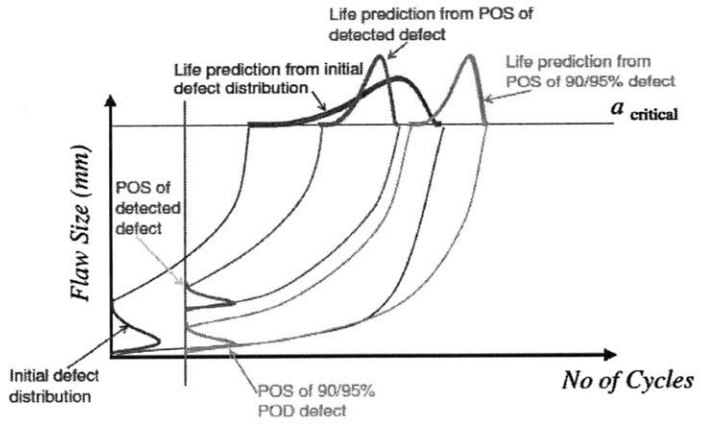


Fig. 3.5-17: Reduction in Life Prediction Scatter Using Latest Inspection Results [Brennan and DeLeeuw 2008, Wang et al 2009]

The conventionally used Miner's cumulative damage rule has several disadvantages to fracture mechanics approaches. The first is related to the effect of local yielding, which makes the loading sequence important. The loading sequence is not accounted for in Miner's rule. If a cracked component is subjected to a relatively large load, "crack blunting" often results, whereby a plastic region with compressive residual stresses is generated at the crack tip, making it less sharp. This diminishes the effect of subsequent loads. Therefore, small loads followed by a large load may be far more damaging than vice versa.

Another disadvantage of the cumulative damage approach is that it does not account for the mean stress, which may be significant depending on the level of residual stresses. Alternatively, therefore, the cyclic strain approach has been proposed for some regions such as web intersections [Fricke et al 1987]. A comparative study between the S-N and the cyclic strain approach has been carried out using data of cracks from a bulk carrier [Pedersen 1996]. Results showed that the S-N approach is more conservative while the cyclic strain approach is more sensitive to the applied loading.

The cumulative damage approach is also very sensitive to input parameters that are inaccurate to start with. The damage ratio is proportional to the applied stress raised to the power of the gradient of the S-N curve of a structure. This is generally equal to around 3. That means that the cumulative damage calculated by Miner's rule is approximately proportional to the applied stress raised to the cube. Consequently, any inaccuracy in predicting applied stresses is amplified in the calculation of fatigue life. Damage is caused by the stress fluctuations so the percentage error in the calculated damage is approximately three times the percentage error of the wave/weather induced stresses. Predicting wave induced stresses over a 30 year lifespan is very difficult because of significant effects such as global warming and climate changes that designers often neglect. Therefore, errors resulting from the conventional approach can be dramatic. Namely, if we take the typical value of 3 for the gradient of the S-N curve, a 20% error in the stress amplitude due to waves would result in an error of ~60% in the cumulative damage! Significant improvement is therefore needed in estimating fatigue life of ships.

3.6 Crack Monitoring

3.6.1 Inspection Planning

Inspections are carried out throughout the service life of ships by various maritime organizations including classification societies, the flag authority and the port state control when ships enter or leave ports. Fig. 3.6-1 shows a summary of the type of bulk carrier inspections.

Organization	Regulation, rule, guidance	Survey	Inspection area & item
IMO	International conventions and class rules (mandatory)	Initial, Annual, Intermediate, Periodical/Renewal	Safety, pollution and load line ISM, ISPS
Classification societies			Hull and machinery
Port state	Memorandum of Understanding	On purpose (targeting of ships)	Hull and machinery Safety, pollution, load line
Flag state	National regulations	Initial, occasional, periodical	
Insurance company (including P&I Clubs)	Insurance / P&I requirements	Insurance inspections	CAS / ESP (mandatory)
Terminal operators	Local regulations and procedures	Safety & pollution prevention survey	Cargo handling and equipment, procedures, loading master
Cargo owners	Commercial requirements	Charterer/vetting (oil majors, CDI, OCIMF/SIRE, etc.)	CAP, cargo operation and management, survey on purpose, risk-based analyses
Ship owners / managers			

Fig. 3.6-1: Bulk carrier Inspections by the various Maritime Organizations [Wang et al 2009]

Regular inspections are scheduled throughout the ship service life by classification societies. Their frequency and the items which are viewed each time vary with the type of survey and the ship's age. IACS Classification societies carry out the following hull surveys.

Special Survey:	Carried out every 5 years and every time there is a change of classification society
Intermediate Survey:	Carried out during the 2nd or 3rd year after each Special Survey
Annual Survey:	Carried out every year and may coincide with an Intermediate or a Special Survey
Occasional:	Carried out randomly if there is a particular reason such as a damage or a request by the port state control

The scheduling of inspections is based on the accumulated experience of maritime organizations over time, primarily regarding the plate thickness diminution. It has been shown in the past that the geometric properties of the hull girder and its structural components follow a Gaussian distribution [Ivanov 2002, Ivanov 2001].

The hull girder strength is maintained through control of its section modulus for vertical bending while the strength of structural components and plates is controlled through plate and flange thickness. [Ivanov et al 2003] present both the hull girder's section modulus and plate and flange thickness as probabilistic functions at any ship's age in order to assess the probability that a ship hull will meet the renewal criteria over a given time period.

Classification societies and IMO have developed criteria for the strength of the ship hull girder and its structural components based on data from ship's operation [ABS 2002b, IMO 2000]. The requirement by IACS is that the longitudinal strength of a ship should remain above 90% of when it was built. In practice, this means that the minimum permissible section modulus of a ship in service is about 90% of that for a new construction [Caridis 2001]. Generally, plates are required to be renewed when the thickness drops by 20-30%, depending on the location. This applies to both mild and high tensile steel plates.

According to [Paik et al 2003b], it would be better to schedule steel renewals based on a structural strength criterion rather than on plate thickness, in order to account for the effect of dents and cracks on strength. Consequently, if strength falls below a critical value, such as 90% of the original strength as required by IACS, repairs can be carried out.

[Paik et al 2003b] carried out extensive theoretical, numerical and experimental studies to investigate the effect of general corrosion, pit corrosion, fatigue cracks and local denting damage on ultimate tensile strength of ship structures including time-dependent risk

assessments. "Knock-down factors" (factors of reduction) of the ultimate axial and shear strength are deduced for each parameter which can be multiplied to give a combined factor of reduction. The current ultimate axial and shear strength of a damaged plate can then be obtained by multiplying this factor by the original strength. The knock-down factor for the effect of fatigue cracking damage on Plate ultimate strength is given by:

$$R_{xc} = \frac{\sigma_{xu}}{\sigma_{xuo}} = \frac{A_o - A_c}{A_o} \qquad (3.6\text{-}1)$$

where: R_{xc} = Factor or reduction due to crack damage

σ_{xu} = Ultimate axial strength of cracked plating

σ_{xuo} = Ultimate axial strength of un-cracked plating

A_o = Cross sectional area of plating

A_c = Cross sectional area involved by cracking damage

This can be applied for both tensile, compressive and shear loading. Even though the approach ignores crack orientation, it reasonably predicts the plate ultimate strength at a somewhat pessimistic side. Fig. 3.6-2 shows the time dependent characteristic for the ultimate hull girder strength of a cape with and without repairs for sagging including pitting corrosion and a crack by [Paik et al 2003b].

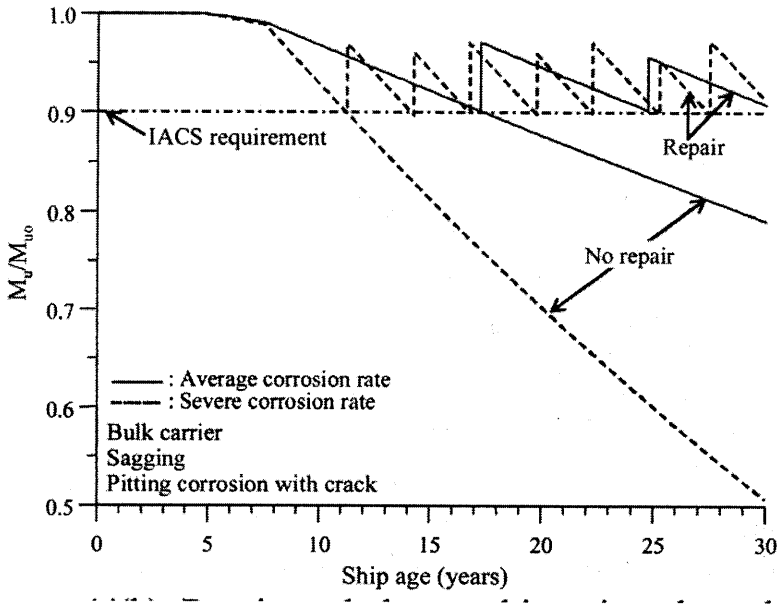


Fig. 3.6-2: Time-Dependent hull girder strength of a 170,000dwt bulk carrier [Paik et al 2003b]

As indicated by their analysis, repairs could be scheduled by considering a variety of factors that affect hull strength rather than just merely corrosion wastage.

Recently, there has been an effort towards a risk-based inspection approach [Truchon et al 2007]. This involves the identification and assessment of structural failures and their consequences, and planning inspections based on the level of risk. The newly proposed ABS Hull Inspection and Maintenance Program (HIMP) is a vessel-specific inspection program that employs risk-based techniques and includes a scoring system (using simple traffic light colors) for identified inspection criteria and a list of target inspection areas [Kalghati et al 2009].

3.6.2 During Inspections

Hull inspections are generally focused on coating breakdown; corrosion or diminution; and damages such as buckling or cracks. The identification of all these factors is critical as they all ultimately lead to cracking.

Coating breakdown is particularly important in ballast tanks as it is the only means of protection when they are empty. Classification societies record the quality of ballast tank coatings under three categories; "Good" which refers to minor spot rusting; "fair" which includes local breakdown at edges of stiffeners or weld connections and/or light rusting over 20%; and "poor" with coating breakdown of over 20% or hard scale of 10% of the areas under consideration [IACS 2004].

Assessment can either be visual or instrumented. Percentage area charts are traditionally used for comparison in order to determine the percentage area of coating breakdown by visual inspection. Instrumented methods, however, involving the use of electrochemical patch robes, which measure coating barrier properties, provide a more reliable and consistent quantitative measure of the coating quality.

The most important point of the survey is to identify if the coating failure has occurred. Coating failure first shows up in instrumented measurements, then in sacrificial anode rates, where it shows up as pitting, and finally in visual observations of coating breakdown at welds and edges.

Corrosion is assessed by plate thickness measurements taken by ultrasonic gauge readings. The areas most vulnerable to corrosion are discussed under Section 3.5.4. A good understanding of these is essential in order to inspect the critical areas in more detail and to take measurements at the correct locations in large surfaces.

Regarding cracking, inspections should be based on experience of where cracks occur. Some of these cracking-prone areas are discussed under Section 3.5.2. Cracks are also likely to be found at the locations where coating breakdown or corrosion has been identified. Often, cracks may not be evident during inspection due to dirt, poor lighting, difficulty of access, or compression of the two surfaces. Even in close-up inspections, cracks can be almost undetectable when they are closed by the loading condition [Holzman 1992, Ferguson 1991b]. Rust scale adhering to the surface also often presents a smooth and regular surface making it difficult to detect any cracks. Therefore, it is important to first clean and then carefully inspect the critical areas. In some cases, the crack origin or tip may not be visible, so the other side of the plate has to be examined. A similar example is in the cracks of hatch coamings which can only be seen by looking over the hatch opening if they have not yet

propagated out to the deck. Fig. 3.6-3 shows an average estimate of the probability of detection as a function of crack size.

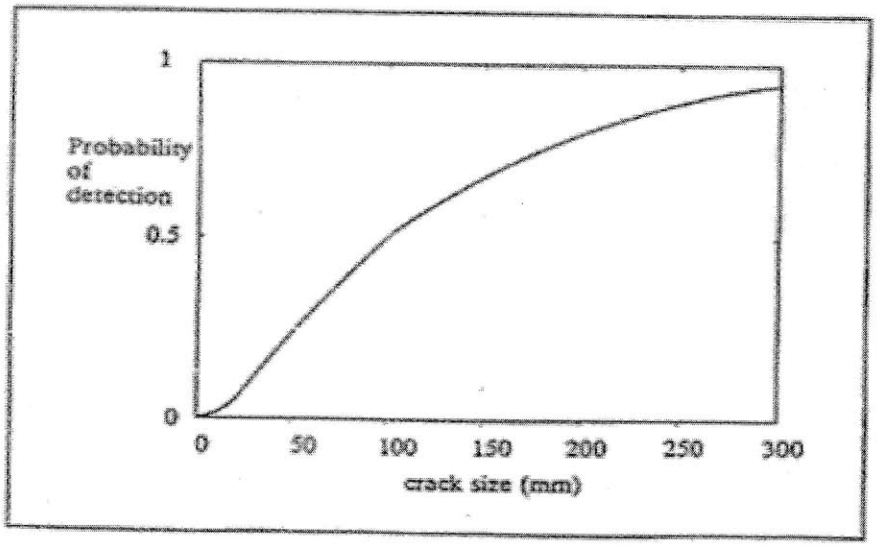


Fig. 3.6-3: Probability of detection as a function of crack size [Barltrop 1992]

It is consequently vital for an inspector to have a good understanding of the areas being inspected and also of the importance of cracks depending on both size location and origin. The chance of identifying cracks is then increased and dangerous cracks can be distinguished from other less critical defects.

When cracks are detected in the hull, the normal procedure is to replace the cracked plate with a new one. If this is not possible, a hole is sometimes drilled at the crack tip, as a temporary solution. This reduces the stress concentration and prevents further propagation. At locations, such as cast iron engine components, where small cracks cannot be welded, they are often tied together using the "metal lock" method. There are several methods used to detect cracks. These include:

- ***Visual*** – Easiest and most basic / surface cracks only
- ***Ultrasonic*** – Access to difficult regions / subsurface cracks / size and shape
- ***Magnetic Particle Inspection*** – Very easy / surface cracks only
- ***Dye Penetrant*** - Only large surface cracks on plane surfaces
- ***Radiographic (X-Ray)*** – Subsurface cracks / only size (a shadow)

The use of cameras to aid inspections is also very promising [Roy 2000, Armitt and Henning 2000, De Petris and Macro 2000], as it allows for inspection from a distance without disrupting operation and without the need for a cherry picker to gain access.

Acoustic Emission Technology (AET) for crack detection has also been known to the marine industry for a number of years. It has been applied in many industries to detect cracks, corrosion and leaking [Athanasios et al 2008]. Only recently, however, has it developed to a stage where it can be used reliably to monitor propagating fatigue cracks in ships. It was initially developed to locate earthquakes but it is currently used on large structures and probably in ships in the near future.

A typical system, such as the BALRUE, would comprise of a 24 acoustic emission and 212 non-acoustic channel data acquisition unit, a laptop PC and a human command interface [MER 2002b]. An array of sensors is strategically distributed on the structure. Filtering, grouping and location algorithms are then used to detect propagating cracks. The diagrams in Fig. 3.6-4 show a typical acoustic map (right) used to locate propagating fatigue cracks in steel (left).

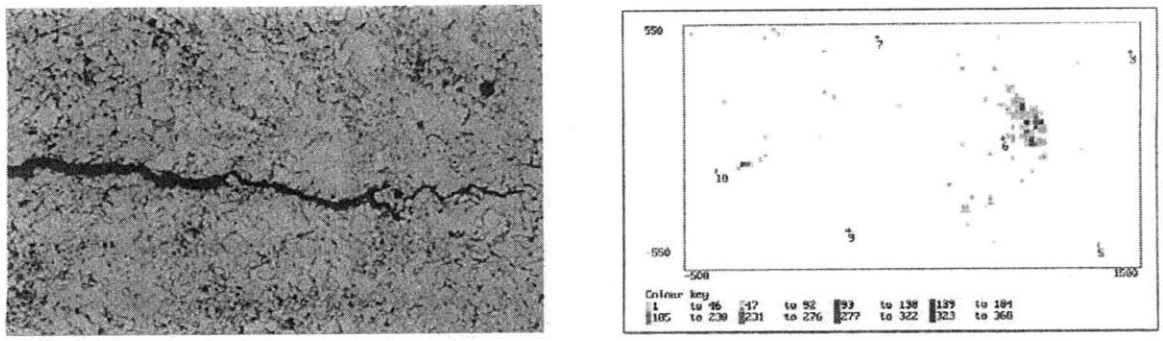


Fig. 3.6-4: A monograph of a crack in steel (left), and a typical acoustic emission map (right) used to locate propagating fatigue cracks [MER 2002b]

Some of the most important benefits include the detection and monitoring of cracks without prior knowledge of their existence or location, and also monitoring on a continuous basis or depending on the weather as suggested by LR [MER 2002b]. It also provides the information required to permit operation under certain circumstances and to delay repair until an opportune economic moment.

The decrease in time spent at ports has increased the need for automated inspections. This has resulted in several recent developments. An example is the the autonomous, wall-climbing robot for nondestructive inspection of storage tanks [Kalra and Gu 2007], the Automated Ultrasonic Testing Technique (Dijkstra and De Raad 2006), and the ROV stereovision system for ship hull inspection [Negahdaripour and Firoozfam 2006].

3.7 Design

3.7.1 Fit for Purpose Design

Besides designing for maximum strength and survivability of a vessel, there are a series of other design considerations which must be taken into account for a successful design. First, there must be a clear understanding about the way a vessel is intended to be used in order to make the correct design decisions.

While all new ships should be safe in the most hostile wave environments, some designs are known to age better than others. Owners often intend to sell ships at the age of about ten years, while others plan for a longer use. The commercial advantages offered by High Tensile Steel (HTS) and the associated problems as a ship ages are now well understood. When designing for the short term, therefore, it is common to use more HTS. When designing for a typical 30 year fatigue life, it is important to have a good understanding of the "correct" locations, in which HTS will not cause problems. A much smaller percentage is then normally used.

Another example is the design for alternate hold loading. This provides several advantages such as the ability to moderate the ship rolling motion by increasing the height of the centre of mass, or the fact that fewer holds require cleaning. Most important, however, is the time saved during cargo operations. This is achieved because fewer holds are unloaded each time while the bottom part of the holds is most time consuming. Alternate hold loading is preferable when loading high density cargos such as iron ore but this increases the hull stresses. As a result, special design and strengthening of the required structural members is necessary, to allow this type of loading. Fig. 3.7-1 shows a finite element model of a hull section during alternate loading with the associated stresses.

Regarding correct design for the intended use, there are often problems associated with the required cost. Some ships were built to low standards but then used in a wide range of trades, for which they were not suited. This is overcome by a introducing a common minimum standard that addresses the needs for all common cargos and a common design life.

According to Mr Bowring, most yards will always supply the bare minimum, since most faults will not show within the 12 month guarantee period, and there is almost no collection of data by the industry that would identify yards routinely building ships with faults [MER 2002a]

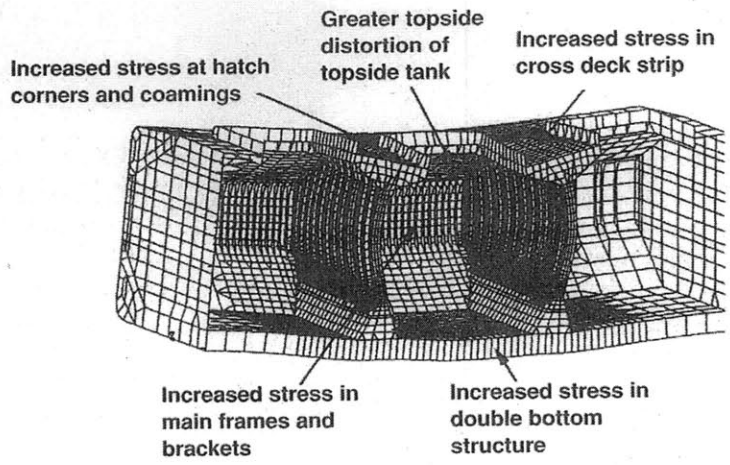


Fig. 3.7-1: Hull Stresses under Alternate Loading condition

[MER 1997]

There is no doubt that the ship design plays a major role in the problems developed by a ship throughout its service life. This is evident in sister ships that often have the same problems even when owned and run by different operators in different trades. A good design does not eliminate cracks but it reduces the rate of development after they have initiated. If good manufacturing standards are used in a high quality yard, then crack initiation is delayed, since there are presumably fewer and smaller defects to start with. Therefore, a good shipyard, combined with a good ship design lead to higher quality ships that last longer.

An important aspect of design is its influence over other critical parameters. It is important when designing to ensure conditions that promote easy, safe and effective operation, maintenance and inspection. A typical example of a design for easy and effective operation is the use of large hatch openings. This facilitates cargo operations but also has significant implications on the hull's torsional resistance [Plaza 1998]. Compromises like this are important and frequent in the design stage.

Designing for a cheap construction is important, but also for cheap maintenance. Compromising between those two is very frequent. For example, full penetration welds in cargo bulkheads increase fabrication costs relative to fillet welds, but make these critical components less vulnerable to corrosion and fatigue.

Finally, design for ease of inspection is also very important. An example of failing to do so is the construction of joint bottom and top-side ballast tanks. This, not only eliminates the option of ballasting the topside tanks when a leak develops in the double bottom tank, but it also makes inspection of the bottom tank impossible when the ship is in ballast. Another example where design makes inspection difficult is in the double hull construction. The following chapter provides a detailed analysis of the double hull design for its use in bulk carriers.

3.7.2 The Double Hull Bulk Carrier Debate

The first double hull ship was built by William Petty in 1662 [Wheater 2000]. Double hulls became mandatory for tankers over 5000dwt by the MARPOL Convention since the early 1990s in response to the *Exxon Valdez* disaster and phase out dates for the different types range until the later 2010s [Naval Architect 2003a, Naval Architect 2003b, GMOPIG (a), DF Dickins Associates Ltd. 1995]. In 2002, K-line (Wawasaki Kisen Kaisha) ordered the first ever double-hull capesize ships. The two 205,000dwt bulk carriers were ordered from Imabari Shipbuilding in Japan for delivery in 2005 [Flynn 2002].

The issue of double hull bulk carriers hit the headlines in the shipping industry a few years ago after the proposals of the IMO for its enforcement to newbuildings. Any modification as such, would have a great impact on ship construction and maintenance, which inevitably will reflect on the cost of freight. Consequently, an enormous amount of mental energy, as well as time and money, has been spent by both government and industry experts regarding this matter [De Bievre 2004a]. Fig. 3.7-2 shows the modification in the cargo hold region in going from single to double hull.

The main reason which triggered research in this direction was the aspect of safety and protection of the environment [Lloyd's List 2004a]. IACS has also been considering the

implementation of the double hull to other types such as containerships for the future [Landon 2004].

One of the strongest supporters of the double hull configuration was the ITF general secretary who characteristically accused the opposition of "favouring short term cost saving over sea farers lives". He also raised the question why the double hull was made compulsory for tankers and not bulk carriers claiming that "an oil spill costs an owner more than a dead crew" [O'Mahony 2004a].

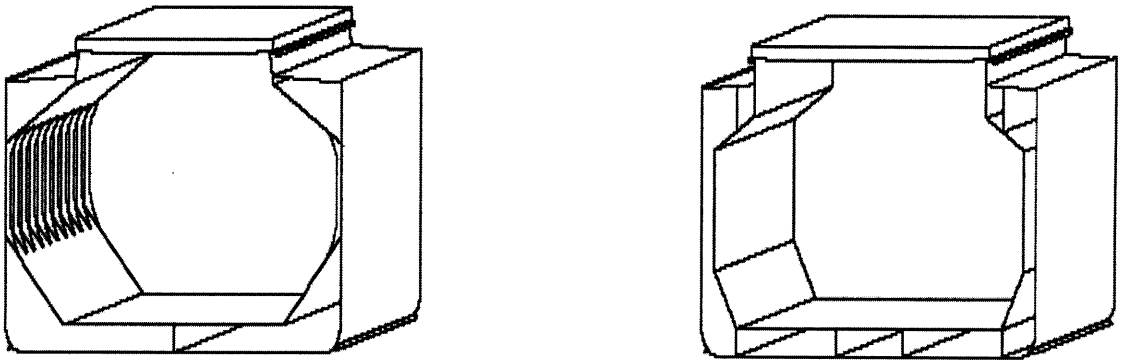


Fig. 3.7-2: Single hull (left) compared to Double hull (right)
[Graig Shipping plc. & Carl Bro A/S]

Prevention of pollution is clearly not the case in bulk carriers. Bearing in mind that tankers are of different construction and operate under different conditions, it would be very unwise to make assumptions and directly compare the two. Capesize Bulk carriers carry non-polluting cargos such as coal and iron ore, so the only risk of pollution would be from bunkers. If this was the objective however, the double hull could simply be confined just to the fuel tanks as is now being considered independently [Lloyd's List 2005a]. It should be noted that even for tankers, the effectiveness of the double hull configuration has been disputed and is not clearly the ideal solution regarding safety and pollution prevention [Langdon 2004, Langdon, 2003, The Motor Ship 1991].

The concept behind the double hull configuration is that during a collision, the cargo holds remain isolated from seawater and flooding is thus confined to the void space which separates the two shells. However, this only applies to low energy collisions (rarely the case of total loss) where the inner shell remains unaffected [Efthymiou 2004].

An advantage is that reduced hold width and the consequent reduction in free surface area of the holds would make the ship less prone to instability due to free surface effects in the case of partial flooding. Furthermore, the increased steel cross sectional area due to the secondary shell with longitudinal framing results in increased shearing strength. This reduces the probability of shear failure in the vertical direction.

However, twice the number of hulls does not necessarily mean twice the strength and the double hull is also faced with several disadvantages in the case of inner shell failure. Under that scenario for example, water is isolated from the void space at the other end of the hold, resulting in asymmetrical flooding and subsequent heeling of the ship to the side of the collision. Double hulls are also exempt from many regulations imposed to s-hulls by SOLAS-X11 [Corbett et al 2004a] including flood testing. As a consequence of this, some yards have found the overall cost of the double hull to be even lower than the s-hull and have been accused of providing ship owners with a cheap solution! [Corbett et al 2004a, Tradewinds (a)].

The small number of double hulls and the fact that they are all relatively new severely limits the validity of statistical data (comparing accidents) and makes the assessment of the proposed configuration a true challenge. It should also be noted that the double hull recommendation came from a study, which only considered pre-1998 bulk carriers [Bowring 2003]. Standards have greatly improved since then and continue to do so for newbuilding s-hulls which not only have to comply with tougher regulations [Corbett 2004], but they are also scrutinized by surveyors in ports.

Instead, one can consider accidents of the past and assess whether a double hull would make a real difference. There are two very famous, tragic examples which suggest the opposite. These are the s-hull cape *MV Christopher* (Dec.2001) [Lloyd's List 2004a], and the double hull OBO *MV Derbyshire* (Sept.1980). Both have been thoroughly investigated, they were both about 165,000dwt and both failed due to progressive flooding. In the case of *MV Christopher*, flooding started through the first hatch cover (forward) so obviously, a double hull would not have made a difference as it also didn't do so in the Derbyshire 21 years earlier [Woinin 2002, SSC]. Today, ships are designed using the principle of inherent redundancy to prevent this domino effect and all ships have to comply with the according regulations [Tradewinds (a), De Bievre 2004b].

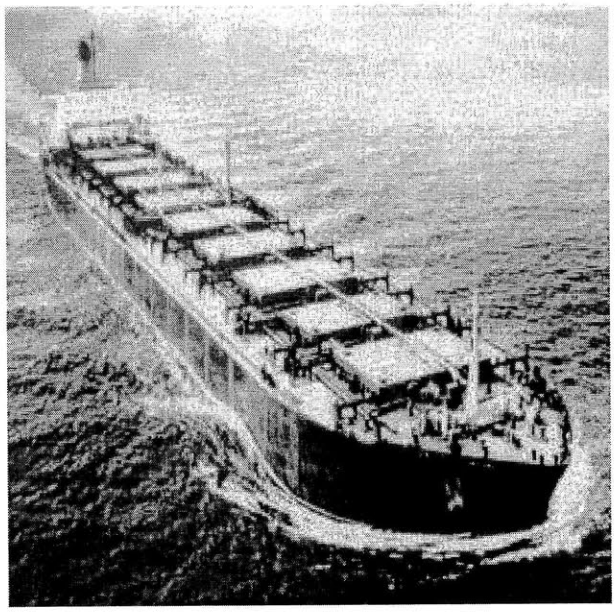


Fig. 3.7-3: Double Hull Ore Bulk Oil Carrier *MV "Derbyshire"* [SSC]

Fig. 3.7-4: Capesize Bulk Carrier *MV Christopher [Corbett 2002]*

Key factors on the double hull design are maintenance and inspection. Since the width of the space separating the two shells in double hulls is approximately 1m [Naval Architect 2003a], both are extremely difficult. Entry is via the top side ballast tanks and access is consequently prohibited when the ship is ballasted. This also provides a very good excuse to prevent inspection in general for prominent reasons. Potential corrosion in the

double hull space due to the local break-down of coating is immense because of the frequent impact from grabs during discharge. As a result, existing double hull type vessels are typically scrapped 2 to 3 years earlier than comparable s-hulls [O'Mahony 2004b, Vassalos et al 2004]. Bearing in mind that new bulk carriers are designed for a 30 year fatigue life [Lloyd's List 2004b], the inability to properly maintain the double hull space may increase the chances of structural failure. Statistics also exist which show a far higher incidence of fatigue problems in double hulls [Vassalos et al 2004]. An example is shown in Fig. 3.7-5.

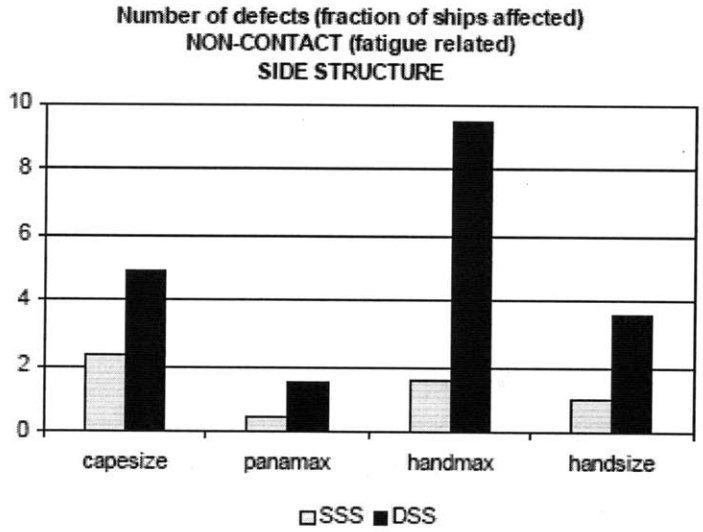


Fig. 3.7-5: Fraction of ships affected between 1990-1999 by side structure fatigue Comparing s-hulls (SSS) with double hulls (DSS) [Vassalos et al 2004]

There are also fears that the limited number of older double hulls to confirm their durability and the limited experience in their operation may also prove unsafe.

Having discussed the safety issue concerning the double hull, it should be noted that there are other more effective and efficient ways of improvement. Examples include the forecastle and wave breaker which became compulsory for capes after the *MV Christopher* incident, stronger hatch covers, improved scantling design, enhanced surveys and stronger bulkheads etc. As BV committees commented, "Single skin design bulk carriers could become much safer if the additional steel requirements for the double-side skin design were to be strategically distributed in the scantling" [Corbett et al 2004b].

Besides safety issues however, there are many operational advantages of the double hull design. Chris Williams, director at Graig comments "We designed the Diamond double hull bulker from the shipowner's point of view. We came up with the design before the whole double-hull thing became a debate" [Corbett et al 2004a]. Contrary to the s-hull, frames are placed on the outer shell, which leaves the cargo hold with a smooth surface free of discontinuities. This allows quicker dispatch at ports, less stevedore damage, effective cleaning of holds without the obstacles presented by frames, and easier maintenance and inspection [Lloyd's List 2004a, Jones 2002, Fricke et al 1998, Jang et al 1998].

Terminal time is of major importance to ships and shippers and is probably the greatest advantage of the double hull. This is achieved due to less obstruction to bulldozers during discharge; avoidance of cargo getting lodged between frames; easier cleaning without the need for entry of shore workers to holds to remove residual cargo (also a great health and safety issue); and easier inspection without the need of a cherry picker which can be a major problem to find and load on large gearless ships. Terminal operators claim that double hulls have a 10% faster discharge rate for coal and that the mechanical damages per ton discharged is 6 times lower than in s-hulls [Naval Architect 2003a]. [Vassalos et al 2004] suggests a 6.5% reduced time in port overall for a cape by employing a double hull.

Maintenance within the hold is also made easier. Welded frames are difficult to maintain and are very vulnerable to grooving corrosion especially when exposed to corrosive cargos such as Australian coal. Sand blasting is much easier on the double hull whose design also provides large areas of smooth surfaces for the rust-bust machine to work on. In the case of damage to the side of the hold however, repair works are very difficult since both sides need to be accessed.

A big concern in double hulls is the use of the space between the two shells. The double side spaces could be used for ballasting as in the handymax type "Diamond" [Lloyd's List 2005b]. The gain in ballast volume could possibly allow the elimination of the topside tanks, which will regain part of the lost cargo volume. The same may apply to hopper tanks though hoppers are also convenient to guide the cargo towards the centre of the hold. On the other hand, ballast is very corrosive and as discussed earlier, ballast tanks are the most corrosion prone region of the ship's hull. According to Alan Gavin, principal surveyor for Lloyd's Register, "...Because of the narrow width of the wing space and the cellular

construction, atmospheric corrosion within the upper spaces will be more significant," [The Motor Ship 1993].

Noting the difficulty of maintenance and inspection discussed earlier, it would seem much safer for the area to be used as void space which would provide much higher corrosion resistance. Additionally, some yards are also very concerned that ballast would give rise to excessive bending moments in the flooded condition [Naval Architect 2003a].

A disadvantage of the double hull design is the additional steel as part of the hull. Several yards and classification societies suggest that the lightship of a double hull will be in the region of 3-5% higher than of an equivalent s-hull [O'Mahony 2004b, DNV 1997]. This makes the ship more expensive to built, increases consumption (due to deeper draughts) and leads to loss of deadweight. ABS has calculated the additional steel cost in the double hull capesize bulk carrier to be about $484,000 while savings due to reduced maintenance and cleaning amount to approximately $9,700 per year [ABS]. More detailed calculations by [Vassalos et al 2004] which include steel, coating and construction costs as well as running costs such as increased fuel consumption, increased maintenance and repair costs and loss of earnings due to reduced deadweight and volumetric capacity, add up to $4,869,264 for a cape. The benefits to the ship owner, port and stevedores due to reduced time in port as well as increased scrapping value in the same analysis add up to $556,414. There are experts, however, who suggest that the structural weight could be reduced reasonably in comparison to the existing double hull designs" [Jang et. al 2002].

More important than the loss of deadweight is the loss of grain capacity (cubic meters of cargo hold space). This may not be such a great issue for high-density cargos like iron ore but will be of major importance in the trade of lower density cargos such as coal. Ways, which have been considered to reduce the loss in freight earning capacity (both weight and volume), include the use of high tensile steel and the reduced double bottom depth respectively, but this may have a negative effect on the strength of the hull girder [Naval Architect 2003a]. There is extensive research going on to perfect a steel/concrete sandwich double skin using a special lightweight 900 kg/m3 concrete aggregate as shown in Fig. 3.7-6.

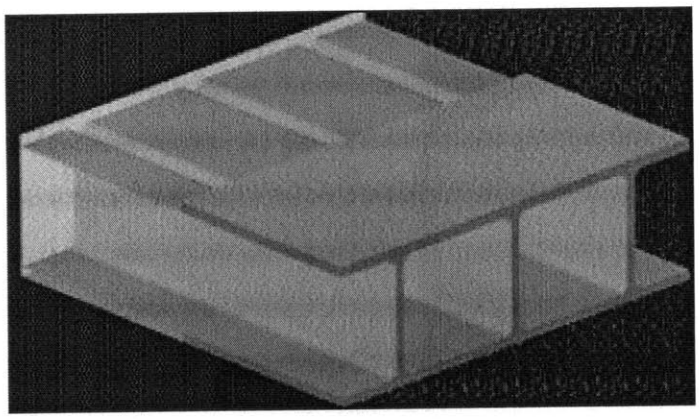


Fig. 3.7-6: Steel Concrete Sandwich double hull structure [Naval Architect 2003b]

This will be stiffer and hence will allow narrower double hull and d-bottom spaces to be occupied saving more cargo space. There are fears, however, that it will be more uneconomic if regulations are imposed on the minimum width of the double hull space [Naval Architect 2003b].

As a conclusion, excluding safety issues, it should be left to the market and owners' discretion to judge which is the most competitive design and this is not the purpose of legislation. As Arthur Bowring states "*Commercial considerations should be left to market forces, not to regulation*" [Bowring 2003]. Therefore, it is natural that the proposal was voted against by 32:22 [O'Mahony 2004a, Corbett et al 2004b]. Nevertheless, there have been proponents of the double hull who have been pushing for it to be mandatory, mainly for commercial reasons. An example includes Luis Dreyfus, an owner of double hull bulk carriers who a year later issued a plea for the adoption of double hulls as the standard for large bulk carriers. He was arguing that this would get rid of the 15%-20% of the world fleet which are substandard and whose owners would have difficulty finding the resources to convert them to double hulls [Spurrier 2005].

There are several owners who seem to prefer the double hull design, for example Transmed [Lloyd's List 2004a], Angelicoussis [Lloyd's List 2004b], K-Line and Dreyfus [Corbett et al 2004a]. Many including Transmed seem unaffected by the IMO decision to reverse its previous decision for compulsory double hull design as they have continued to order double hull capesize bulk carriers [Lloyd's List 2004a, Corbett et al 2004a].

Both the s-hull and the double hull designs have advantages and disadvantages and it will be interesting to see which is going to be most widely adopted in the future.

3.7.3 Designing against Cracks

Cracking is generally associated with corrosion, rough treatment in a rough environment, and with the neglect of fatigue and stress concentrations in the design and fabrication. According to Lloyd's Register, one of the main factors which can contribute to structural failure and loss of bulk carriers is the design of details such as the main frame bracket toes [MER 1997].

Individual fatigue analysis for such details has been carried out in the past in order to improve design [Andersen et al 1995, Hansen et al 1995, Sørensen 1995] and fatigue design criteria have been established [Capanoglou 1993]. Design has a strong influence on the cracks that a ship will develop during its service life. An example where this is evident is in European ships whose construction is significantly more stiff and heavy than Asian ones, resulting in more cracks.

One of the most important precautions required in the design stage is to avoid high stress concentrations. These can result from geometrical discontinuities, corners, sharp edges, holes, connections, welds, changes in thickness, hard spots etc. A hard spot is defined as a point of high rigidity in a more flexible structure i.e. when there is an abrupt change in rigidity [LR 2004a]. According to Lloyd's register, a hard spot occurs when the distance between the end of a bracket and the next supporting floor or stiffener exceeds 80cm [LR 2004b].

Another way to reduce the probability of cracks is by enhancement of critical locations. A remarkable difference in the applied stress range can be achieved by the attachment of transverse frames in topside tanks. Cracks can also occur due to the misalignment of connected units. This is because of the resulting bending moment and high stress concentration. A typical example is the misalignment of two brackets that are attached on either side of a plate. This is illustrated in Fig. 3.7-7.

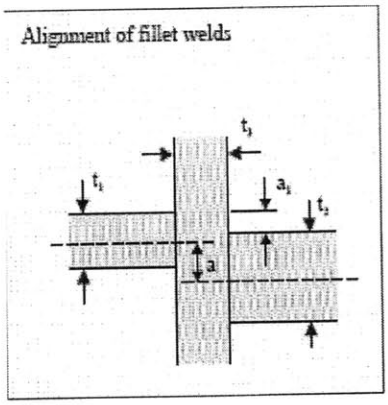


Fig. 3.7-7: Resulting moments and stress concentrations due to the misalignment of connections across a plate

Besides preventing cracks, it is also important to consider the implications and to ensure an acceptable outcome after they develop. Crack arrest sites are frequently used to stop cracks from propagating to large lengths. However, they are sometimes avoided because they are expensive, and do not allow for large continuous sections that are convenient in construction. Another example where fatigue prone design is tolerated is in the use of scallops. These are a recognized high stress concentration site but are essential for the assembly of blocks during fabrication.

3.7.4 Design Methods

Classification societies' rules for ship scantlings are generally derived from experience-based criteria that include many semi-empirical formulae. However, these formulae-based rules are a significant development from the pure deterministic table rules of the 1950s [BMT CORTEC LTD 1993]. Ship designs in the past were solely based on static principles which were modified by empirical factors to account for actual dynamic conditions [MER 1993].

A good understanding of the possible loads to which a hull may be subjected, is critical in design. As put by [Saunders 1965], "It is necessary to coordinate what seas look like to seafarers with what naval architects imagine them to be". Waves of significant heights

"Hs" in the range 13 to 15 meters can be expected in severe storms of Beaufort 10+, and consequently waves of up to 26 to 30m may be encountered [Faulkner et al 1996]. The resulting hull stresses and bending moments may depend on numerous parameters and are by no means straight forward.

In general, loads from the sea are transmitted from the shell plate to the secondary members (stiffeners), from there to the primary members (large webs), and finally to the hull girder. Loads are transmitted along this path by shear and bending via welded connections. These connections form the topic of detail design. The type of detail and design at these locations is critical to structural safety, because small cracks can propagate from these welds and cause significant damage.

Our understanding of the loads acting on the hull has improved significantly over the past few years and this has impacted the design of ships. It was assumed that the major hull loads were carried by the main deck on the two sides of ship. Consequently, the cross deck plates between hatch openings were made thinner. After several studies, we came to realize that higher stresses act on cross decks. This may be due to torsional effects that are imposed by twisting and compression as a result of heavy cargos in adjacent holds [The Motor Ship 1994]. Furthermore, the cross deck structure may be subjected to side loads during bad weather conditions. As a result, thickness requirements of cross deck plates have increased significantly.

The increasing use of Finite Element Analysis FEA over the past 30 years has also enhanced our understanding of the stresses to which the various structural components are subjected during different situations. Fig. 3.7-8 shows a typical 3-D finite element model of a cargo hold of a double hull cape.

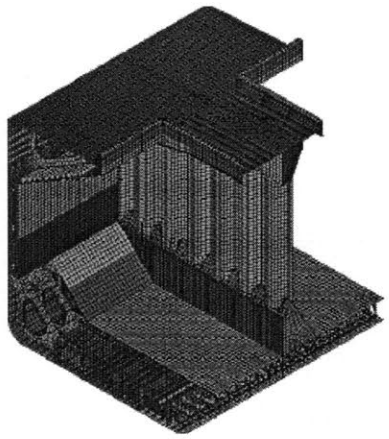


Fig. 3.7-8: 3-D F.E. Model of a Double-Hull Cape [Vassalos et al 2004]

The detailed stress results obtained from the F.E.A. can be evaluated to assess the fatigue strength at specific locations with greater accuracy. This allows for a more efficient allocation of scantlings while avoiding excessive conservativeness in the areas that are less understood.

The methods currently used for estimating fatigue life are quite inaccurate while there is limited use of fracture mechanics. A better understanding of the stresses acting throughout the hull, however, will lead to better designs of higher fatigue strength and a reduction in fatigue related problems.

3.7.5 Hull Strength and Flooding Survivability

IACS requires the structural strength of ships to remain above 90% of their original value. This is controlled through several parameters including the section modulus and moment of inertia of the hull girder and the thickness of plates. There are also section modulus requirements for stiffeners that are contributing and that are not contributing to longitudinal strength. According to the rules of ABS, LR, and BV, the minimum hull girder section modulus at the mid-ship section for ships between 90 and 300 meters in length is given by:

$$Z_{\min} = 0.01 \times \left[10.75 - \left(\frac{300 - L}{100} \right)^{1.5} \right] \times L^2 \times B \times (C_b + 0.70) \qquad (3.7\text{-}1)$$

Where: Z_{min} = Minimum Hull Girder Section Modulus (cm^2m)

L = Scantling length (m)

B = Ship Beam (m)

C_b = Block coefficient at summer load

Besides a minimum standard regarding hull diminution, there are additional rules that ensure safety and the ability to survive harsh weather conditions. One of the most important ones concerns flooding survivability. "... bulk carriers over 150m in length, designed to carry solid bulk cargos with a density of 1,000kg/m3 and above, shall have sufficient strength to withstand the flooding of any one cargo hold..." [Mortensen 1998]. According to the IMO 1997 SOLAS Conference, all new single skin bulk carriers built on or after 1st July 1999 are required to have sufficient strength to withstand flooding of any one cargo hold, also taking dynamic effects of the water in the hold into account [IACS 2004, IACS 2002, Plaza 1998]. The rules for older vessels require that the ship can withstand the flooding of cargo hold number 1 in all approved loading conditions [Mathiesen 1998].

High danger is associated with the flooding of a cargo hold because of the consequent progressive collapse of bulk heads. This was the cause of the two major cape incidences "Giga 2" (140,000dwt built in 1981) and "Pos Challenger" (149,000 built in 1992). The crucial point is the bulkhead between cargo hold 1 and 2, since about 40% of casualties involve water ingress into cargo hold 1 [Plaza 1998]. Work on the collapsing of bulkheads has been carried out since a long time ago [Caldwell 1955, Paik et al 1998c], and more recently using non-linear FEA modelling [Paik et al 1997b, Grundy 1997].

The numbers of cycles to failure (N) in a bulkhead can be approximated as follows:

Typical hot-rolled 0.2%C steel under large cyclic strains: $N = \frac{6400}{\Delta\varepsilon}$ [Fuchs et al 1980]

(3.7-2)

For a butt weld: $N = \frac{1000}{\Delta\varepsilon}$ [Guerney 1979] (3.7-3)

For a fillet weld: $N = \frac{400}{\Delta\varepsilon}$ [Guerney 1979] (3.7-4)

By simple calculation, therefore, one can observe that for a small cyclic strain of 1%, and a loading period of 10s, the fatigue life is about 2.8 hours for a butt welded bulkhead and 1.1 hours for a fillet weld. Evidently, the strength of a bulkhead is highly dependent on the welds. Lloyd's Register requires the upgrading of the bulkhead lower end weld connections to a deep penetration standard as shown in Fig. 3.7-9 [Tustin 1998].

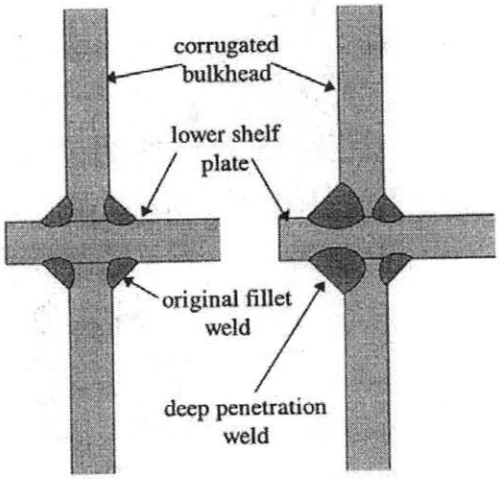


Fig. 3.7-9: Fillet weld upgrading [Tustin 1998]

The residual strength of the hull girder is often decreased substantially due to fatigue cracking and corrosion. Therefore, progressive flooding may also lead to total hull girder collapse [Paik 1994]. Another important consequence of progressive flooding is that it can eventually lead to the loss of stability and capsizing in rough seas [Turan et al 1994].

It is possible for accidental flooding to occur in any hold but there is a view that it occurs most often in cargo hold 1. More than 40% of all water ingress incidents have occurred in Hold No 1, while in 90% of the cases, water ingress was through the side shell [Mathiesen 1998]. Water ingress through the side shell is usually due to a combination of wave slam and hull girder bending or twisting, after a reduction in residual strength due to

fatigue cracking, mechanical damage or corrosion. Flooding is then followed by collapse of the bulk head separating the first 2 holds since, unlike the collision bulk head, it is not designed to withstand the hydrostatic pressures that are further amplified by the ship motion [Grundy et al 1998].

The other common way of flooding is after the collapse of hatch covers under heavy sea loads on the deck. This forms a vital design aspect. Side shell failure accounts for half of bulk carrier casualties while water ingress through hatches accounts for 20% [Jones 2003]. Research in hatch cover design and failure with respect to water induced loads, maintenance and operation, has been carried out with reference to case studies and using FEA [Faulkner 2001, Faulkner et al 1996, Byrne et al 1998, Byrne 1995, Hansen 1982].

In response to several hatch related casualties, a fore castle is required in new ships, old ships are retrofitted with a wave break barrier, and requirements on the ability of hatch covers to withstand severe weather conditions have increased. The total cost of upgrading a bulk carrier to URS21 standards is approximately 4% of the total cost of 9 covers and this would increase the weight of the hatch covers by about 33% [Langdon et al 2002]. The cost of replacing covers on existing ships is approximately six times higher, although in some cases, reinforcements may be possible at a lower cost [Langdon et al 2002].

This example demonstrates that it is not always cheaper in the long term to design to the currently minimum required standard. Another example is oil tankers that were constructed with a small double hull before the legislation was enforced, and were given a significantly extended phase-out date.

3.7.6 Grounding and Collisions

Besides designing to prevent damage, it is equally important to design with respect to ship performance after damage has occurred. There has been an increasing interest in accurately predicting the consequences of collision or grounding accidents, in order to account for them during the design stage.

One of the most famous early studies on collisions was carried out by [Minorsky 1959]. Based on 26 ship collisions, he developed a simple empirical equation to relate the absorbed energy E (tons-knots^2) with the destroyed material volume R_T (ft^2-in). The equation is $E = 414.5R_T + 121{,}900$. Since then others have proposed various modifications based on this equation [Zhang 2002, Wang and Ohtsubo 1999].

Rigid wedge cutting of thin metal plates has been studied extensively since the Exxon Valdez oil spill in Prince William Sound, Alaska, on March 24, 1989. This research affected tanker safety regulations drastically, leading to the adoption of the double-hull. The process has been modeled differently by various research groups. Far-field plastic deformation and near-tip fracture are considered the main direct mechanisms, while friction is also occasionally considered as an indirect mechanism.

Experimental methods have been used to determine the governing parameters. [Lu & Calladine 1990] proposed a single-term formula to describe the required work, incorporating the effects of far-field plastic deformations and near tip fracture. [Atkins 1990 and Atkins 1991] on the contrary, supported the idea that two independent parameters must be used, one for each region.

[Wierzbicki & Thomas 1993] propose a closed-form solution, based on a simple kinematic model, using a single parameter to describe both near-tip and far-field areas. The quasi-static equilibrium of cutting is expressed using the principle of virtual work, and the membrane work near the crack tip is calculated using CTOD theory. This approach combines plasticity, fracture mechanics and friction in a simple formula. It supports prior one-parameter experimental results by [Lu & Calladine 1990], while also considering the contribution of friction. It also demonstrates the interdependence of far-field and near-tip deformations, thereby mitigating the need for two independent parameters to describe the required work.

The steady-state case of wedge cutting of metal membranes was also studied by [Zheng & Wierzbicki 1995]. A plastic zone at the wedge tip, a transient bent flap zone, and a transient zone were identified. Each was modeled using geometric analysis, while the wedge force and rolling radius were calculated using membrane theory. A frictional force term was added and a closed-form solution was derived, using a kinematic admissible velocity and displacement, defined such that the actual cutting pattern was consistent. The wedge force

solution was found to be dependent to the friction force and to the flow stress. A parametric study was then carried out and results were validated with experimental data from [Lu & Calladine 1990], [Yahiaoui 1994] and [Astrup 1994]. This technology provided a reliable analytical tool for the prediction of steady-state wedge cutting of metal membranes. Theoretical and experimental results were compared and empirical results were established.

Analytical methods for studying collision and grounding have been developed and used extensively since these earlier studies [Simonsen and Tornqvist 2004, Wang et al 2002a, Wang et al 2002c, Pedersen 2002, Brown et al 2001, Brown 2001, Suzuki et al 2000b, Wang et al 2000a, Paik et al 1999, Wang and Ohtsubo 1999, Simonsen 1997, Ohtsubo et al 1997, Wang et al 1997, Wierzbicki et al 1993]. With the rapid development of computer technology however, FEA simulations are becoming more efficient and provide much more detail than other methods. Their reliability has been demonstrated and they have been used for the simulation of both collision and grounding accidents [Ozguc et al 2005, Kajaste-Rudnitski et al 2005, Yamade et al 2005, Wu et al 2004, Lehmann and Biehl 2004, Wu 2004, Jiang and Gu 2004, Tornqvist 2003, Endo 2001, Lehmann et al 2001, Glykas et al 2001, Kitamura 2001, Kitamura et al 2001, Kitamura et al 1998, Kuroiwa 1996]. It is often helpful to combine these two approaches and use an analytical method in order to decide on the FEA parameters such as mesh size.

One of the main challenges in non-linear FEM is analyzing problems like the simulation of cracking [Wang et al 2002c]. The most common assumption is that fracture initiates when the "equivalent strain" reaches a critical value [Wu 2004]. Efforts have been made to calculate this value of critical rupture strain from large scale tests and real life observations [Wang et al 2002a, Kitamura 2001]. The element size is perhaps the most critical parameter for its assessment [Simonsen et al 2000].

Though this assumption regarding crack initiation is convenient for numerical and analytical solutions, it is not theoretically proven. More sophisticated models which consider material behavior around the crack tip are also being developed [Simonsen et al 2004]. Another difficulty is that very fine meshes are required due to the high complexity involved. This increases calculation time. Simulation of one second of an accident, for example, requires about a week of CPU time, whereas a linear model for a design purpose lasts about ten minutes [Wang et al 2002c].

It is important to assess the risk of collision and grounding accident scenarios, based on the probability of occurrence and on the consequences. Parameters which should be considered include the residual strength and reserve stability after the accident, as well as the environmental impact. One of the main challenges is to predict the energy released during the impact, and the ability of the hull to absorb it. A significant amount of research has gone into this [Lehman et al 2001, Suzuki et al 2000a, Paik et al 1999, Pedersen et al 1998]. Studies have also been performed to investigate the response during accidents with respect to design [Tikka et al 2000, Paik et al 1999, Kitamura et al 1998, Kitamura 1996]. These provide a good guidance in designing against collision.

Some classification societies have introduced requirements related to collisions and groundings. ABS provides a method to check the residual strength of ships after grounding or collision [ABS 1995]. GL also uses a notation to rank the resistance of a vessel against a pre-defined set of scenarios. Standards against collision, however, have not yet been set and this is probably due to the lack of knowledge so far.

Research has been carried out on the residual strength of ship hulls after collision or grounding [Wang et at 2002b, Paik et al 1998b, Wang et al 2000b]. [Wang et al 2002b] provide simple equations for the quick calculation of hull strength during an emergency situation. These are of the form:

$$\frac{Z'}{Z} \approx 1 - \alpha_1\left(\frac{b}{B}\right) - \alpha_2\left(\frac{b}{B}\right)^2 - \alpha_3\left(\frac{b}{B}\right)^3 \qquad (3.7\text{-}5)$$

Where: Z'/Z = Ratio of final to original section modulus of deck or bottom

b/B = Ratio of damaged to total length (vertically or horizontally)

$a_{1,2,3}$ = Tabulated constants depending on the ship type and dimensions

Their findings show that the residual strength after accidents depends on the ship type and that it is irrespective of dimensions. The reserve of residual strength during collision in bulk carriers ranks between that of tankers which are 1st and containers which rank 3rd [Wang et al 2002b].

Expanding knowledge of the dynamic behavior of structures under impact loads has presented researchers and naval architects with the challenge of creating a collision-resistant ship. An important step towards this achievement was the development of a Y-shaped support web that was patented by Hans Ludolphy, R&D coordinator at Royal Schelde Naval Shipbuilding in the Netherlands [Van Dyck 2002a].

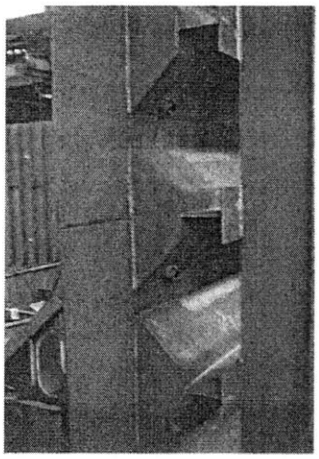


Fig. 3.7-10: Construction of Y-Shaped Web [Van Dyck 2002a]

During a collision, the structure deformation absorbs the force by a combination of bending buckling and stretching. This has also been verified by successful collision tests, as shown in Fig. 3.7-11.

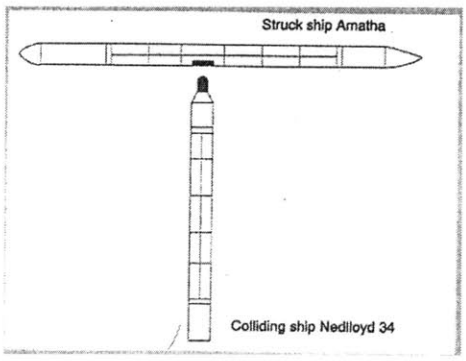


Fig. 3.7-11: Collision tests of the Libra Dynamics Collision Resistant Ship Structure in Holland [Van Dyck 2002a]

The structure can easily be fitted to a single or double hull ship and only slightly increases newbuilding costs while significantly improving structural safety [Van Dyck 2002a].

Japan has been collecting data on collisions since 1991 in an endeavor to design a "crash-worthy ship structure". Full-scale tests were performed on grounding in 1994 and collision in 1997, as well as dynamic and quasi-static impact tests in MHI's Nagasaki shipyard. A computerized model of the effects of these tests was then created. This led to the development of a more collision/grounding-resistant hull structure but also to the development of a commercially viable type of steel that is said to yield but not fracture [MER 1998].

A significant amount of research has led to major developments towards creating a hull that can withstand grounding and collision. Fracture mechanics, however, has a long way to go until it can be used to calculate the effects of the impacts on the hull. FEA methods, similarly, are still not advanced enough to accurately predict the dynamics and resulting damage of ship collisions within a reasonable CPU time. Consequently, it will take some time before such designs can become standardized in capes.

3.8 Steels

3.8.1 High Tensile Steel

Various grades of ship building steels exist, comprising of both mild and HTS. The introduction of HTS in shipbuilding is generally regarded as one of the most significant developments over the past 30 years. The yield stress of HTS 36 (grades A, D & E) is 355MPa compared to 235MPa of mild steel (grades A, B, D & E). These are the most common grades used in ships, but intermediate yield stresses of 265MPa and 315MPa are also available, as well as higher grades like HTS 40 (A-D &E) with a yield stress of 390MPa [IACS 1996].

At first, HTS was only confined to the upper flange of the hull girder and occasionally the lower flanges. The upper flange refers to the main deck plating and longitudinals, the sheer strake, and the top strake of the longitudinal bulkheads. The bottom flange includes the bottom and bilge platting with their longitudinals, the double bottom girders, and the tank top plating. Gradually, as more experience was gained, HTS was extended to all longitudinals and transverse material. It has been used extensively since the early 1980s.

The use of HTS allows for thinner plates that can still cope with the applied loads. This decreases the lightship, thereby reducing construction and fuel costs, and increasing deadweight capacity. This improves the specification, making a ship more attractive to buyers. The shipyard also finds it more attractive since less steel is handled during construction, thereby reducing the costs of production.

The yield stress for HTS 36 is almost 50% higher than that of mild steel. Weight savings of 25-30% were thus common with the use of HTS during the 70s and early 80s [Mortensen 1998]. However, weight savings through the use of HTS were then reduced to approximately 15% [ABS 1991]. Today, this value varies significantly across ships. It is interesting to note the increase in percentage of HTS with bulk carrier size, as shown in Fig. 3.8-1.

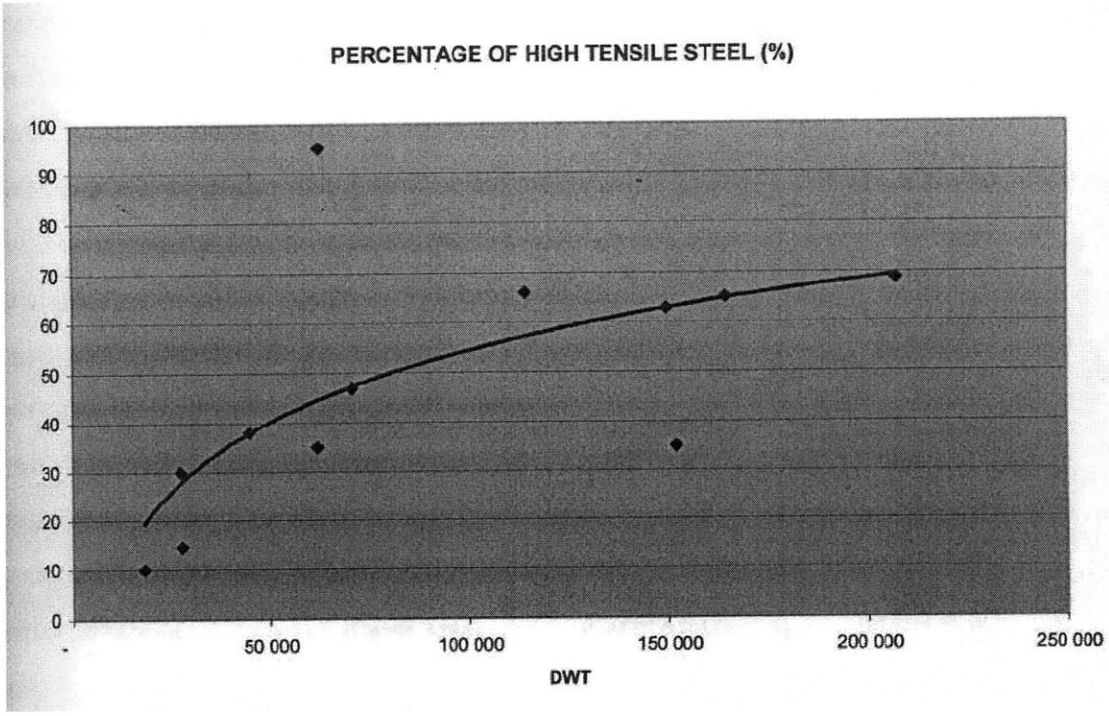


Fig. 3.8-1: Percentage of HTS against bulk carrier size [DNV 1997]

The use of thinner plates through the application of HTS has several commercial advantages to offer. However, the structure is subjected to higher stresses because the loads are applied over reduced cross sectional areas. Since fatigue strength is not increased, this dramatically impacts crack growth rates, which vary approximately with the cube of the applied stress (Section 3.5.6). Unless appropriate measures are taken, HTS will endure a shorter fatigue life [Ferguson et al 1991].

In addition, thinner plates are associated with higher bending displacements (flexing) throughout the hull girder and with a phenomenon known as "springing" (vibration of the hull with short sea waves), which is very common among HTS-built vessels. This further aggravates fatigue and results in coating breakdown, which accelerates corrosion. This is particularly important because corrosion allowances (quoted as a percentage of the initial thickness) are already reduced to start with (in absolute terms) due to the use of thinner plates. Therefore, HTS uses up the corrosion margin earlier than mild steel [LR 1991].

Another problem associated with high tensile steels is that they are more difficult to weld and more prone to cracking because they are less tolerant to deviations from optimally

established welding parameters. Since fatigue strength is not increased when introducing HTS, the effect of defects in welding and alignment problems is magnified. Consequently, details which gave satisfactory service life in a mild steel vessel may not do so in a comparable HTS vessel. Therefore, higher quality control and a highly skilled workforce are required. This increases maintenance cost.

Areas in which many failures have been noted on HTS vessels include scallops of transverse webs and bracket connections of longitudinals. Extra care is necessary in alleviating stress concentrations in HTS vessels.

Due to these problems, there is a tendency of avoiding HTS in primary structural members over the past few years. However, this is not always true, since in some cases, the savings in cost, consumption and capacity may outweigh the disadvantages over a certain period of time. Typically, Japanese owners prefer the use of HTS as they often build ships to operate for about 10 years before selling them. Corrosion and fatigue cracking problems begin to play a major role during the later years of a ship's life. Therefore, HTS is a more attractive solution in this case. Table 3.8-1 summarizes the main advantages and disadvantages of HTS over mild steel.

HTS ADVANTAGES	**HTS ASSOCIATED PROBLEMS**
Reduced Capital Cost: Reduced Lightship (~15%).	Structural problems: Higher Stress Concentrations, nominal working stresses and strains (flexing), while fatigue strength is not increased.
Profitable: Increased Deadweight and reduced fuel consumption.	Increased maintenance Costs: Higher Corrosion rates and reduced corrosion margins. Higher skill labor and less standard repair materials required

Table 3.8-1: Advantages and Disadvantages of using HTS as opposed to mild steel

3.8.2 Anticorrosive Steel

Nippon Steel Corporation (NSC) developed an anticorrosive steels that claims to slow down the progress of pitting corrosion to about a fifth of that in regular steel, irrespective of maintenance or environmental conditions [Burton, R. 2004]. Its cost is acceptable and its performance is verified experimentally as shown in Fig. 3.8-2. It might have a positive environmental impact by displacing paint coatings, particularly in ballast tanks.

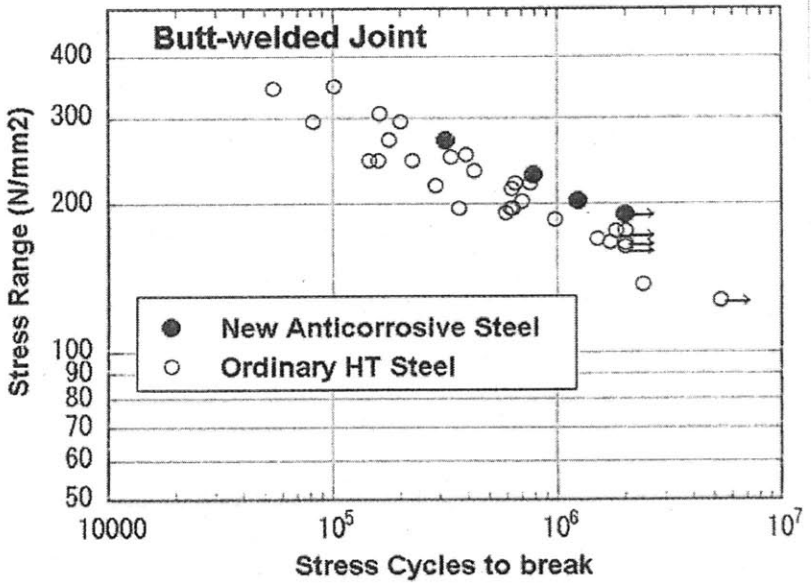


Fig. 3.8-2: Fatigue Performance of a butt-welded joint confirmed by NSC and MHI [Burton 2004]

3.8.3 Steel Products for Shipbuilding

There has been a recent trend towards higher performance, exclusive-use ships, and improved construction productivity. This has resulted in the need for new steel products and technologies. JFE has developed 6 products to address those needs including four plate products, one pipe product and one TMCP technology for shapes for shipbuilding. These are discussed in detail by [Suzuki et al 2004]

The size of containerships has increased rapidly over the past few years, requiring plates of higher strength and thickness. This, however, poses problems in weldability and toughness. High thickness requires high heat input during welding which coarsens the microstructure in the Heat Affected Zone (HAZ). Adding alloying elements and increasing the carbon equivalent to improve strength also limit weldability and toughness. In the "EWEL" high heat input, Thermo-Mechanical Control Process (TMCP) plate, excellent properties and weldability are achieved by using Super-OLAC (online accelerated cooling technology) to get a yield strength of 390 N/mm2 at low carbon equivalent and upper bainite levels (detrimental to toughness), optimum TiN to refine grain size in the HAZ, and microalloying technologies to control microstructure in the HAZ. These steels have been adopted to large containerships and LPGs and have received excellent evaluations so far.

Longitudinally Profiled (LP) Plates, or taper plates, have a continuously changing thickness which is achieved by continuously changing the roll gap during rolling. They can be applied to bulkheads, the deck, bottom plates etc. and offer significant reductions in welding and material requirements. For example, 2500t LP plates were used in a 170,000t bulk carrier reducing weld length by 700m and steel weight by 218t. Adoption has increased dramatically since 1993 and bi-directional LP plates recently developed.

Clad Steel Plates consists of a base material (a carbon steel or low alloy steel plate) and stainless steel (or other material) plates bonded on one or both sides. The base plate offers the required strength while the other plates offer protection and other properties required on the outside. This results in a composite plate with properties that are not possible using a single material. They are particularly useful in chemical tankers which need to withstand severe loading conditions while they also require high corrosion resistance as they are exposed to a variety of chemicals. Application of Stainless clad plates in tankers, therefore, has increased substantially since the beginning of the 1990s. There are various manufacturing processes but JFE Steel uses the rolling cladding process. Accelerated corrosion tests, tensile tests and Charpy impact tests were carried out on JFE clad steel plates with satisfactory results showing sufficient properties for hull construction.

Crude oil tankers are subjected to "vapor space corrosion" in the area just under the decks. The average corrosion rate in vapor space is about 1mm/year so the long service life of tankers often requires expensive replacements. The New Anti-Corrosion No 5 (NAC5)

plate promises to extend the service life of deck plates by approximately 5 years. TMCP technology is applied to reduce the carbon equivalent to the level of conventional steels thus achieving equivalent weldability. Cyclic corrosion tests simulating the environment under the deck were carried out on conventional steel and NAC5 plates without primer. The corrosion rate of both the base metal and the weld metal was about 10% lower in the NAC5 plates.

The pipes of oil tankers are exposed to oil and seawater and oil on both sides so they are required to have high sea water corrosion resistance and corrosion wear resistance. JFE-MARINE-COP offers the corrosion resistance and corrosion wear resistance of cast iron with an equivalent weldability to 400MPa steel. JFE-MARINE-COP with 1% Cr has approximately half the corrosion rate of conventional 400MPa steel. No corrosion was observed in the base or weld metal of JFE-MARINE-COP cargo oil pipes on the vessel Benetia after 3 years of service. It can be manufactured in outer diamterers ranging from 76.3mm to 1016mm and JFE Steel currently produces ~5000t/yr.

JFE was the first in Japan to manufacture shipbuilding steel shapes and has been a leader in the field ever since. It has a long production line of shapes and is certified to produce for a wide range of standards and applications. Shapes for shipbuilding are asymmetrical both in the vertical and longitudinal direction so material properties and manufacturing design in the hot rolling process are important. JFE has introduced equipment such as an exclusive-use shot blasting device for shapes and the first water cooling type TMCP technology for shapes (originally used for plates), thus enabling it to meet low C_{eq}, high toughness requirements and achieve weldability equal to that of plates. High accuracy rolling is achieved 2-hi rolls by applying FEM analysis.

JFE has developed and commercialized several advanced shipbuilding steel products in the past several years. They include plates TMCP for reduced welding time in containerships, LP plates that save on material and weld length, NAC5 anticorrosive plates for crude oil tankers, clad plates for chemical tankers, the JFE-MARINE-COP reduced corrosion wear cargo pipes for tankers and a wide range of shape steels using TMCP technologies and achieving weldability equal to that of plates. Increased adoption of those is expected in the future while JFE Steel group will continue to introduce new products.

3.9 Stress Analysis

3.9.1 Overview of the Hull Stresses

Capes are subjected to various loads throughout their life. These are very difficult to predict because of uncertainty in weather predictions, the random nature of wave-induced and cargo-loading-induced bending stresses etc. Loads can be divided under static or dynamic. Static loads are those which remain relatively constant with time. Examples include cargo weight, hydrostatic pressure and ballast weight. Dynamic loads are fluctuating and are responsible for fatigue. Examples include wave induced loads, cargo induced loads during cargo operations, internal slamming during ballast passage, and tank sloshing, which is particularly damaging in low filled tanks.

Bending moments are generally divided into still water and wave or weather induced. Each classification society has its own prediction method, based on empirically derived rules. Still water bending moments result from the cargo and ballast loading condition. They effectively impose a mean value about which weather induced bending moments fluctuate. Wave induced loads are generally transmitted from the shell plate to the secondary members (stiffeners), from there to the primary members (large webs), and finally to the hull girder. Loads are transmitted along this path by shear and bending in the welded connections.

Even though fatigue is caused by the wave induced dynamic loads, the still water bending moments are also crucial. This is because fluctuations about a higher mean value is much more likely to exceed an allowable stress limit, resulting in a fracture or a permanent deformation (yielding).

Besides global bending moments, there are a series of other factors that may cause cracks. Examples include shear forces, weather induced stresses and slamming, corrosion and wear, damage or overstressing during cargo operations, collision or grounding, sloshing in ballast tanks etc.

3.9.2 Iron Ore Loading and its Implications

There is a prevalence of iron ore cargos in bulk carrier losses. Most of the reasons for this are associated with its high density. Dedicated iron ore carriers are designed so that cargo holds are full when loaded but they are very rare. In capes, iron ore is either loaded in alternate holds, leaving four holds empty, or homogeneously, in which case all holds are partially loaded. Note that even in alternate loading of iron ore, bulker holds are only about two-fifths full [NK 1992].

Partly loaded holds allow for a large floodable volume and provide no counterforce to the hydrostatic sea pressure loads against the shell plate. This combined with transverse bending of the double bottom due to cargo weight, cause flexing and fatigue of the side shell and frames. Furthermore, the dense slurry that forms during flooding often causes bulkheads to collapse.

During loading, iron ore is dropped from into the holds from high above. This results in impact damages and dents which then form stress concentration sites. Due to its abrasiveness, iron ore also leads to wear and coating breakdown. Corrosion is exacerbated by the typical sequential loading of abrasive iron ore and corrosive coal. The high density of iron ore also permits high loading rates which increase the chances of deviating from loading plans. This is discussed in Section 3.9.3.

Free surface effects are not a great danger with iron ore. However, inadequate cargo trimming in partly loaded holds can lead to non-uniform loading. This increases local stresses on the double bottom. Furthermore, the vessel's stiff and rapid rolling motion, due to heavy ore, increases the dynamic loads from the cargo, water and hull mass, exacerbating the loading situation [NK 1992, Ferguson 1991a]. This is more intense if cargo is loaded homogeneously because the centre of gravity is lower. In alternate loading, the ship's centre of gravity is higher and the rolling period is about 10% higher than in the homogeneous loading condition [Plaza 1998].

A significant advantage of alternate loading is the time saved in terminals. Only five cargo holds have to be discharged instead of nine, while the bottom part is the most time consuming. Furthermore, fewer holds require cleaning and inspection. During loading, time is saved because cranes need to move less frequently from one hold to another.

Alternate loading is used with high density cargos like iron ore, which accounts for more than half of the capesize trading volume. Cargos in capes often come in 2 bunches (some times of a different grade of iron ore), that have to be unloaded in two consecutive ports. In this case, the only option is a homogeneous loading condition on the first trip, followed by alternate loading on the second. This is because cargo redistribution after unloading the first bunch is usually impossible since loading and discharging facilities are not both available in the same port. Even when they are, it is very difficult, expensive and time consuming.

Alternate loading is fast, cheap, convenient and effective but it also amplifies hull stresses. The maximum shear force, bending moment and tank top pressure, all approach the maximum permissible levels, leaving only little reserve strength for the case of accidents. Alternate loading involves higher loads on the inner bottom plates of laden holds. It also involves high shear stresses on the longitudinal girders that support the cargo weight in one hold, along with the up-thrust acting on the empty adjacent holds. This is demonstrated in Fig. 3.9-1 and Fig. 3.9-2, which shows a finite element model of a cargo hold under alternate loading.

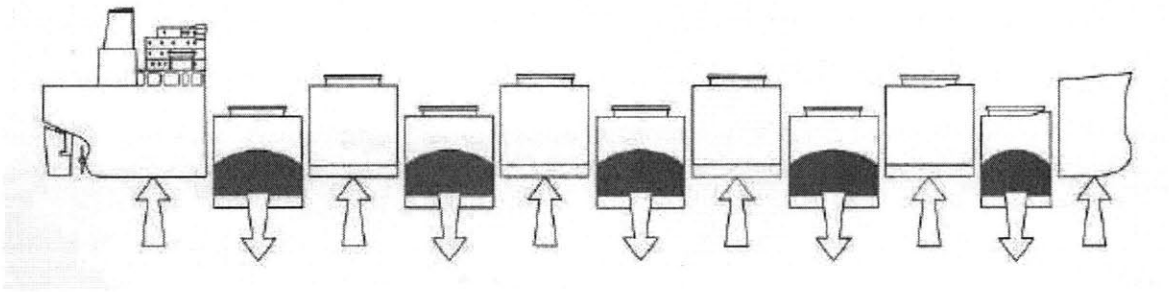


Fig. 3.9-1: Alternate Loading Still Water Shearing Action of the Hull Girder of a Cape [IACS 1997]

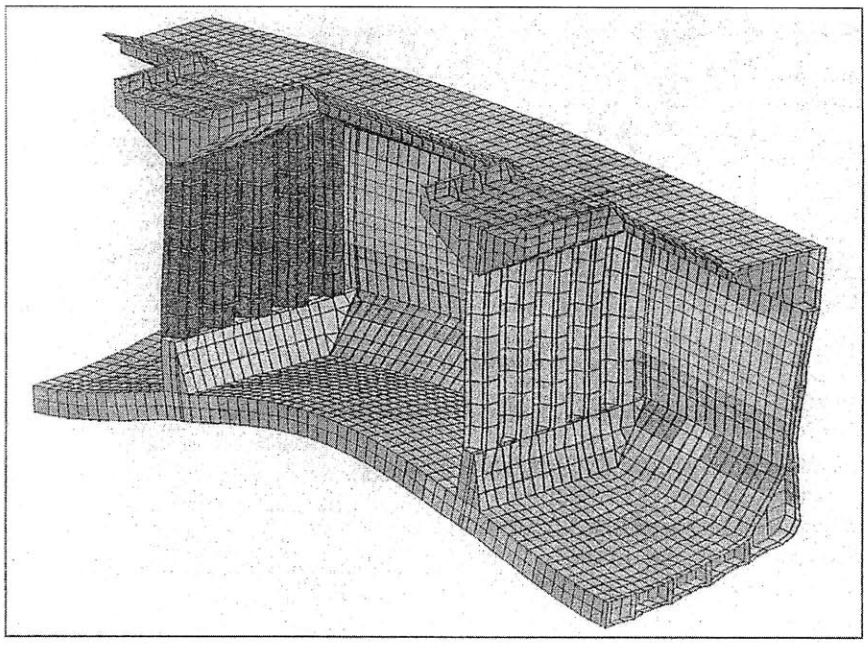


Fig. 3.9-2: F.E. model of a D.Hull BC. Cargo Hold under Alternate Loading (deformations magnified) [Shipping World & Shipbuilder 1997a]

Besides the double bottom, other locations that are highly stressed during alternate loading include the main frames and brackets, the top side tanks, the deck (particularly at the hatch corners), the hatch coamings and the cross decks. Special design is required, with strengthened structural members, in order to allow alternate loading. Regulation XII/14 of the 2004 SOLAS Amendments, states that single hull bulk carriers over ten years old will not be allowed to carry cargo of a density exceeding 1780kg/m3 (mainly iron ore) with any hold loaded to less than 90% of the maximum allowable cargo weight. The only exemptions are vessels which comply with the Reg. XII/5 structural strength requirements and the Res. MSC 168(79) s-hull side structure criteria [IMO 2004]. Most capes are strengthened and are permitted by classification to perform alternate loading, but many owners avoid it as a safety precaution, particularly in older vessels.

3.9.3 Damage during Cargo Operations

The dramatic increase in the transportation of iron ore over the late years has resulted in heavy congestion at terminals. This increases pressure to speed up cargo operations to unprecedented rates.

Heavy weight grabs weighing up to 36 tons [Plaza 1998] are used to unload capes. Therefore, careless handling can result in serious structural damage, setting the stage for corrosion and cracks. When unloading a large cape, 8,000 to 12,000 grab movements are required at approximately 1 minute intervals [Ferguson et al 1993]. Therefore, mistakes and subsequent damage are inevitable.

The use of pneumatic rams, bulldozers and pneumatic or hydraulic hammers to dislodge cargo that is stuck between frames, also contributes to failure of the shell plating. Catastrophic failure of the shell plating is suspected of being the cause of a number of vessels disappearing without trace over the past several years [IACS 1998, Shipping World & Shipbuilder 1997b]. Bulldozers or even grabs are used to vibrate the bulk heads by banging them to remove sticky cargo which may adhere on them.

It is generally understood that the rate of loading and discharging has a great effect on ship fatigue. This has been a great issue in regions like Brazilian iron ore terminals which have capacities for loading rates up to 16,000 tonnes/hr. Such loading rates are achieved by means of conveyor belts that may be several kilometers long.

It has been suggested that dynamic effects of high loading rates may directly affect the ship's structure. However, this is unrealistic as the rate required to induce dynamic hull flexing is of the order of a thousand tonnes per second [Corlett et al 1992]. Even at the highest loading rates, therefore, the ship is quasi-static, in structural terms.

Though fatigue effects have not been scientifically explained in terms of fracture mechanics, *"...damage over time caused by high speed loading have been suggested by experts as the possible causes of initial structural damage"* [Corbett 2006a]. One reason why damage may occur at high loading rates is the increased likelihood of deviating from the loading/unloading sequence plan. Exceeding the permissible shear forces and bending moments or overstressing the local structure is very likely when deviating from a

loading/unloading sequence plan. Dramatic proof of what can go wrong came about in 1994 when a bulk carrier broke in half during loading at a port in South America [Oceansatlas].

Loading and discharging plans consist of a sequence of cargo and ballast operations that are carefully calculated to avoid locally exceeding permissible stresses throughout the process. A high number of passes (cargo pours) minimizes hull stresses, but is also very time consuming and inconvenient. Fig. 3.9-3 shows a loading plan from a cape in Brazil, involving loading rates of 16,000 tonnes/hr.

Actual Loading/Unloading Plan

The loading or unloading plan should be prepared in a form such as shown below
A different form may be used provided it contains the practical information enclosed in the heavy line box

Issued date: 31-1-2000

LOADING OR UNLOADING PLAN Version No._ (delete as applicable)	Date: 18 MAY 2006	Vessel's Name: MV CAPE LORD			Voyage No. V/27-L
Load / Unload Port: TUBARAO, BRAZIL	Cargo(es) IRON ORE	Assumed stowage 25F3/MT Factor of cargo(es)	Ballast pumping rate: 2500 M3 (T/Hr)	Dock water Density: 1.025 (T/m3)	Max draught available (HW) / Max air draught in berth
To/From Port	Last Cargo IRON ORE	No. of loaders/ dischargers 1	Load or discharge rate 16,000 (Tonnes/Hr)		Min draught available (LW) / Max sailing 17.66M arr. draught : 9.27M

9	8	7	6	5	4	3	2	1
14,566 MT	15,814 MT	15,784 MT	14,737 MT	15,480 MT	15,966 MT	15,965 MT	15,972 MT	13,345 MT

Totals: Grade: Tonnes Grade: Tonnes Grade: Tonnes Total = 137,629 MT Tonnes

Pour No.	Cargo Hld No	Cargo Tonnes	Ballast Operations	Time required (hours)	Comments: NO.1	Calculated Values Draught (m) Fwd	Calculated Values Draught (m) Aft	Maximum BM*	Maximum SF*	Calculated Values (in meters) Air Draught	Calculated Values (in meters) Draught mid	Trim	Observed values (in meters) Draught Fwd	Observed values (in meters) Draught Aft	Observed values (in meters) Draught Mid
					ARRIVAL CONDITION	6.14	9.27	31%	43%	17.90	7.70	3.12			
1	5	8,000	PO DBT 2 P/S=75% / GO TS 3P/S57%	1H	1ST RUN / BALANCE = 7,480 MT	6.49	9.66	27%	50%	18.66	8.07	3.17			
2	1	7,000	PO DBT 1 P/S=71% / GO TS 1P/S 0%	1H	1ST RUN / BALANCE = 6,345 MT	7.75	8.81	33%	45%	17.05	8.29	1.07			
3	7	8,000	PO DBT 3 P/S=70% / GO TS 4P/S56%	1H	1ST RUN / BALANCE = 7,784 MT	7.75	9.59	28%	43%	17.21	8.67	1.84			
4	3	8,000	PO DBT 1P/S=43% / GO TS 2P/S56%	1H	1ST RUN / BALANCE = 7,965 MT	8.42	9.60	28%	48%	16.09	9.01	1.18			
5	9	7,000	PO DBT 3 P/S = 41%	1H	1ST RUN / BALANCE = 7,566 MT	7.51	11.63	34%	51%		9.57	4.13			
6	2	8,000	PO DBT 1P=14%, 1S=26% / TS2=0	1H	1ST RUN / BALANCE = 7,972 MT	8.72	11.00	39%	58%		9.86	2.28			
7	6	7,000	PO DBT 2 P/S=49% / GO TS3P/S14%	1H	1ST RUN / BALANCE = 7,737 MT	8.47	11.82	30%	47%		10.15	3.35			
8	4	8,000	PO DBT 2 P/S=24% / GO TS3P/S=0	1H	1ST RUN / BALANCE = 7,966 MT	9.57	11.64	30%	45%		10.60	2.07			
9	8	7,000	PO DBT 3 P/S=14%	1H	1ST RUN / BALANCE = 8,814 MT	9.18	13.04	15%	21%		11.11	3.86			
10	5	7,480	PO DBT 2 P/S = 6%	1H	2ND RUN / COMPLETE	9.88	13.48	30%	44%		11.68	3.60			
11	1	4,345	PO DBT 1P = 6 %	1H	2ND RUN / BALANCE = 2,000 MT FOR TRIMMING	11.43	12.62	15%	37%		12.02	1.19			
12	7	7,784	PO DBT 3 P/S = 5% / GO TS4P/S13%	1H	2ND RUN / COMPLETE	11.35	13.81	17%	48%		12.58	2.46			
13	3	7,965	STRIPPING DBT 1P	1H	2ND RUN / COMPLETE	13.28	13.34	26%	53%		13.31	0.06			
14	9	5,566	GO TS 4P/S = 0 / STRIP DB 2P	1H	2ND RUN / BALANCE = 2,000 MT FOR TRIMMING	12.51	15.11	16%	39%		13.81	2.59			
15	6	7,737	STRIP DB 2S	1H	2ND RUN / COMPLETE	12.99	16.09	41%	57%		14.54	3.11			
16	2	7,972	STRIP DB 3P	1H	2ND RUN / COMPLETE	15.46	15.08	33%	47%		15.27	-0.38			
17	8	8,814	STRIP DB 3S	1H	2ND RUN / COMPLETE	15.01	17.22	33%	60%		16.11	2.21			
18	4	7,966	STRIP DB 1S / STOP LOADING	1H	2ND RUN / COMPLETE / DRAFT CHECK	16.19	17.41	52%	65%		16.80	1.22			
19	9	2,000		30M	3RD RUN / COMPLETE	15.99	17.99	48%	75%		16.99	2.00			
20	1	2,000		30M	3RD RUN / COMPLETE / DRAFT SURVEY	16.70	17.66	37%	70%		17.18	0.96			
					SEA GOING	16.70	17.66	55%	89%		17.18	0.96			
		137,629 MT													

NO DEVIATION FROM ABOVE PLAN WITHOUT PRIOR APPROVAL OF CHIEF MATE OR MASTER.
Pours to numbered 1A, 1B, 2A, 2B etc., when using two loaders.
Abbreviation: PI=Pump In GI=Gravity In F=Full PO=Pump Out GO=Gravity Out MT=Empty
All entries within the box must be completed as far as possible. The entries outside the box are optional.

Name / Sign (Terminal):
Name / Ship (Sign): C/Mate Agripino R. Medel

Bending moments (BM) & shear forces (SF) are to be expressed as a %age of maximum permitted in-port values for intermediate stages, and of maximum permitted at-sea values for the final stages. Every step in the loading/unloading plan must remain within the allowable limits for hull girder shear forces, bending moments and tonnage per hold, where applicable. Loading/unloading operations may have to be altered to allow for ballasting/de-ballasting in order to keep values within limits.

NOTED & APPROVED BY: CAPT. ARMANDO N. CURIA
MASTER

REFERENCE: FLEET MEMORANDA MANUAL (M.11/S.3/No.5
FILE : REGISTER OF COMPANY FORMS
CODE: SF/CARGO/05.

Fig. 3.9-3: Typical Loading Sequence of a Cape Loading Iron Ore in Tubarao-Brazil at Rate of 16,000 t/hr

The impact forces which are generated when loading at 16,000 t/hr from a height of 18.3m are around 9 tons. Furthermore, some terminals aim to increase loading rates up to 32,000t/hr in the future [Ferguson et al 1993].

Even with a good intention and effort by the crew and stevedores to accurately follow the plan, this may be difficult due to delays in communication between the ship and terminal, or because terminal instrumentation does not give accurate loading rate information [IACS,

1998, Williams 1998, Isbester 1991]. Surveys in the past have revealed discrepancies of up to 8000 tons between shore scales and draught readings [Grey 1991]. According to Lloyd's Register, one of the contributory causes of structural failure and loss of bulk carriers is the lack of precise information regarding the weight of cargo in individual holds [MER 1997]. A 5% or 10% overload in one hold, could increase the still water bending moment by up to 15% or 40% of allowable values in sea going condition respectively [DNV 1998, DNV 1997]. Bearing in mind that stopping requires careful planning and may take several minutes [Oceansatlas], such overload conditions can easily occur at high loading rates.

According to IACS the main problems associated with overloading are the synchronization of loading and ballasting operations, the sensitivity of the hull girder shear forces and bending moments to overloading, and local structure overloading. Other reasons include inaccurate terminal weighing equipment providing incorrect data, limited time available to check the draught, and excessively loading cargo in a hold to compensate for partial bunkers [IACS 1998, IACS 1997].

It is shocking to note that, besides language and communication issues, the loading plan is often not followed, while some ships do not even have one, or have plans that don't work [Doughty, 1997]. Sometimes it is very inconvenient or impossible to stop loading in one hold and move to another according to plan. This is particularly difficult in some terminals that are unable to move the loading system along the dock. That requires the ship to move backwards and forwards in order to comply with the loading plan [Shipping World & Shipbuilder 1997b]. As a result, ships have been kept on anchorage until further notice, because their loading plans deviated from the terminal's standard procedures, which other waiting ships were ready to accept [Mortensen 1998]. This puts a terrible pressure on the master, since any delays may cost tens of thousand dollars to the owning company.

The main problem leading to overstressing is the coordination of loading and deballasting or vice versa. Loading must not exceed pump deballasting rates, but this may be difficult due to lack of capacity or information. Furthermore, ships may be tempted to continue loading, even if pumps cannot keep up, in order to remain on hire. This problem increases with age since, the deballasting rate tends to get slower as the ship gets older, while the loading rates of terminals tend to be upgraded [Isbester 1998, Corlett et al 1992]. As a

result, still water bending moment design values have been reportedly exceeded by 10-30% during loading operations [Soares 1990].

Bulk carrier losses in recent years have been well documented and in many cases have been the result of excessive stresses, induced by non-adherence to the loading plan, due to lack of information during loading or because minor attention was paid to the mandatory loading manual and diagram with regard to the loading procedure [Shipping World & Shipbuilder 1997b, Intercargo 1998a, MER 1997].

The officer in charge is responsible of ensuring that the loading sequence and agreed upon loading rates are followed, that stevedores are closely monitored and all damages reported, and that effective communication with the terminal is maintained. They also have to be in a position to stop all operations immediately if any deviations are observed [IACS 1998, IACS 1997].

3.9.4 Still Water Bending Stresses

The still water bending and shear stress distributions throughout the hull depend on the loading condition. Capes in general sail under 4 standard loading conditions, except in rare circumstances. These are "homogeneous loading" whereby all cargo holds are similarly loaded, "alternate loading" where every second hold is loaded, "light ballast" where only the ballast tanks are ballasted, and "heavy ballast" where usually one or in some cases two cargo holds are also ballasted.

The worst loading condition in terms of stresses is the alternate loading condition. Usually, only the odd numbered cargo holds are loaded but in some cases, the cargo in the front three holds may be evenly distributed as shown in Fig. 3.9-4. This allows the cargo in hold 2 to support the bulkhead in the case of flooding of hold 1 [Mortensen 1998], but is not very convenient so it is rarely adopted.

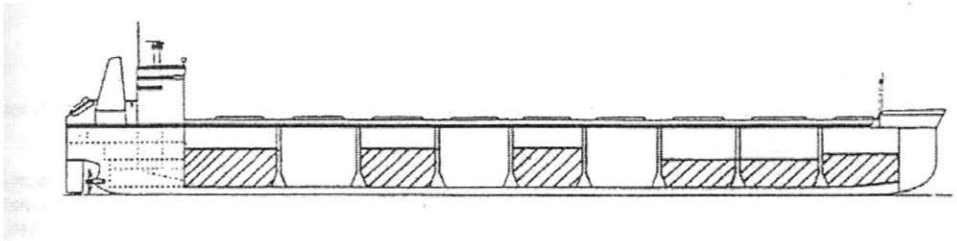


Fig. 3.9-4: "Traditional" Alternative Loading Condition [Mortensen 1998]

Homogeneous loading is the most common and safe loading method. Heavy ballast is the conventional way of ballasting as opposed to light ballasting. This usually involves the additional ballasting of cargo hold 6 in order to increase the draught and thereby avoid slamming which can lead to high stresses. Light ballasting is some times performed for small trips if allowed by the weather and usually during repairs or idle time before loading in order to clean the cargo hold.

Today, each ship has a software program that calculates the shear forces and bending moments along the ship depending on the loading conditions. These are referred to as the still water loads. Fig. 3.9-5 to 3.9-9 show typical examples under the four standard loading conditions and block loading, which is a much rarer partly loaded configuration that also required reinforcement as alternate loading.

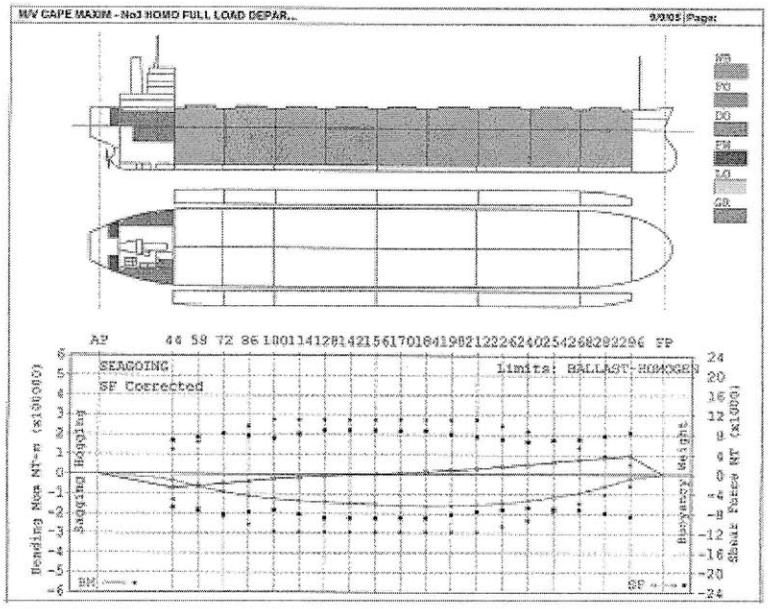


Fig. 3.9-5: Typical "ANCO" - Shear Stress and Bending Moment Distribution under Homogeneous Loading

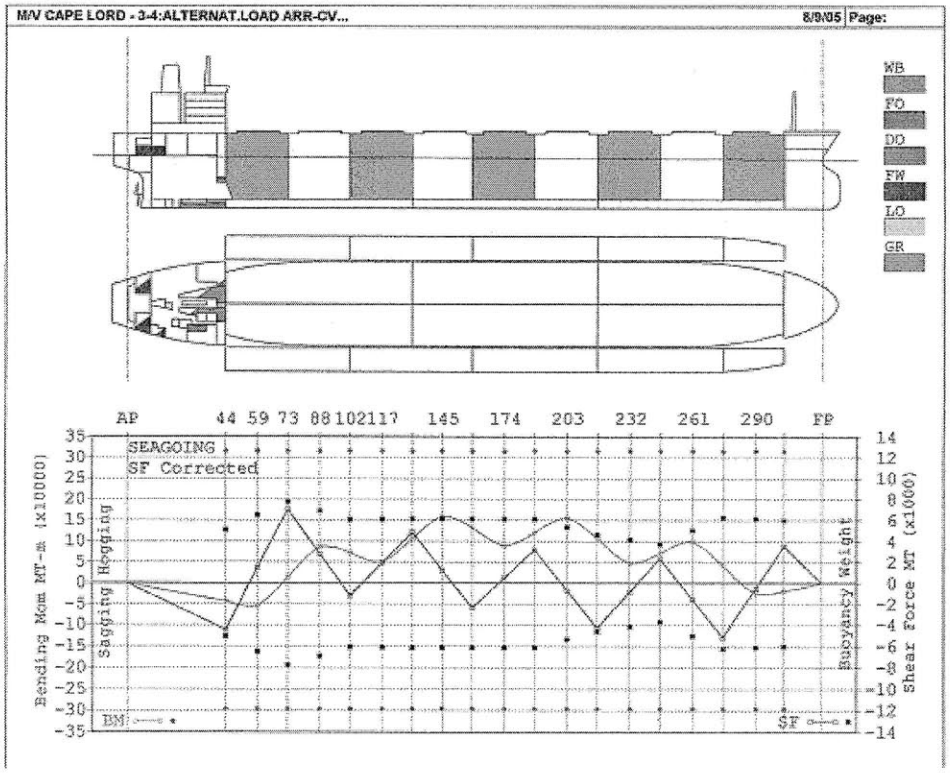


Fig. 3.9-6: Typical "ANCO" - Shear Stress and Bending Moment Distribution under Alternate Loading

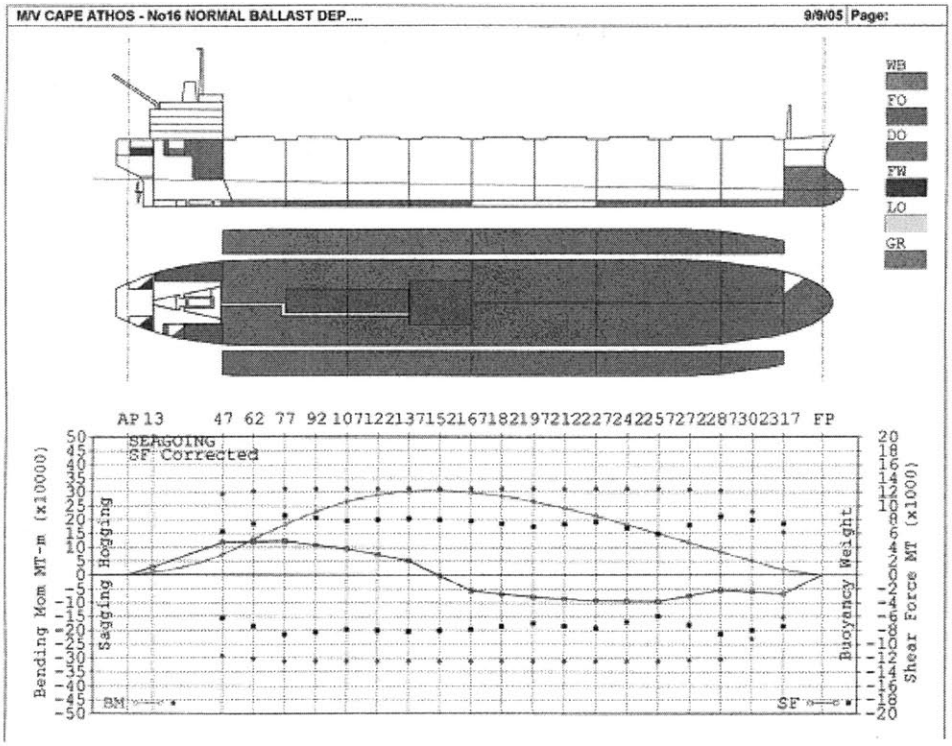


Fig. 3.9-7: Typical "ANCO" - Shear Stress and Bending Moment Distribution under Light Ballast

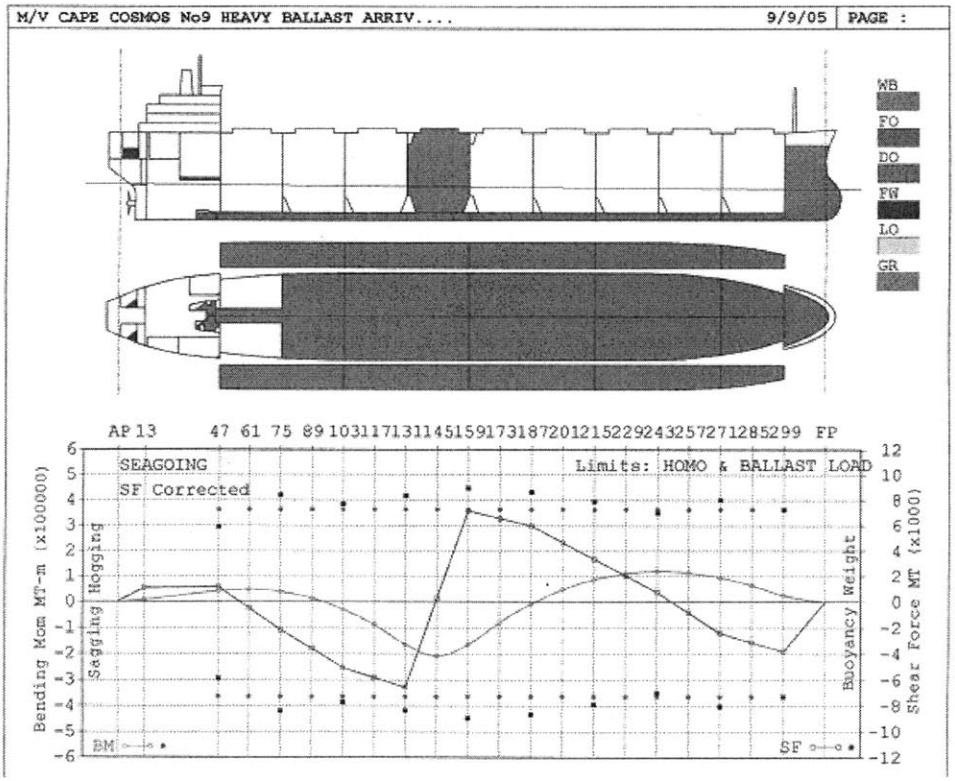


Fig. 3.9-8: Typical "ANCO" - Shear Stress and Bending Moment Distribution Heavy Ballast

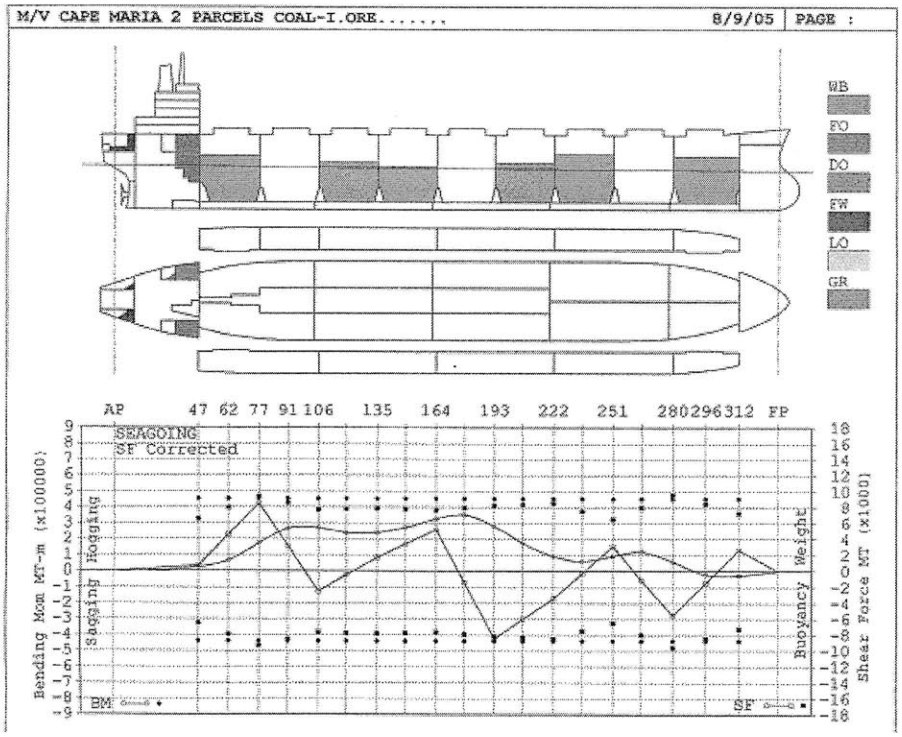


Fig. 3.9-9: Typical "ANCO" - Shear Stress and Bending Moment Distribution under Block Hold Loading

Besides this procedure, cargo mass calculations are also carried out to check whether the maximum or minimum permissible loads are exceeded in any hold, location or structural member. Each ship has a loading manual (booklet) for these calculations that is often complemented by a loading instrument, usually incorporated in the ship's loading software. This is always approved by the classification society. The loading instrument enables effective planning and control of cargo and ballasting operations, rapid calculations of shear forces and bending moments, and the identification of imposed structural limits [IACS 1998]. Fig. 3.9-10 shows the cargo mass results of a ship's software for the alternate loading condition.

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HOLDS CARGO MASS CHECK
Based on Local Loading Diagrams

Compartment	Mid Draft (m)	Actual Load (MT)	Harbour			Sea		
			Min (MT)	Max (MT)	Status	Min (MT)	Max (MT)	Status
No1 Cargo Hold	17,03	22675	0	23260	OK	0	23260	OK
No2 Cargo Hold	17,03	0	0	20224	OK	0	20224	OK
No3 Cargo Hold	17,03	29576	0	30339	OK	0	30339	OK
No4 Cargo Hold	17,03	0	0	21072	OK	0	21072	OK
No5 Cargo Hold	17,03	29190	0	29945	OK	0	29945	OK
No6 Cargo Hold	17,03	0	0	20606	OK	0	20606	OK
No7 Cargo Hold	17,03	29272	0	30027	OK	0	30027	OK
No8 Cargo Hold	17,03	0	0	20308	OK	0	20308	OK
No9 Cargo Hold	17,03	24861	0	25652	OK	0	25652	OK

Fig. 3.9-10: Cargo Mass Analysis for the Alternate Loading Condition

Among other rules, the ISM code also requires the installation of a loading instrument, which is capable of providing information on hull girder shear stresses and bending moments for all ships in excess of 150m [IACS 2005].

Having examined the stresses distributions during each loading condition in relation to the maximum allowable, it would be interesting to note the implications if these values are exceeded. Fig. 3.9-11 shows the progressive collapse behavior of a cape for different levels of initial imperfections (such as cracks) in hogging if the allowable bending moments are exceeded.

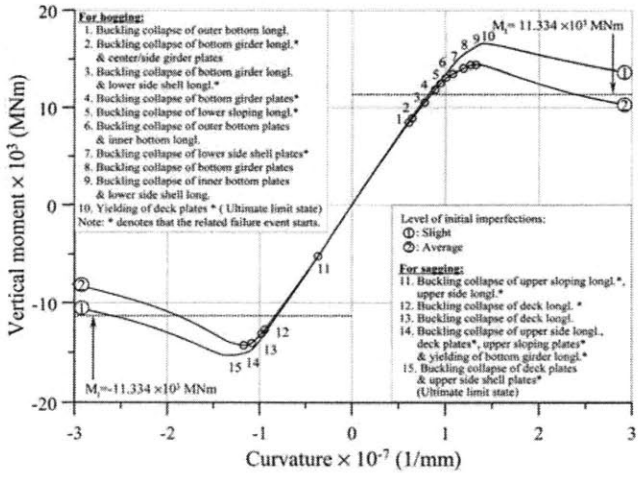


Fig. 3.9-11: Progressive collapse behavior of a 170,000dwt single sided bulk carrier under vertical moment varying the level of initial imperfections [Paik et al 2002]

The stress distribution in the hull at the point of collapse is also depicted in Fig. 3.9-12 and 3.9-13.

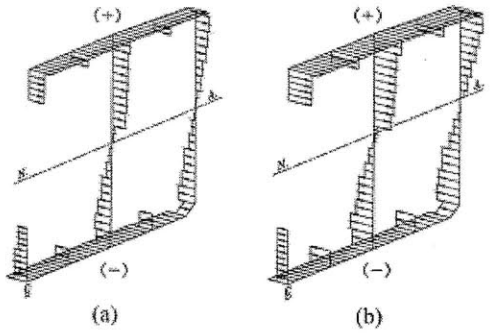


Fig. 3.9-12: Variation of the longitudinal stress distribution during progressive collapse under hogging moment (a) pre-ultimate limit regime, (b) ultimate limit state [Paik et al 2002]

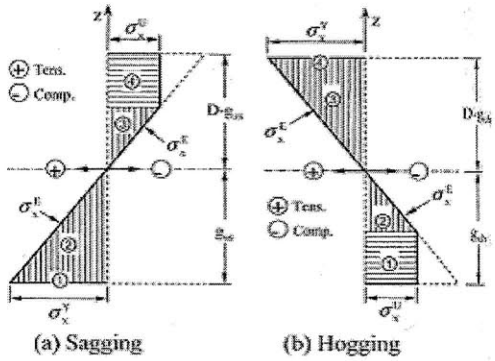


Fig. 3.9-13: Longitudinal Stress Distribution Over the Ship's Cross Section at the Overall Collapse State [Paik et al 1995]

3.9.5 Wave Induced Loads

Weather induced loads are a determining factor in a ship's life and can cause significant damage over years through continuous fatigue cycles or within a few hours in a strong storm. A simulation of the bending moment and shear force evolution, roughly corresponding to that in which the *Onomichi-Maru* lost her fore peak and sank, is shown in Fig. 3.9-14. Studies by [Bishop et al 1990] have concluded that the ratio of bending moment

to shearing forces in the hull are proportional to the distance along the hull for about 20% of the hull length.

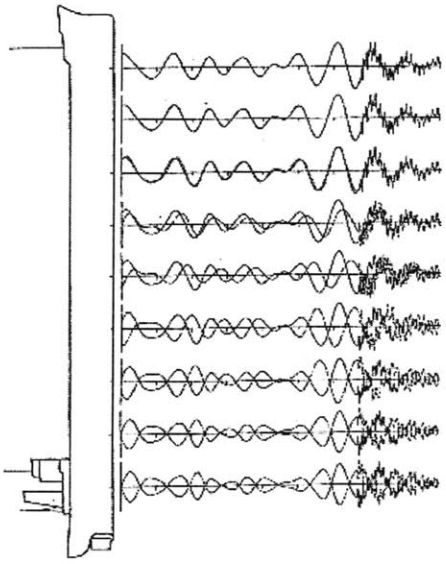


Fig. 3.9-14: A Random simulation depicting the Bending Moment and Shear Force along the hull of *Onomichi-Maru* against time [Bishop et al 1985]

Capes are particularly vulnerable to sea loads due to their large size. The design wave load is different for every ship and varies between 5 and 6 tonnes/m^2 for large bulk carriers [Langdon et al 2002]. During 20 years of operation, a cape experiences approximately 10^8 wave load cycles [Vassalos et al 2004].

The worst condition in terms of total bending stresses is when a ship loaded in sagging encounters a sagging wave. This maximizes the tension on the bottom plate, while the compression is taken by the topside tanks. Alternatively, [Thayamballi et al 1996] have carried out simulations on a cape loaded in hogging (with CH 4 empty) as it encounters a hogging wave, thus maximizing the tensile stresses on the deck. Their results showed an applicable load BM value of 773,200tm (of which the still water BM was 253,540tm) for the intact condition compared to 310,000tm which is the maximum allowable; and 1,011,600tm (of which the still water BM was 491,900) when CH1 is flooded with 6110t. These results demonstrate the effect of flooding, showing how allowable stresses may be exceeded while the still water stresses are within acceptable limits even in the intact condition.

[Paik et al 2003b] calculate the mean bending moments on a cape during a 3hr storm to be 4.673 GNm in hogging and – 4.210 GNm in sagging, and the still mean water bending moments to be 5.93GNm. The wave induced bending moment is also presented as a function of wave height in Fig. 3.9-15.

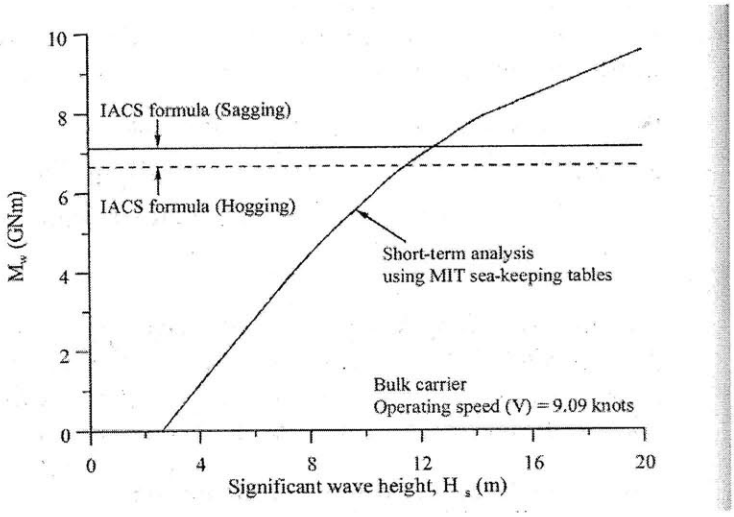


Fig. 3.9-15: Variation of Wave-Induced Bending Moment of a 170,000dwt bulk carrier as a function of significant wave height [Paik et al 2003b]

One of the most critical factors in severe weather conditions is maneuverability. A ship with good maneuverability can be more easily guided to reduce the loads acting on it in a storm. Consequently, it is less likely to suffer damages. A 150,000dwt cape is typically fitted with a 11-12MW engine compared to 18-19MW in the early 1980s. While this has reduced daily fuel consumption from 65t to 45t, it has also reduced the maneuverability of the vessels [Langdon et al 2002].

An important factor in the induced bending moments is the size and frequency of the waves encountered. Since wave scatter is a determining factor, there has been a lot of statistical research into the field [Hogben 1990, Hogben et al 1986]. The MIT sea keeping books by [Loukakis & Chryssostomidis 1975] are also often used for predicting the short term bending moments experienced by ships. Fig. 3.9-16 shows the distribution of wave heights worldwide.

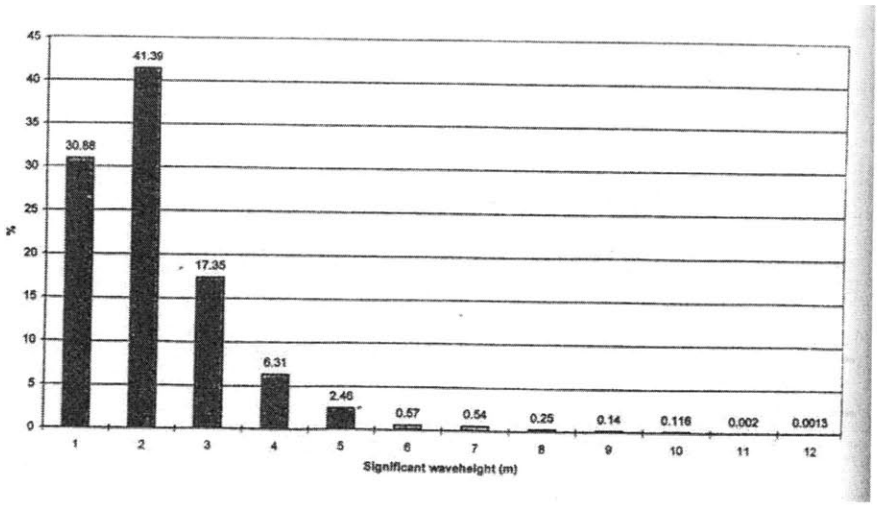


Fig. 3.9-16: Distribution of Waveheights Worldwide [Byrne et al 1998]

Each society has its own empirical formulas for calculating the wave induced bending moments on a ship's hull but they all recommend the use of the ship's loading manual for still water bending moment calculations. All methods used for calculating the mean value of wave-induced bending moments, consist of calculating the bending moment amidships, and then using a distribution factor to translate this value at any location along the hull. According to [Paik et al 2003b], the method given by IACS is that used by Bureau Veritas as shown below. Examples from some of the major classification societies are presented below. The mean value of extreme wave-induced bending moments, that a ship is likely to encounter during its life for worldwide service, is given by:

Lloyd's Register: $$M_w = f \times M_{wo} = f \times 0.1 \times C \times L^2 \times B \times (C_b + 0.7) \quad (3.9\text{-}1)$$

American Bureau of Shipping: $$M_w = C_2 \times L^2 \times B \times H \times K_b \quad (3.9\text{-}2)$$

Bureau Veritas: For Hogging: $$M_w = 190 \times 10^{-3} \times C \times L^2 \times B \times C_b \quad (3.9\text{-}3)$$

For Sagging: $$M_w = -110 \times 10^{-3} \times C \times L^2 \times B \times (C_b + 0.7) \quad (3.9\text{-}4)$$

Germanischer Lloyd: For Hogging: $$M_w = 0.19 \times L^2 \times B \times C_0 \times C_L \times C_b \quad (3.9\text{-}5)$$

For Sagging: $M_w = -0.11 \times L^2 \times B \times C_0 \times C_L \times (C_b + 0.7) \times C_M$

(3.9-6)

Where: M_w = Wave induced bending moment amid ship in kNm

f = Ship service factor = 1 for unrestricted sea going service

$C = 10.75 - \left(\frac{300 - L}{100}\right)^{1.5}$ for ship length between 90 and 300m

C_b = block coefficient at summer load waterline

L = Scantling Length

B = Ship Beam

$C_2 = 0.0234Cb + 0.002$

H = wave parameter depending only on ship length L

$K_b = 1.4 - 0.5Cb$

C_M = GL Distribution Factor, equal to c_V amidships for the sagging condition (instead of 1) where c_V is an influence factor depending on ship speed

C_0, C_L: See GL rules Section 4 A.2.2

In all the formulas, except GL's sagging condition, the wave induced bending moment amidships is only a function of the ship length L, beam B and the block coefficient C_b. The value obtained is then multiplied by the longitudinal distribution factor of each classification society in order to obtain the wave induced bending moment anywhere along the ship length. Plots of the tabulated values from the different rules are presented in Fig. 3.9-17 to 3.9-19 along with GL's prediction in Fig. 3.9-20.

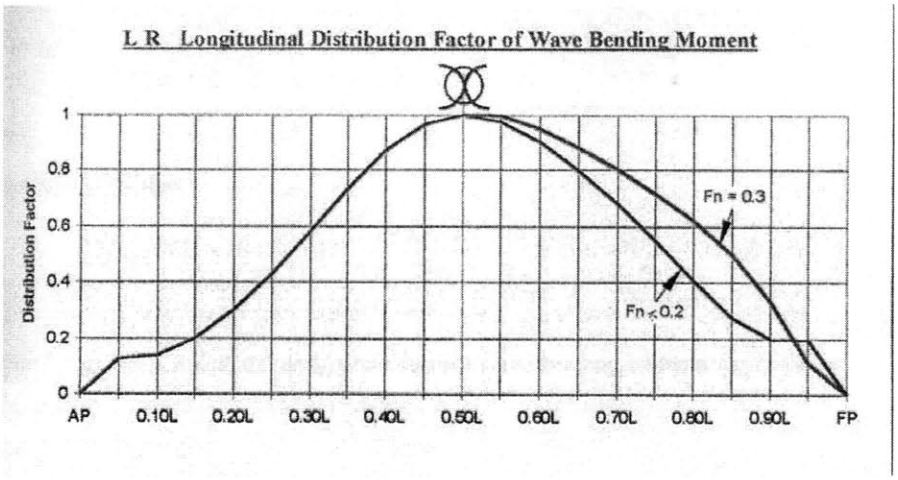


Fig. 3.9-17: Plot of LR Longitudinal Distribution Factor of Wave Bending Moment

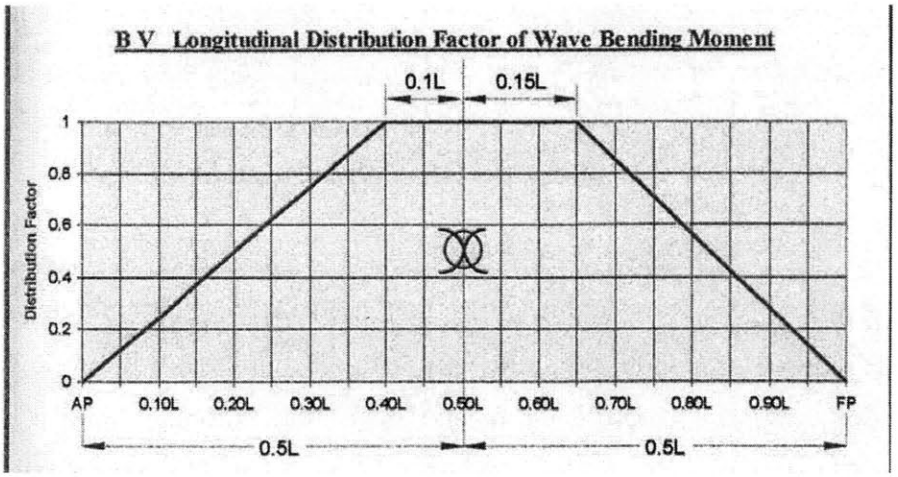


Fig. 3.9-18: Plot of BV Longitudinal Distribution Factor of Wave Bending Moment

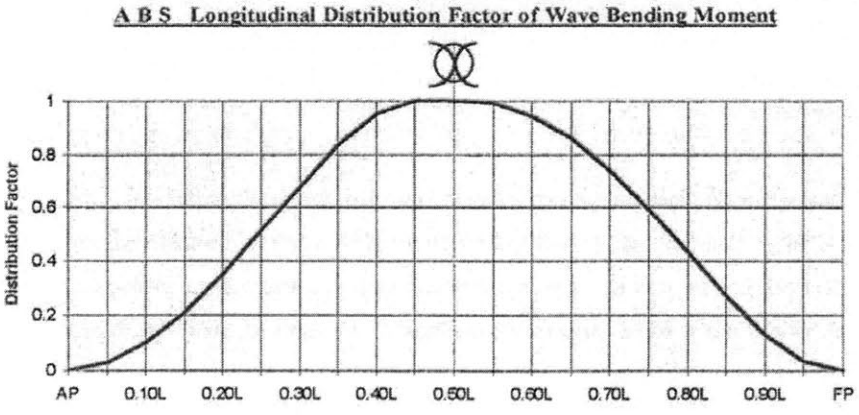


Fig. 3.9-19: Plot of ABS Longitudinal Distribution Factor of Wave Bending Moment

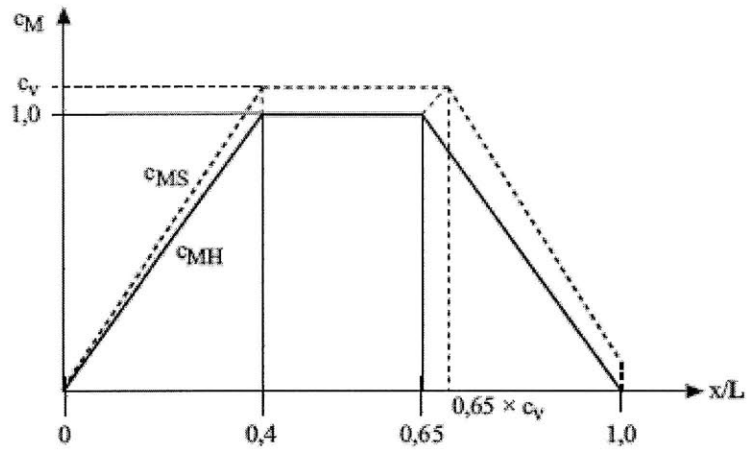


Fig. 3.9-20: Wave Induced Bending Moment Distribution Factor for Hogging c_{MH} and for Sagging c_{MS} and Influence Factor c_V [GL 2005a]

Where: $$c_V = \sqrt[3]{\frac{v_0}{1.4 \times \sqrt{L}}}$$

v_0 = Ship Speed

The shape of the wave induced bending moment distribution may influence the distribution of cracks throughout the hull. This will be examined in the following chapters. The distribution is approximately the same for the classification societies considered. The bending moment peaks amidships and decreases more or less symmetrically towards the stern and bow.

Besides wave induced bending moments, significant fatigue damage may also be caused directly by the water pressure on the side shell. [Hansen and Winterstein 1995] propose a model to analyze the sea loads on the side shell of a tanker and compare it with 1,990 reported fatigue cracks in 4 single hull 165,000dwt vessels by [Schulte-Strathaus 1991]. In their wave model, they account for the Froude-Kryloff pressure (from the incident wave potential φ_I, in absence of ship) and for changes in hydrostatic pressure due to vessel oscillations in calm water, and they neglect diffracted and radiated waves (wave potential φ_D and φ_R due to presence and oscillations of vessel in calm water). They get their wave parameters using a weighted average of the available statistics in the different Marsden

zones, based on the specified trades of the vessels. Their results show that the water pressure is of paramount importance as it accounts for the majority of the expected fatigue damage.

3.9.6 Real Time Stress Monitoring

Significant improvements in safety are achieved by controlling still water and wave bending stresses by appropriate loading and by the use of real-time stress monitoring systems. In new ships, sensors are placed on the deck and bulk heads allowing for continuous display of real time information. This enables close monitoring of stresses during loading/unloading and ballasting/deballasting procedures. Thereby, it can be ensured that the vessel works within its design limits, greatly reducing the risk of hull damage by cargo overloading.

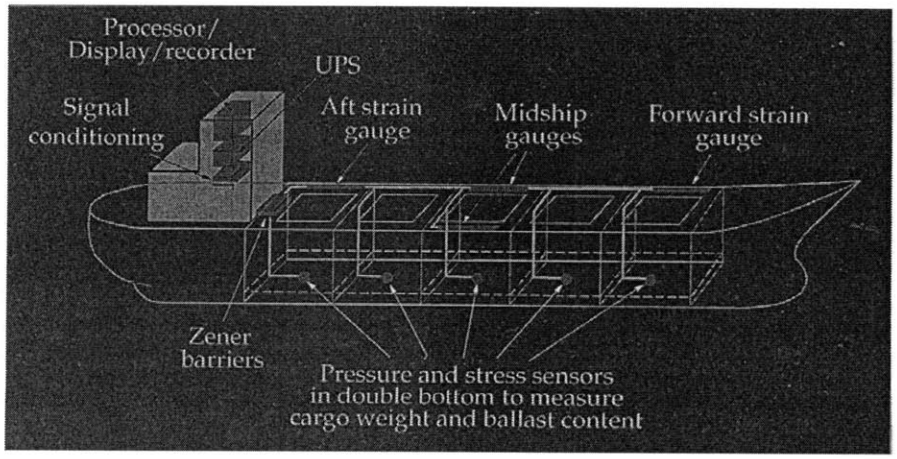


Fig. 3.9-21: Typical Cargo Load and Hull stress monitoring system [MER 1994]

By monitoring stresses during ship operations, loading can be stopped if the stevedoring company fails to follow the ship's loading instructions. The stevedore is obliged to sign an agreement to this before the commencement of loading. Data collected during loading operations and voyages can also be used to monitor fatigue.

In addition to all these measures, improvements are made by choosing speed, course and route in order to avoid excessive loads. Integrated hull condition monitoring systems

have been developed, which, in addition to continuous display of stresses, also provide a choice of route (using a radar), and guidance during severe weather conditions. This is achieved by combining measurements of the wave parameters, the ship motions and the hull stresses [Steen et al., MER 1994]. Fig. 3.9-22 shows the display of a hard weather avoidance system.

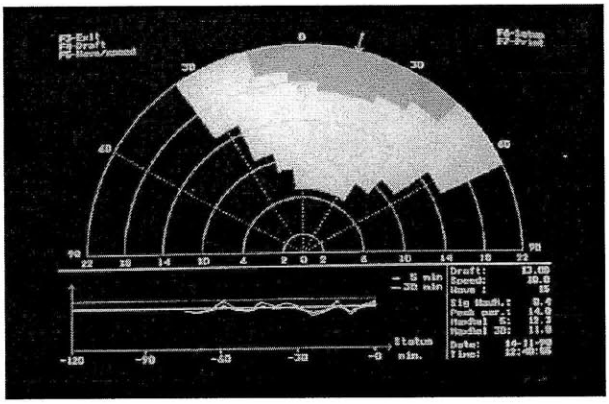


Fig. 3.9-22: Display of the Hard Weather Avoidance System (MARINETEK 1990)

[Karlsen, 1990]

CHAPTER 4

Structural Reliability Analysis

4.1 Stress Survey

4.1.1 Overview

It is generally believed that cracking is caused primarily by the bending stresses although other factors, including shear stresses, impact and damage, may also have an influence. The permissible total bending stress given by the ABS classification rules is 1784 kg/cm^2 [Ivanov et al 2004a].

The ship can be modeled as a beam and the bending stress at any location in the hull is related to the vertical bending moment at the corresponding ship length by beam theory as follows.

$$\sigma_b = \frac{My}{I} = \frac{M}{Z} \qquad (4.1\text{-}1)$$

Where: σ_b = bending stress

M = vertical bending moment

I = second moment of area

y = vertical distance from the neutral axis

Z = section modulus

The bending stress is thus maximized on the deck and bottom plate of the ship at any location along the length. Its magnitude depends on the section modulus and the bending moment at the corresponding location along the length. Each ship has a deck section modulus and a bottom section modulus (which is slightly larger). These values are relatively constant throughout the cargo hold region, since there are no major geometric changes. Though the limit is on the bending stress, it is equivalent to quote the bending moment as a percentage of the maximum allowable. Consequently, we are mainly concerned with the distribution of the bending moments along the hull.

The total bending moment acting on the hull is determined by superimposing the fluctuating wave induced bending moments and the still water bending moments. The wave

induced bending moments will be distributed throughout the hull as shown in Fig 3.9-17 to Fig. 3.9-20 of Section 3.9.5. The still water bending moments that are experienced by a ship throughout its life depend on the ship type, its trade and its loading patterns. Statistical analysis that was carried out extensively in the 1970s has shown that still water bending moments obey a Gaussian distribution [Mano et al 1977, Ivanov et al 1975, Lewis et al 1973, Ivanov 1973, Soares et al 1982].

Capes are quite unique in their structure with specific trading and loading patterns that are very different to those of smaller bulkers and other ship types. A focused analysis is, therefore, presented in the following section in order to determine the distribution of the average still water bending moments imposed on a typical cape throughout its operating life.

4.1.2 Still Water Bending Moment Analysis

4.1.2.1 Average Time under each Loading Condition

The record books of fifty capes were used to evaluate the average percentage of time spent under each of the four common loading conditions, denoted by the letter "κ". Four consecutive voyages were considered at a time, in order to account for round trip averages. These were chosen from different years in order to account for the changes in loading patterns over time. It was noticed that, on average, the use of alternate loading has decreased slightly over time. The cracks which have been recorded in capes so far also depend on the loading procedures of the past. Since we will later examine the correlation of crack initiation and growth rates with stresses, the results were left unmodified in order to reflect historical usage patterns.

Idle time, repair time (in the water) and cleaning time were all included and account for the majority of light ballast time. Dry docking only accounts for a small percentage of the time and this was neglected. Only the 4 standard loading conditions were accounted for since other types are quite rare. Consecutive voyages were chosen so as not to coincide with dry docks or any rare loading conditions.

It was considered reasonably accurate to distribute the loading and discharging time (which accounted for less than 10%) evenly between the 4 loading conditions. This was done under the assumption that during loading homogeneously (which is most common), the various stages of the process can be approximated by a change from a combination of alternate loading and heavy ballast to combinations more closely resembled by homogeneous loading and light ballast. Correspondingly, when a ship unloads from the homogeneous loading condition, the transient states of the ship tend to move from combinations of homogeneous loading and light ballast to those resembled better by alternate loading and heavy ballast. After making the above assumptions, the results of the survey were compiled and are summarized in Table 4.1-1.

50 CAPE AVERAGE LOADING CONDITION TIME DISTRIBUTION	
LOADING CONDITION	**AVERAGE % TIME**
HOMOGENEOUS LOADING (κ=1)	39.5
ALTERNATE LOADING (κ=2)	16.3
HEAVY BALLAST (κ=3)	36.4
LIGHT BALLAST (κ=4)	7.8

Table 4.1-1: Average time sailing under each loading condition

4.1.2.2 Average Still Water Bending Moment Distribution in the Ship Hull

The loading program "ANCO" of twenty capes was used to calculate the still water bending moments at 20 locations "ℓ" along the ship length under each loading condition. The program allows the input of any amount of cargo or ballast in each hold or tank respectively and calculates the shear stresses and bending moments at every point "ℓ" along the hull. It then outputs the result as a percentage of the maximum allowable still water bending moment (%BM). Average values of the twenty ships were calculated for each

location under each of the 4 loading conditions. The results are presented in Fig. 4.1-1 to 4.1-4.

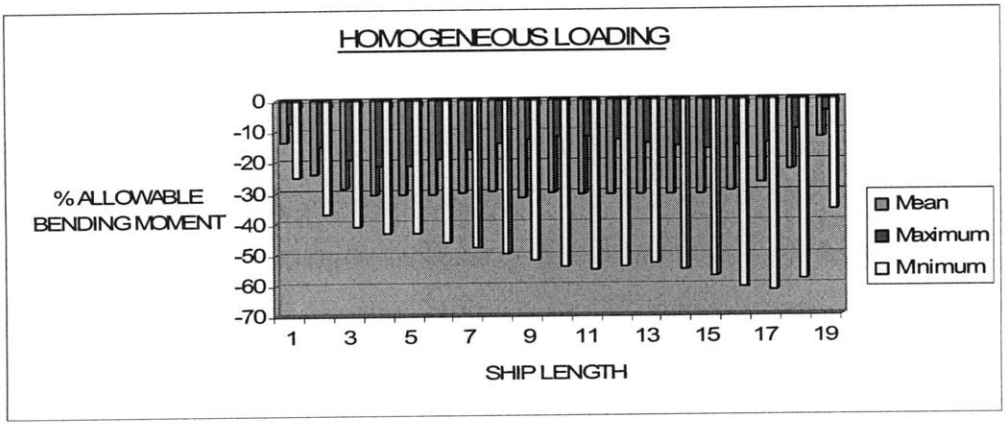


Fig. 4.1-1: Average Bending Moment Distribution as a Percentage of the Maximum Allowable for the Homogeneous Loading Condition

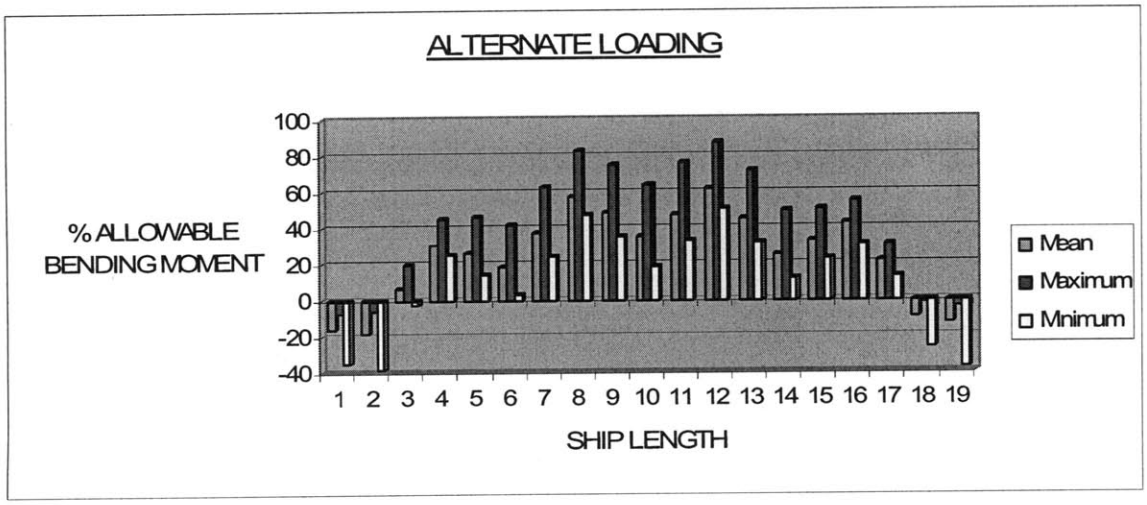


Fig. 4.1-2: Average Bending Moment Distribution as a Percentage of the Maximum Allowable for the Alternate Loading Condition

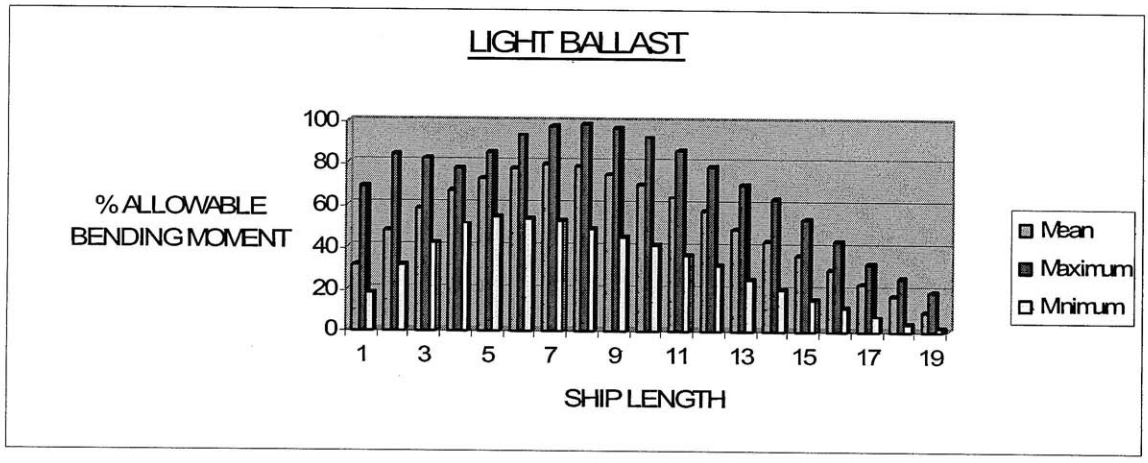


Fig. 4.1-3: Average Bending Moment Distribution as a Percentage of the Maximum Allowable for the Light Ballast Condition

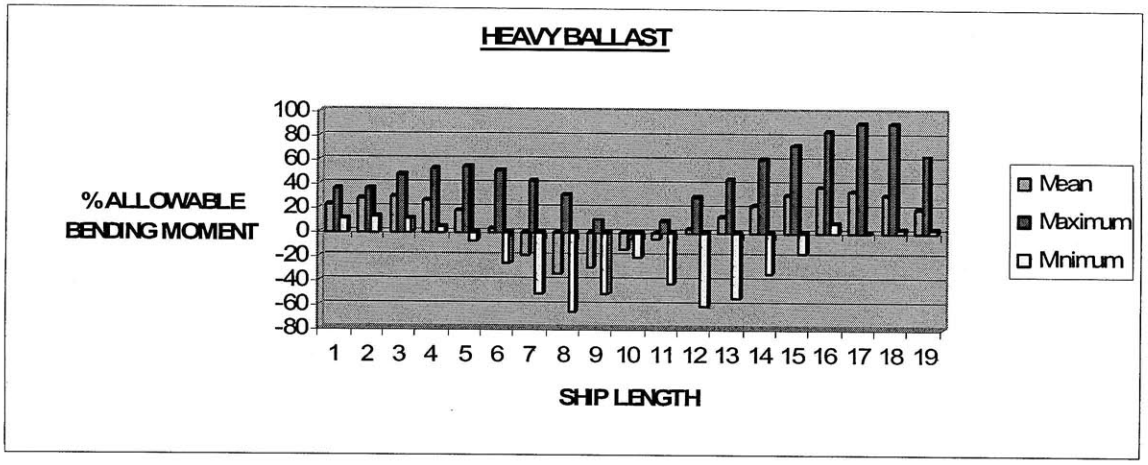


Fig. 4.1-4: Average Bending Moment Distribution as a Percentage of the Maximum Allowable for the Heavy Ballast Condition

The results shown in Fig. 4.1-1 to 4.1-4 were combined with the average percentage time spent under each of the four loading conditions from Table 4.1-1, to evaluate an average percentage of the allowable still water bending moment along the ship length. This was evaluated as follows.

$$\%\overline{BM}_{\ell} = \sum_{\kappa=1}^{\kappa=4} \left(\%t_{\kappa}\right)\left(\%BM_{\kappa,\ell}\right) \qquad (4.1\text{-}2)$$

Where: $\%\overline{BM}_{\ell}$ = Average % of allowable bending moment at location " ℓ "

$\%t_{\kappa}$ = Average time under each loading condition "κ" (Table 4.1-1)

$\%BM_{\kappa,\ell}$ = Average % of allowable bending moment at location " ℓ " under each loading condition "κ" (Fig. 4.1-1 to Fig. 4.1-4)

Note that the average percentage of allowable bending moment, $\%\overline{BM}_{\ell}$, is equivalent to the average percentage of allowable bending stress. The value was evaluated along the ship and plotted as a function of " ℓ ", as shown in Fig. 4.1-5.

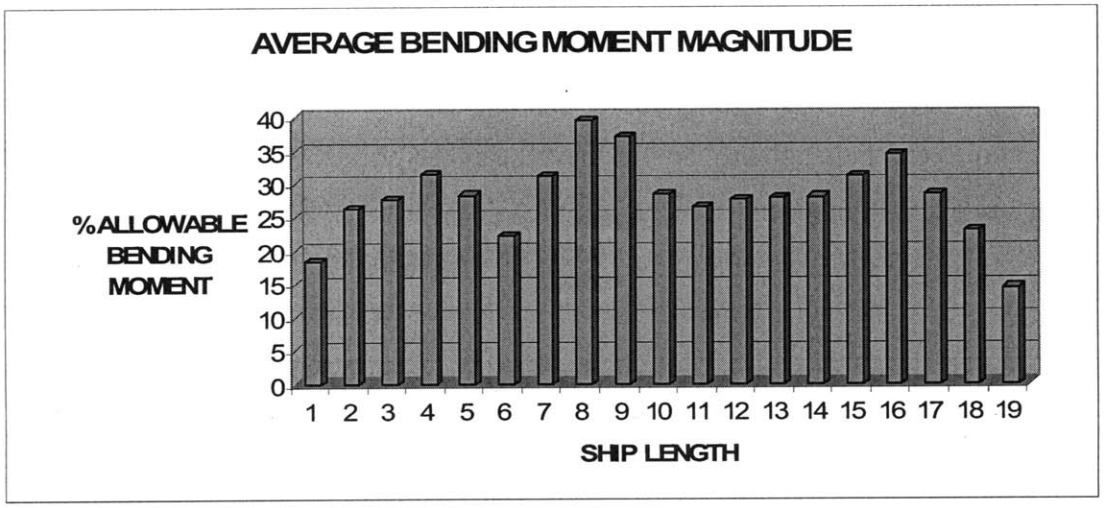


Fig. 4.1-5: Average Percentage of Allowable Still Water Bending Moment along the Ship Hull

It should be noted that this graph only gives an indication of the average magnitude of still water bending stresses to which a capesize bulk carrier is subjected throughout its life. The actual bending moment distributions experienced at any time will be given by superimpositions of still water bending moments (Fig. 4.1-1 to 4.1-4) and wave induced bending moments (Fig 2.9-17 to 2.9-20 of Section 3.9.5).

4.2 Crack Distribution

4.2.1 Previous Work on Cracks

Theoretical, analytical and numerical methods have been developed to assess the problem of cracks in many ways. Modeling of the marine environment, however, and accurately predicting the actual conditions and stresses are practically impossible. Therefore, it is essential to take direct measurements from ships and any conclusions derived as such will be much more reliable for the time being.

Extensive research of this sort has been carried out to cover the aspect of corrosion in great detail. As outlined in Section 3.5, several databases of direct ultrasonic gauge readings have been collected and statistical studies have been performed. Similar studies on cracking, however, are very limited and most are quite old as can be seen in Table 4.2-1, which summarizes all such studies reported over the past 50 years.

DIRECT MEASUREMENT BASED SHIP CRACK LITERATURE 1958 – 2005			
Author	**Classification Society**	**Number of Ships/Type**	**Type of Data**
[LR, ABS and DNV 2006]	LR, ABS & DNV	224 Double Hull Tankers	1,949 Defects (1,323 Cracks Included)
[JBP 2005]	BV, CCS, NK, KR, RINA & RS	76 Single Hull VLCC Tankers built after 1985	Fatigue Damages
[GL 2005b Private Correspondence]	GL (72 of 145)	145 Bulk Carriers	783 Damages
[GL 2005b Private Correspondence]	GL	193 Tankers	1,201 Damages
[NK (b) Private	NK	124 (Tank, Ore C. &	643 Cracks

Correspondence]		Bulkers)	
[DNV 2002 Private Correspondence]	DNV	-	221 Cracks / 304 Damages
[LR 1999 Private Correspondence]	LR	1,405 Bulkers	19,115 Damage Defects
[Bea et. Al 1995]	-	10 Tankers	3600 cracks
[Yoneya et al 1993]	NK	18 VLCC	~180 cracks
[Ferguson et al 1993]	LR	Bulk + OBO	Damages
[Schulte-Strathaus 1991]	-	4 S-Hull 165kdwt + 5 D-Bottom or D-Hull 35-188kdwt	1990 + 1660 Fatigue Cracks
[Exxon 1983 Private Correspondence]	-	>40 Exxon Tankers	Cracking/ Corrosion
[SSC 1980]	-	36	3,555 Cracking/Buckling
[Jordan et al 1978]	-	~50 (various)	6,856 damages
[Antoniou 1977]	-	233 Tankers	25,652 Cracks
[ABS 1976]	ABS	535 Bulk Carriers	104 Damages
[ABS 1976]	ABS	411 Tankers	413 Damages
[LR 1976]	LR	-	Cracks
[NK 1976]	NK	176 (Tank / Ore C./ Bulkers)	Cracks
[LR 1975]	LR	-	Defects
[ISSC 1973]	-	73	Cut-out Damages
[Yamaguchi 1968]	NK	97	Damages
[Vedeler, 1958]	DNV	-	Cracks
[NK (a)]	NK	-	Damages

Table 4.2-1: Crack and Damage Surveys

This is mainly due to the high confidentiality and difficulty of access to raw data which is never available to the public. Most of the work has been carried out by classification

societies who have access to the data of ships in the fleet under their classification. Many of them do not report details of their findings but only use them to develop their rules. Consequently, many of the surveys are not published and the number of ships and defects of the surveys are usually not made available.

Classification societies are so careful in protecting the confidentiality of the data, that they sometimes even withhold anonymous statistical results. In their survey of defects of double hull tankers (including cracks), [LR, ABS and DNV 2006] simply state *"Because of the small number of ULCC's (i.e. they can easily be identified) this data has been withheld"*.

Some of the surveys only focus on a certain age group of vessels or only examine a particular area such as the After Peak [LR 1976]. Furthermore, very few surveys have been performed specifically on cracks. Most cover a wide range of damages or failures including dents, buckling, corrosion etc.

The work most closely aligned with the current project's objectives was that of Prof. Antoniou who performed an 8 year crack survey on Tankers of all sizes, coming for repairs at the shipyard of Skaramangas in Greece during the 1970s [Antoniou 1977]. The work of Schulte-Strathaus at U.C. Berkeley in the early 1990s, also appears to cover the whole range of fatigue cracks but is only limited to 9 vessels. Surprisingly, no survey has been performed on capesize bulk carriers in particular where the problem is most crucial.

4.2.2 Objective

The aim of this section is to examine the whole spectrum of cracks developed throughout the life of capesize bulk carriers which are known to be most vulnerable to the problem. Important statistics are presented regarding the location, size and frequency of cracks with respect to the ship's age. It should be noted that since only a particular size group of bulk carriers is considered, an investigation of the above parameters with respect to ship length or deadweight is not feasible. Finally, the aim is also to examine the methods of repair for the various cracks with respect to crack origin, location and size.

It is also important to note that there are numerous factors affecting cracking behavior. Examples include the shipyard where the ship was built; the operator, crew and maintenance; the location, frequency and quality of repairs throughout the ship's life; the trading route, cargo and the weather encountered by the ship; the classification society, the surveyor and the port of inspection etc. Information may only be available on some of these factors and it is very hard to quantify. As with all research, some parameters have to be neglected. This, however, can be accounted for by working with a large sample of data.

4.2.3 Database

In order to perform the required analysis a large sample size is required in terms of ships, cracks and total crack length. It is also very important to have a good age distribution of the ships in the database. An adequate number of ships is required for each age in order to get a representative average crack distribution throughout the ship's life. The data required consists of ship age at the time of the survey; number, size and location of cracks; and the types of repairs carried out.

Data regarding cracks in its raw state is highly confidential and thus access to it was of great difficulty. As [Adam et al 1991] quotes about defects information in the Lloyd's Register database, *"No identifiable information is released to third parties without the owner's consent. In most cases we can present the data statistically to preserve its anonymity"*. Furthermore, the size of the database in such statistical surveys is crucial to the validity of the results. Therefore, all possible sources were exploited.

The data came from IACS classification societies, ship owning companies and shipyards. Access in most cases was provided under the condition that the data sources and ship names would remain confidential. Classification societies only then have the legal right to release any data unless they have direct permission from the shipowner. In its raw state, the data is in the form of survey reports, some of which are well over 150 pages long. Classification society records included an average of about 30 surveys per ship, of which

about half were hull related and relevant. These were searched in detail and all cracks, locations, crack sizes and repair procedures were recorded.

Unfortunately, when compared to data from owners and shipyards, some of the data from classification societies seemed inaccurate and incomplete. Reasons for this include the fact that only specified locations are inspected in each survey. Ballast tanks for example are not usually inspected in annual surveys. One of the measures taken to deal with this was the use of only one data entry per year for a given ship which includes all the surveys within that year.

Classification societies don't all have the same procedures in terms of reporting and these may also vary between surveyors. The detail of the survey and hence the likelihood of recording cracks depends on many factors including the survey type, the surveyor, the port of inspection, the ship age etc. In addition to this, cracks are often repaired without being reported and repairs are often reported without indicating whether cracks were present beforehand. This is often the case when a large plate has to be replaced due to corrosion wastage, in which case the surveyor may not bother to find all the cracks on the plate and report them. This leads to information which is usually very vague and inaccurate.

It is also often the case that the owners find cracks and repair them without reporting them to the classification society. Consequently, additional records from the ship owning companies had to be referenced in order to complete the data before it could be used. By combining the records of classification societies, shipowners and shipyards for each repair, a more complete set of data was obtained. Table 4.2-2 gives the number of ships from each source and the Venn Diagram in Fig. 4.2-1 illustrates the overlap in the data sources.

NUMBER OF SHIPS FROM EACH SOURCE			
SOURCE	IACS Members	Owners	Shipyards
SHIPS	125	140	126

Table 4.2-2: Number of Ships from each Source

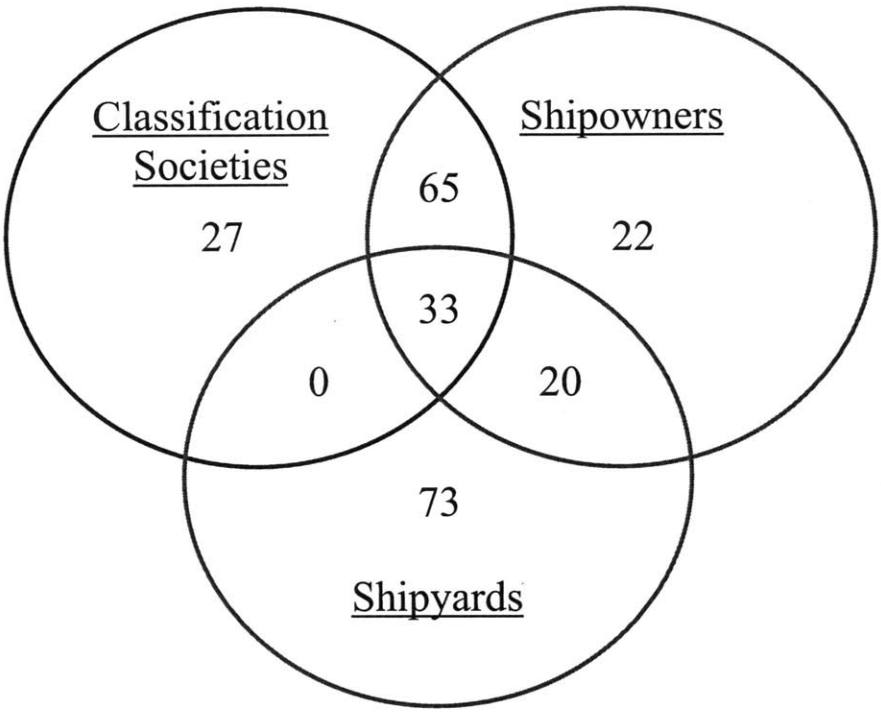


Fig. 4.2-1: Venn Diagram with Number of Ships from each Source

One entry of data was used for each ship every year. This means that cracks reported in several surveys on a ship within one year were all combined into one set (one data entry), and that a ship was reported as two separate entries if data from two different years was used. This resulted in a database size of 240 ships (data entries) with the age distribution shown in Fig. 4.2-2.

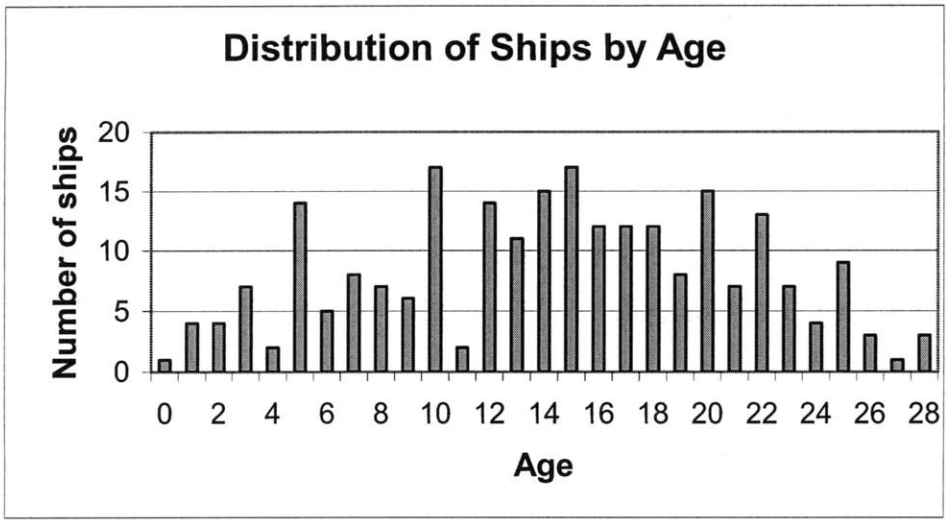


Fig. 4.2-2: Distribution Crack-Database Ships by Age

As can be seen, the data sample is well distributed and covers a wide range of ages. Sharp decreases in the number of ships, however, appear after the age of 5, 10, 15 and 20 years. The main reason for this is that major repairs or surveys are rarely required during the year immediately after a special survey which is normally passed during these ages. Excluding those peaks, the distribution seems to roughly follow a normal distribution and looks relatively symmetric about a mean of approximately fifteen years.

TOTAL DATA SAMPLE	
Total Number of Ships (entries)	240
Total Number of Cracks	29,567
Total Crack Length (km)	7.82
Mean Crack Size (mm)	264
Mean Number of Cracks per Ship	123
Mean Total Crack Length per Ship (mm)	32,582

Table 4.2-3: Final Data Sample

4.2.4 Location Coding System

In order to perform the analysis and present the results, a system of coding was devised, whereby each location is asserted a particular code. The following system was finalized after several modifications that had to be made throughout the analysis. Bearing in mind that any such modifications led to a huge amount of subsequent work in regrouping the data, particularly during the later stages, such a system has to be very detailed and accurate from the beginning. Therefore, the coding system devised here is recommended for future projects. With minor modifications, it could be applied to other types of ships, such as tankers, or used in research assessing different damages such as dents, buckling, corrosion, or coating failure etc.

The ship was divided into 3 zones along the height going upwards as shown in Fig. 4.2-3.

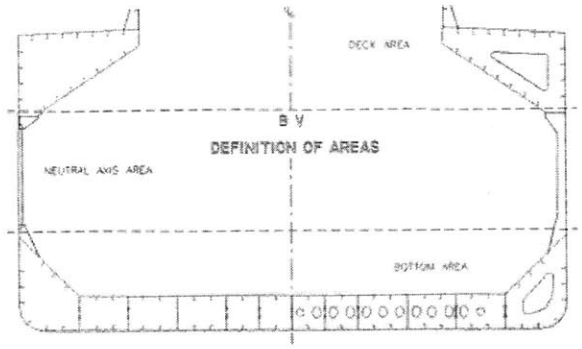


Fig. 4.2-3: BV Definition of Areas [Loukakis, 2009]

The ship was similarly divided into 11 compartments along the length going forward as follows:

Compartment 1: After Peak and Engine Room

Compartments 2-10: Cargo Holds (9)

Compartment 11: Fore Peak

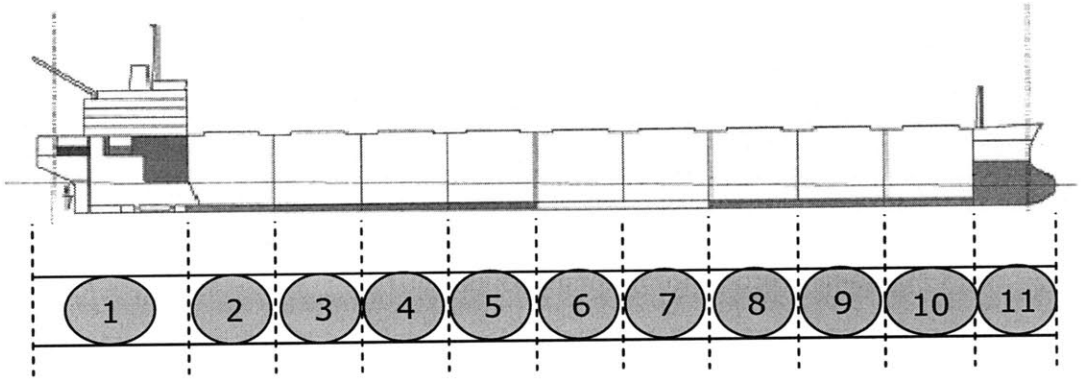


Fig. 4.2-4: The 11 Compartments along the Ship Length

Each compartment includes only its stern bulkhead. This leads to an even distribution of 1 large Bulkhead allocated to each compartment. Each compartment along the ship length was further divided to subsections as summarized below:

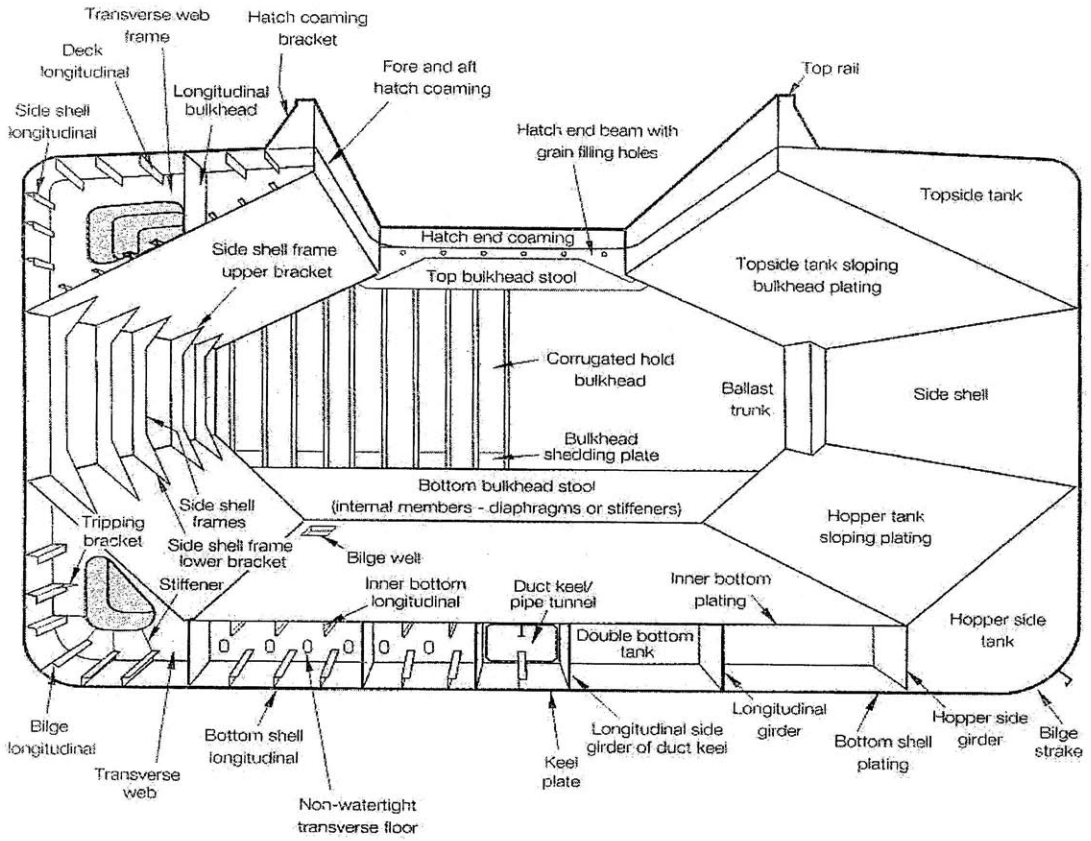


Fig. 4.2-5: Structural Configuration of a Typical Capesize Bulk Carrier

[MER 2002a]

1 DECK AND UPPER WING TANK

a Transverse Web Frame + Transverse bulk heads + Stiffeners	i=1
b Shell plate and shell longitudinals	i=2
c Slopping plates and longitudinals	i=3
d Longitudinal Girder (Longitudinal bulkhead)	i=4
e Hatch coamings and stays (brackets) + Transverse Hatch End Beam	i=5
f Deck plate and Longitudinals	i=6

2 CARGO HOLD

a Shell Plate and Cargo Hold Frames (upper part)	i=7
b Shell Plate and Cargo Hold Frames (mid part)	i=8

c Shell Plate and Cargo Hold Frames (lower part) i=9

3 LOWER WING TANK

a Bilge Web Frames (transverse web) + Stiffeners i=10

b Bilge plate + Bilge Longitudinals + Bilge Keel i=11

c Hopper plate and Longitudinals i=12

d Longitudinal girder and Stiffeners i=13

4 DOUBLE BOTTOM

a Inner bottom plate and Longitudinals i=14

b Transverse floors and stiffeners i=15

c Bottom shell plate and Longitudinals i=16

d Longitudinal Girder and Stiffeners i=17

5 TRANSVERSE CARGO HOLD BULKHEADS

a Upper Stool i=18

b Corrugated Bulk Head Plate - upper part (~30%) i=19

c Corrugated Bulk Head Plate - mid part (~55%) i=20

d Corrugated Bulk Head Plate - lower part (~15%) i=21

e Lower Stool i=22

f Side Trunk (usually in alternate bulk heads) i=23

6 OTHER

a Stringers i=24

b Girders i=25

c Pillars / Struts i=26

Even with a carefully devised system as above, one always needs to make certain adjustments or decisions on how to deal with peculiar data samples. Some examples are given in Table 4.2-4.

ADJUSTMENTS	
CASE	**SOLUTION**
Ships with 8 cargo holds	Cracks found in CH8 repeated in CH9
Ships with over 9 cargo holds	Excluded
Double hull ships	Excluded
Ore Bulk Ore carriers	Excluded
Romanian Ships: Cracks in horizontal tripping brackets of CH1 & CH9	Quoted as cracks in vertical frames (2a & 2c)
New Ships: Tripping brackets (slant plates) included between frames (in old ships, this was done only in CH1).	Quoted as cargo hold frames (2a & 2c)
Rudder Cracks	Quoted as Longitudinal bulkhead (1d)
Engine Room: Cracks in engine or auxiliary components	Not considered as they do not form part of the hull structure
Engine Room: Cracks in the bulkheads of small tanks	Quoted as 1a (transverse) or 1d (longitudinal)
CH9 aft bulkhead has no upper or lower stool (5a & 5e)	Cracks in that region quoted as upper or lower corrugation (5b & 5d)

Table 4.2-4: Modifications in unexpected data

The cracks of the database ranged from 50mm to 8000mm and the vast majority were reported to the nearest 50mm irrespective of their location. Therefore, the database consists of 16 different crack sizes. Under the coding system each crack can be recorded by its size, compartment number (1 to 11) and region (1a to 6c). We can describe this using in a 3D matrix where the "i" index is the region ranging from 1 to 26, the compartment is the "j" index ranging from 1 to 11 and the size is the k index ranging from 1 to 16. Though not very common, a 3-D matrix can simply be implemented in a code as a 2-D matrix of pointers to arrays.

A 3D matrix called $\tilde{C}_S$ is set up for each ship "s" which includes all its cracks. After all the data has been inserted, the matrix component $\left[\tilde{C}_S\right]_{i,j,k}$ gives us the number of cracks of the description given by "i", "j" and "k". For example, $\left[\tilde{C}_S\right]_{22,6,4} = 2$ means that ship "s" has two cracks of 200mm (k=4) in the lower stool (i=22) of cargo hold 5 (j=6).

By summing over the k dimension, we compress the matrix into a 2D matrix, $\tilde{N}_S$ which gives us the total number of cracks (irrespective of size) in each location described by region "i" and compartment "j". The elements of the resulting matrix are given by:

$$\left[\tilde{N}_S\right]_{i,j} = \sum_k \left[\tilde{C}_S\right]_{i,j,k} \qquad (4.2\text{-}1)$$

To get the total crack length in each location, we start by creating a size matrix $\tilde{S}$ which is again 3D but varies only in the k dimension. The elements of the matrix $\tilde{S}$ are given by: $\left[\tilde{S}\right]_{i,j,k} = 50k$ for k=1 to k=16.

$$\left[\tilde{S}\right]_{i,j,1} = 50, \left[\tilde{S}\right]_{i,j,2} = 100 \ \ldots\ldots\ldots \left[\tilde{S}\right]_{i,j,16} = 8000 \qquad (4.2\text{-}2)$$

Now we need to use the two 3-D matrices, $\tilde{C}_S$ and $\tilde{S}$, to develop a 2D matrix $\tilde{L}_S$ which gives the total crack length in each location i,j. The type of operations which take you from 3-D to 2-D are referred to as *"Open Matrix Multiplications"* in contrast to *"Closed Matrix Multiplications"* where the degrees of freedom are held constant. To get $\tilde{L}_S$ we need to develop a new *"Open Matrix Multiplication"* product. To do that, we start from the *Hadamard Product* (a sub-matrix of the *Kronecker Product*) which is used for 2-D matrices.

For 2-D matrices, the *Hadamard Product* , also known as *Entrywise Product* and *Schur Product,* is defined as: $\left[A \cdot B\right]_{i,j} = \left[\tilde{A}\right]_{i,j}\left[\tilde{B}\right]_{i,j}$. (4.2-3)

This is unrelated to ordinary matrix multiplication (inner product) which is defined as: $[AB]_{i,j} = \sum_{r=1}^{n} [\tilde{A}]_{i,r} [\tilde{B}]_{r,j}$. In the *Hadamard Product*, each component i,j in the resulting matrix is the product of the respective components i,j in the individual matrices.

First, we extend the *Hadamard Product* to 3-D matrices and we sum over the k-dimension in order to compress from 3-D to 2-D. As a result, we develop a 2-D L-Matrix matrix in which the elements are given by:

$$[\tilde{L}_S]_{i,j} = \sum_{k} [\tilde{C}_S]_{i,j,k} [\tilde{S}]_{i,j,k} \qquad (4.2\text{-}4)$$

The matrix $\tilde{L}_S$, therefore, gives the total crack length in each location and compartment of ship s

Summary

For each ship "s":

1. We input the data according to crack location and size into $\tilde{C}_S$ (3-D)
2. We compress to $\tilde{N}_S$ (2-D), which gives the number of cracks in each location i,j.
3. We "combine" with $\tilde{S}_S$ using the above defined modified-Hadamard open matrix multiplication product to get $\tilde{L}_S$, which gives the total crack length in each location i,j.

Now for each data sample (ship) "s" we have the ship's age at the time of the repair and the matrices $\tilde{C}_S$, $\tilde{N}_S$ and $\tilde{L}_S$. We can then sum these matrices across all the ships of the database to create combined matrices for the whole data sample $\tilde{C}$, $\tilde{N}$ and $\tilde{L}$. The elements of these matrices are given by:

$$\left[\tilde{C}\right]_{i,j,k} = \sum_{S}\left[\tilde{C}_S\right]_{i,j,k}$$
$$\left[\tilde{N}\right]_{i,j} = \sum_{S}\left[\tilde{N}_S\right]_{i,j} \qquad (4.2\text{-}5)$$
$$\left[\tilde{L}\right]_{i,j} = \sum_{S}\left[\tilde{L}_S\right]_{i,j}$$

We can also sum matrices $\tilde{C}_S$, $\tilde{N}_S$ and $\tilde{L}_S$ across all the ships of a particular age group "A" to create combined matrices for each age ranging from 0 to 28 years. Denote these as $\tilde{C}_A$, $\tilde{N}_A$ and $\tilde{L}_A$. The elements of these matrices are given by:

$$\left[\tilde{C}_A\right]_{i,j,k} = \sum_{S}\left[\tilde{C}_{S\in A}\right]_{i,j,k}$$
$$\left[\tilde{N}_A\right]_{i,j} = \sum_{S}\left[\tilde{N}_{S\in A}\right]_{i,j} \qquad (4.2\text{-}6)$$
$$\left[\tilde{L}_A\right]_{i,j} = \sum_{S}\left[\tilde{L}_{S\in A}\right]_{i,j}$$

After processing all the data, we have developed matrices $\tilde{C}_S$, $\tilde{N}_S$ and $\tilde{L}_S$ for each of the 240 ships, matrices $\tilde{C}_A$, $\tilde{N}_A$ and $\tilde{L}_A$ for each ship age from 0 to 28, and matrices $\tilde{C}$, $\tilde{N}$ and $\tilde{L}$ for the whole data sample.

Having developed theses matrices, we can then sum over the relevant compartments "j", locations "i" or ages "A" in each matrix, to obtain the distribution of cracks or crack lengths along the ship length, height or within each location for each ship, ship age group or for the whole data sample. Many results can easily be derived once the above matrices are developed and can be presented in a graphical form. A selection of those is summarized in Section 4.2.5.

4.2.5 Result Presentation and Analysis

4.2.5.1 The Hull Distribution of Cracks

4.2.5.1.1 Distribution along Ship Length

By summing over the i-components of the $\tilde{N}$ matrix, we compress the 2-D $\tilde{N}$ matrix into a 1-D matrix which gives the total number of cracks from the whole database in each compartment "j". This gives us the average distribution of the cracks (by number) along the ship length. The results are summarized in Fig. 4.2-6.

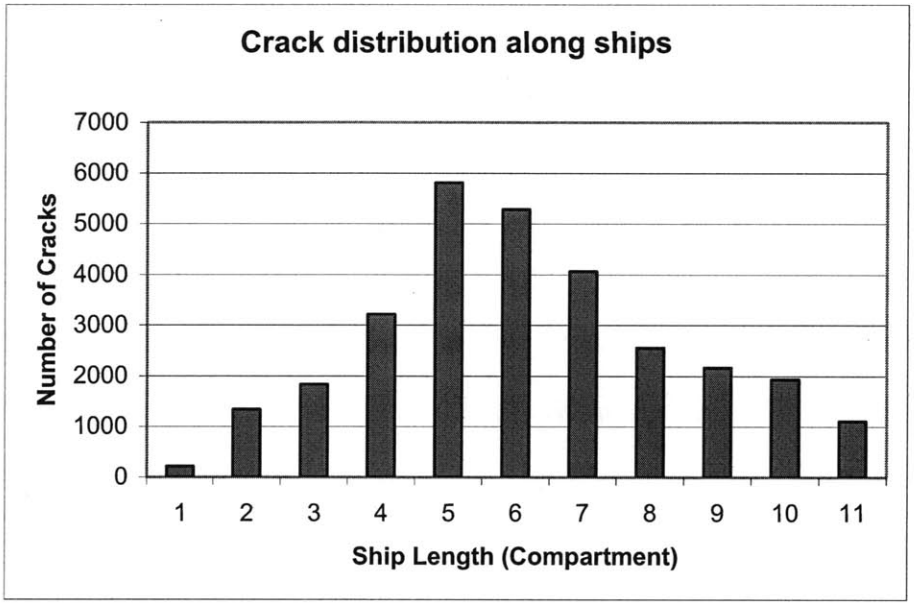


Fig. 4.2-6: Crack Distribution along Ship Length

This result is very close to what would be expected if the ship hull is modeled as a beam in bending where the bending stresses are maximized at the centre. The aft end (j=1), cargo area (j=2 to 10) and fore peak (j=11) account for 0.73%, 95.5% and 6.6% of cracks. A similar analysis on defects (67.9% cracks) in double-hull tankers by [LR, ABS and DNV 2005] showed 6.4%, 82.8% and 10.3% respectively across all ship sizes. Their results for suezmaxes (closest size to a cape), were 4.8%, 89.7% and 5.4% respectively. The results obtained by Lloyd's Register in a damage survey (including cracks) on Bulk Carriers and

OBOs of 65'000dwt and larger, were 9.0%, 77.8% and 13.2% respectively [Ferguson et al 1993].

However, they are in slight contrast with those of Fig. 4.2-6, because the Lloyd's register results are slightly negatively skewed, showing a maximum of hull damages in the forward mid-section of the ship, as shown in Table 4.2-5.

Hull Damages Distribution in Bulk & OBO Carriers of 65 000 DWT +					
Region	AP+ER	MID-AFT	MID	FWD-MID	FP
% Damages	9.01	17.11	27.93	32.74	13.21

Table 4.2-5: Lloyd's Register Hull Damage Survey Results for PMX + size ships [Ferguson et al 1993]

The crack distribution along the hull has a similar shape to the distribution of wave induced bending moments as shown in Fig 2.9-17 – 2.9-20 of Section 3.9.5. A link is thereby demonstrated between the highly stressed areas and those which are prone to cracking. It should be noted that cracks may appear for numerous reasons as discussed earlier and also that the ship structure is strengthened accordingly in the relevant locations to accommodate the high stresses. As a result, this counterbalances the effect and hence weakens the link between the two.

The compartment with the most cracks is j=5, which corresponds to cargo hold 6, with 5,288 cracks (17.88% of the total). This is the cargo hold which is ballasted during the heavy ballast condition in approximately 80% of capes. According to the analysis in Section 4.1, the heavy ballast condition accounts for approximately 36.4% of the time. As shown in Fig. 3.9-5 to Fig. 3.9-9 in Section 3.9.4, heavy ballasting is the worst of the loading conditions. The bending moment peaks at the ballasted hold and the shear force peaks at its adjacent bulkheads with values often exceeding 90% of the allowable stress.

In some ships, cargo hold 4 corresponding to compartment j=7 is used during the heavy ballast condition. Compartment j=7 also shows a relatively large number of cracks. Approximately 5% of the ships, particularly the larger ones, use two cargo holds for heavy ballasting, usually cargo holds 4 and 6. Additional cargo holds (e.g. all even numbered holds) are also often used for port ballast. Heavy ballasting holds are always enhanced. However, as shown in Fig. 4.2-6, an increased crack frequency is still evident in CH6.

In the fore peak region (compartment 11), most of the 1,109 cracks are associated with heavy weather. Dynamic loads arise from the impact of waves at the bow and also due to free surface effects in the fore peak tank when it is partly ballasted. The area is significant enhanced to account for this but sometimes, over-enhancement, again leads to the same problem. Cracks often develop from the inner side of the fore peak if it is over-enhanced, and consequently too stiff, even though there is significantly less flexing in this part of the ship compared to the centre.

According to [Janzen et al 1973], severe damages can also occur in the bottom of the forward vessel when traveling on light ballast if not reinforced appropriately. The cracks which develop at scallops or brackets, depending on the fore peak design, are the most common cracks in this compartment. They are a consequence of wear, design and stress. Most other cracks in the fore peak were only due to corrosion.

The after peak and engine room (j = 1) contained a total of 215 cracks. Overall, cracks towards the stern or bow of the ship are relatively few in number. This is in agreement with the results obtained by [Antoniou 1977]. 82% of crack and buckling failures were also found to occur in the mid-ship portion of the ship in a survey carried out by [SSC 1978].

The reduced number of cracks at the two ends of the ship in the database is mainly accounted for by the lower wing tanks and double bottoms (regions 3 and 4). Bending moments are lower at the ship ends, but more importantly, the geometry is different. The ship "closes up" going backwards or forwards, leading to a higher density of frames and to a smoother curvature of the side shell and bilge web frames with no abrupt corners. The hoppers are also larger than those in compartments closer to mid-ship.

Cargo hold 9 (Compartment j=2) accounts for 1,345 cracks (4.55% of the total) and cargo hold 1 (Compartment j=10) accounts for 1.942 cracks (6.57% of the total). In the survey conducted by [NK 1976], the corresponding locations in 22 Handy/PMX size bulk carriers had 7% and 11% of the cracks respectively while the fore peak tank had the least.

Compartment j=1 which comprises of the after peak and the engine room includes the least number of cracks (215 in total). Very few ships were found to have cracks in the after peak. Stresses in this area are very low compared to those in the rest of the hull. Cracks in this area develop mostly due to wear and corrosion or vibrations from the engine, shaft, propeller or steering gear. Cracks in the rudder trunk were very few and they were located

under the longitudinal bulkhead. They are due to sudden rudder shaft vibration being transmitted from the steering gear.

Very few cracks were also reported in the engine room, again in a small number of ships. These are mostly due to vibration or local stresses and include mainly cracks in bracket or stiffener ends, at the connections of struts with pillars (mostly on struts) (6c), on transverse web frames (1a), and in the small transverse bulkheads (1a) or longitudinal bulkheads (1d) of fuel oil and diesel oil tanks. A few cracks were reported on the main engine but these were not recorded as they are not part of the hull structure. Very few cracks were also reported in the void space of the double bottom region under the engine (4b & 4d). These are very rare and develop due to vibration or as a consequence of low quality welds and small defects.

Finally, it should also be noted that after peak and engine room cracks were more common in newer ships.

4.2.5.1.2 Distribution along Ship Height

By summing over the j-components of the $\tilde{N}$ matrix, we compress the 2-D $\tilde{N}$ matrix into a 1-D matrix which gives the total number of cracks from the whole database in each location "i". This is a (1x26) matrix. Then we can group locations "i" into those which correspond to the bottom, middle and upper part of the ship. This reduces the size of the matrix to (1x3). The cracks in region 6 (Stringers, Pillars, Girders and struts) were distributed to height areas 1, 2 and 3 by a ratio of 4:3:3 respectively which is approximately the ratio by which these structures are allocated along the height. This only has a small influence since region 6 only accounts for 1.6% of the total number of cracks.

The bottom part (height 1) includes regions 3 and 4, 5d, 5e and 40% of 6. The middle (height 2) includes regions 2, 5c, 5f, and 30% of 6. The upper part (height 3) includes regions 1, 5a, 5b and 30% of 6. The results are shown in Fig. 4.2-7.

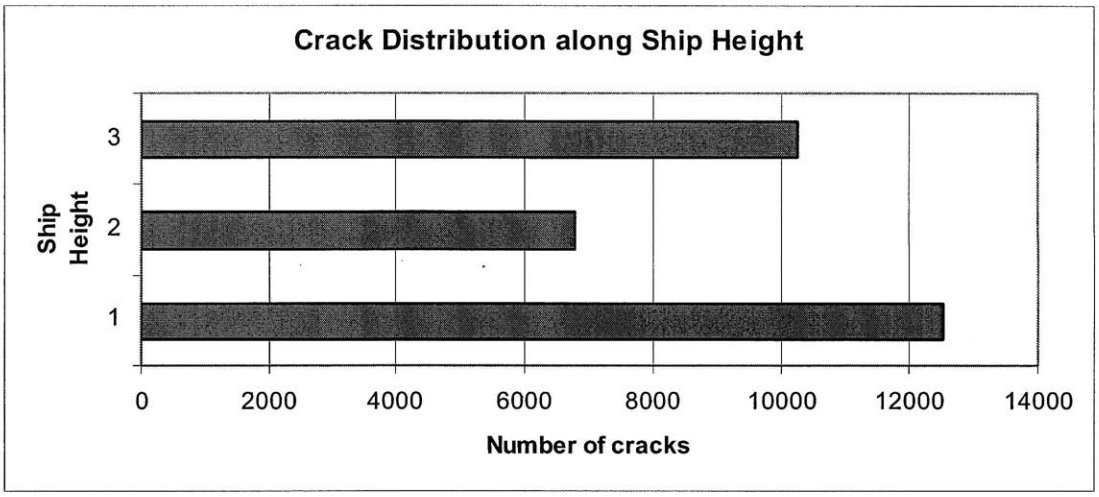
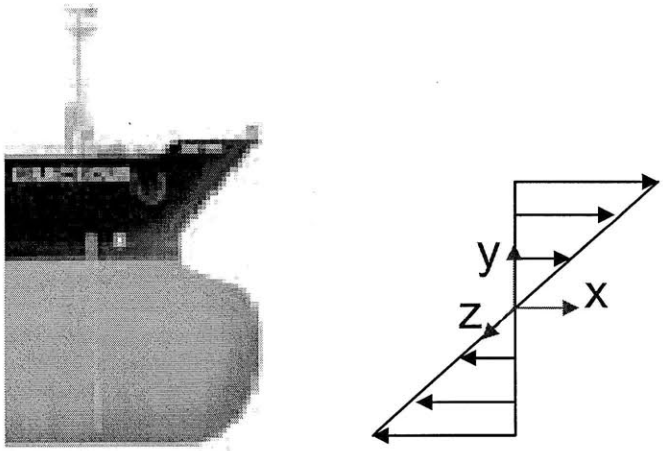


Fig. 4.2-7: Number of Cracks along Ship Height

Evidently, the tension that prevails in the lower height results in the a higher crack frequency. Higher bending stresses are expected near the top and bottom edge of the ship simply by modeling the ship as a beam in bending:



$$\sigma_{xx} = \frac{-My}{I} = \frac{-M}{Z}$$

Fig. 4.2-8: Stress distribution w.r.t. Ship Height

where Z is the section modulus and has two values, one for the region below and one for the region above the centre line. Hence, by looking at the crack distribution along the height,

there seems again to be an association between the highly stressed regions and those prone to cracking.

However, the difference between the number of cracks in the upper (3) and lower (1) zones compared with the neutral axis zone (2) is not very large. The number of cracks near the neutral axis zone (height 2) is largely due to the numerous small components such as brackets which are very susceptible to small cracks. The analysis was thus further extended to provide a distribution of the total crack length in the same regions as shown in Fig. 4.2-9a. This is done by repeating the exact procedure but starting with matrix $\tilde{L}$ as opposed to $\tilde{N}$.

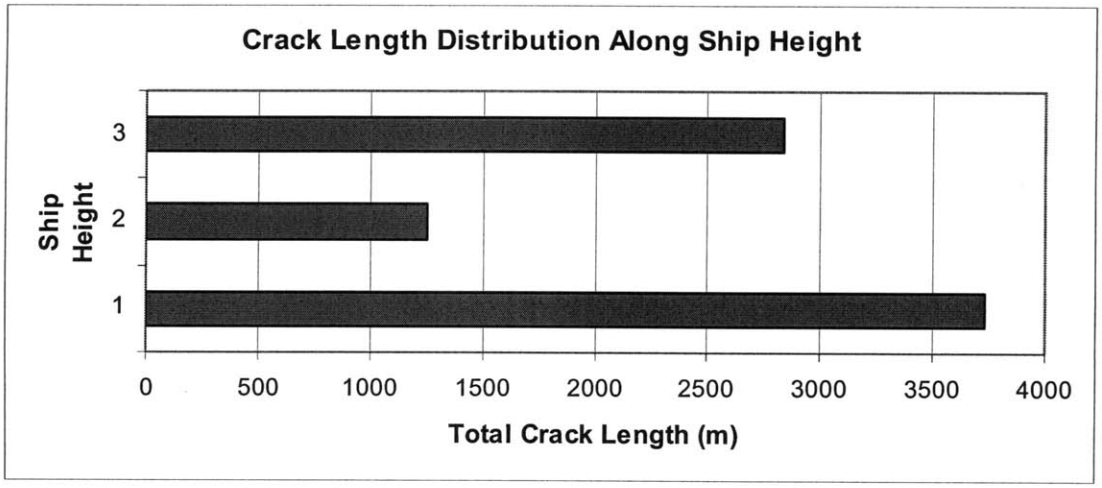


Fig. 4.2-9a: Total Crack Length distribution along ship Height

This clearly shows a more defined increase in the upper and lower regions in comparison to the middle. The higher total crack length in the lower part of the ship is also consistent with the fact that the neutral axis is lower than the middle of the ship.

Similar results were observed by the in a survey of 76 single hull VLCC tankers by the Joint Bulker Project group. These are shown in Fig. 4.2-9b.

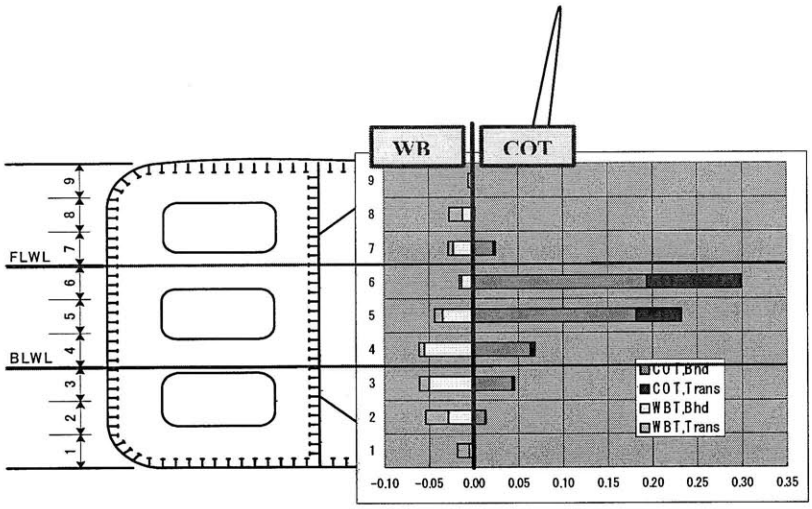


Fig. 4.2-9b: Fatigue Damage Frequency in COT and WBT [JBP 2005]

4.2.5.1.3 Crack Distribution by Location and Repairs

By summing over the j-components of the $\tilde{N}$ matrix, we compressed the 2-D $\tilde{N}$ matrix into a 1-D matrix of size (1x26) which gives the total number of cracks from the whole database in each location "i". Previously, we grouped locations "i" into "height" categories and reduced the size of the matrix to (1x3). Now instead of doing that, we can simply plot this (1x26) matrix in a chart to show the total number of cracks in each location "i" across all compartments. That is shown in Fig. 4.2-10.

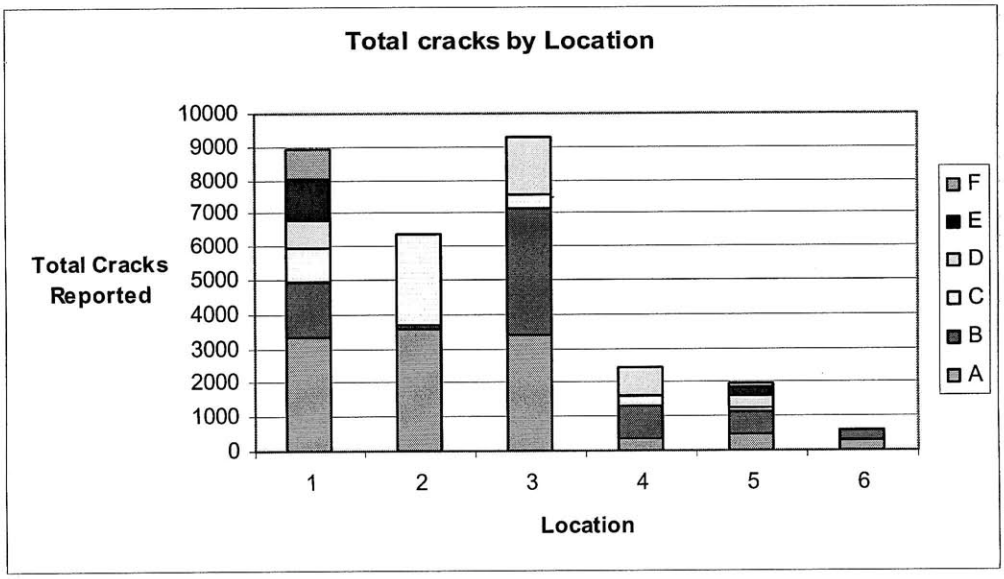


Fig. 4.2-10: Total Crack Distribution in the various Locations

The 2-D $\tilde{N}$ matrix is of size (26x11). We can also break this down into 11 1-D matrixes of size (1x26). Each 1-D matrix corresponds to a compartment "j" and its elements give the number of cracks in each of the 26 locations "i" within that compartment. The results are summarized in Fig. 4.2-11 to 4.1-21.

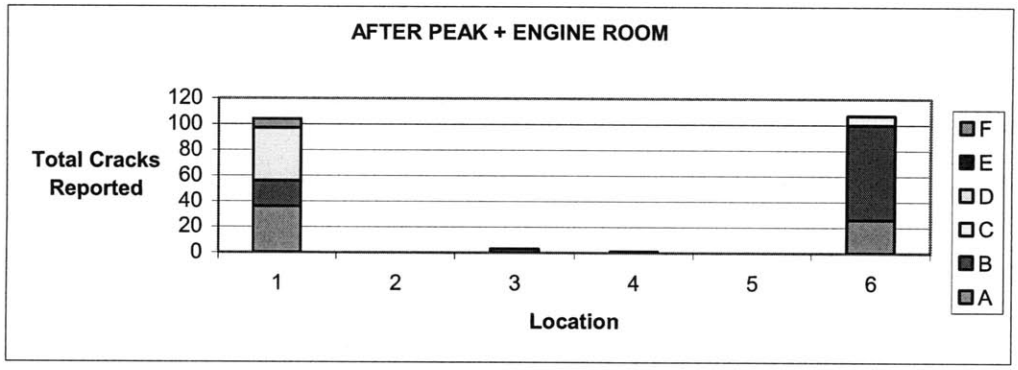


Fig. 4.2-11: Crack Distribution in Compartment 1

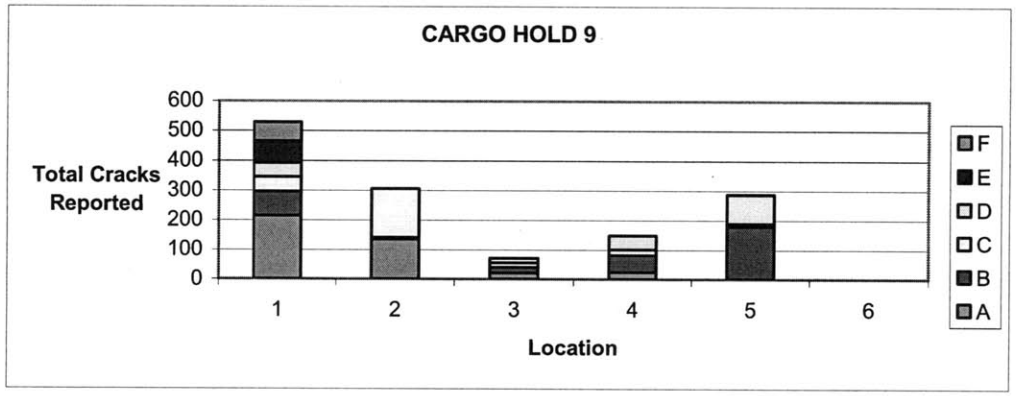


Fig. 4.2-12: Crack Distribution in Compartment 2

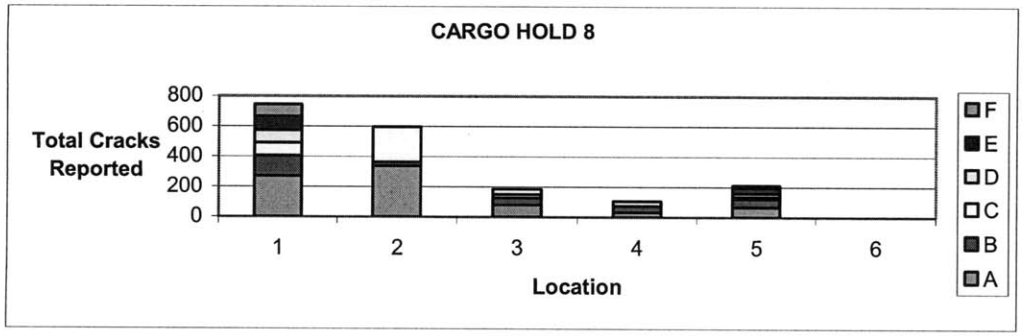


Fig. 4.2- 13: Crack Distribution in Compartment 3

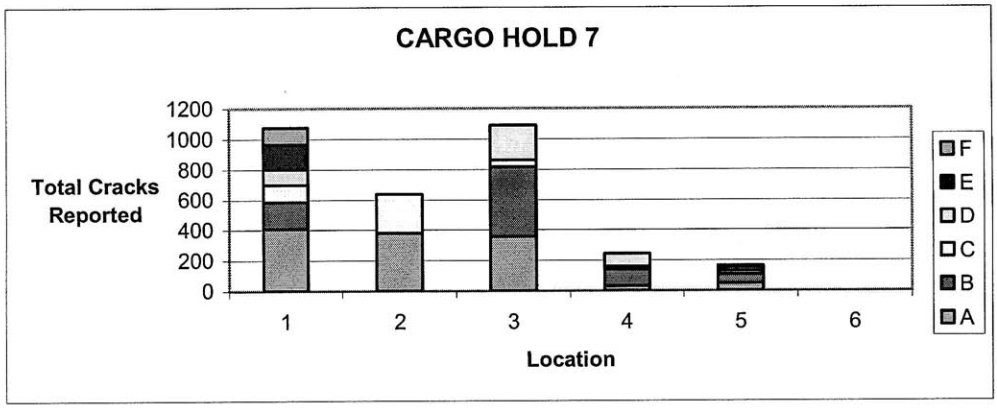


Fig. 4.2-14: Crack Distribution in Compartment 4

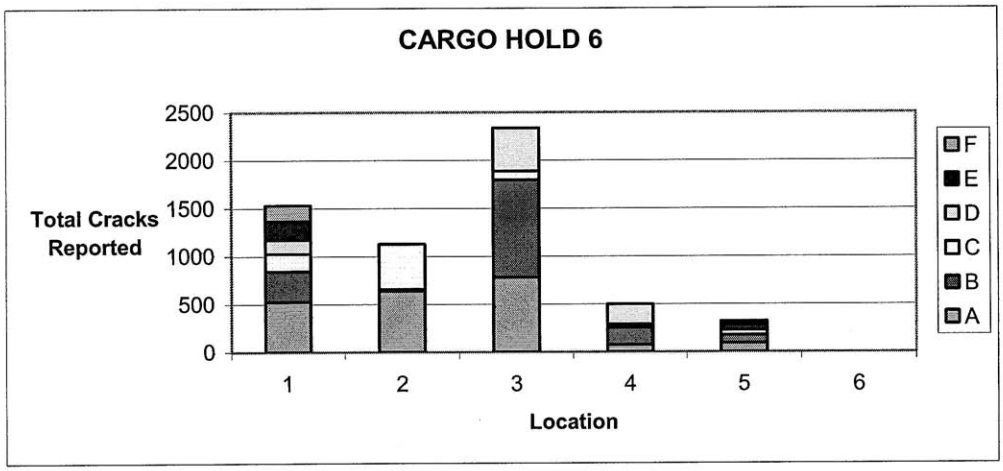


Fig. 4.2-15: Crack Distribution in Compartment 5

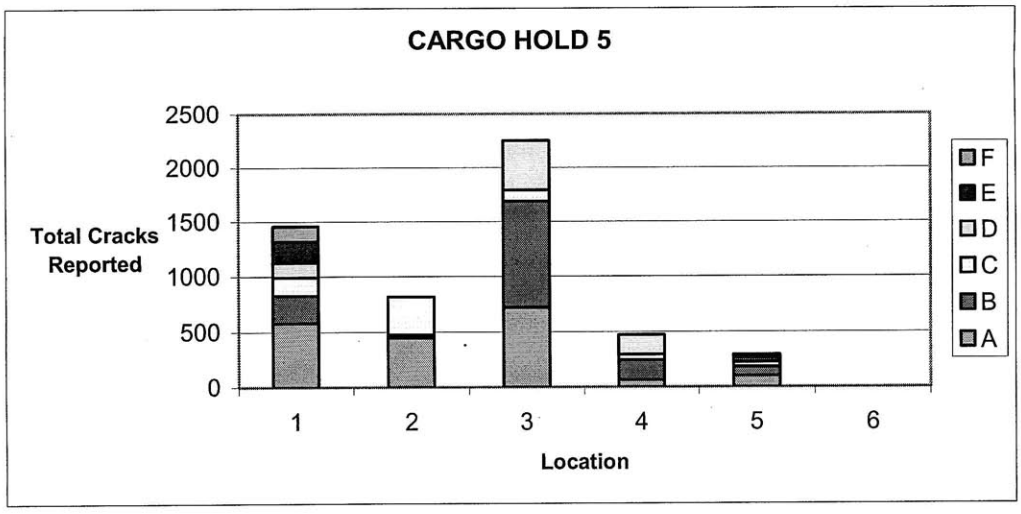


Fig. 4.2-16: Crack Distribution in Compartment 6

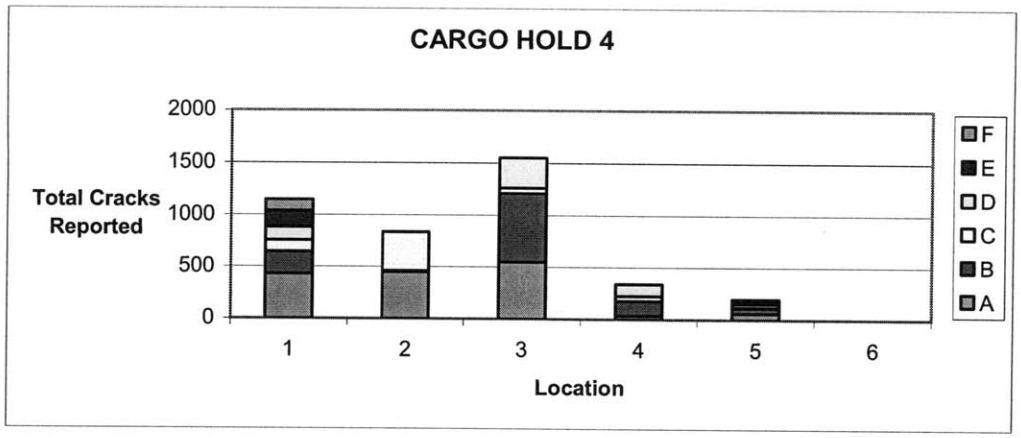


Fig. 4.2-17: Crack Distribution in Compartment 7

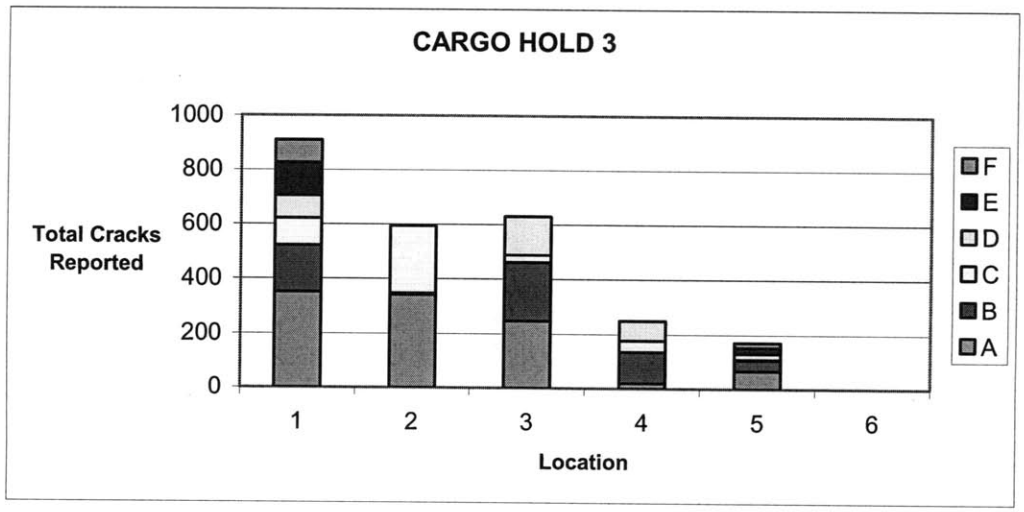


Fig. 4.2-18: Crack Distribution in Compartment 8

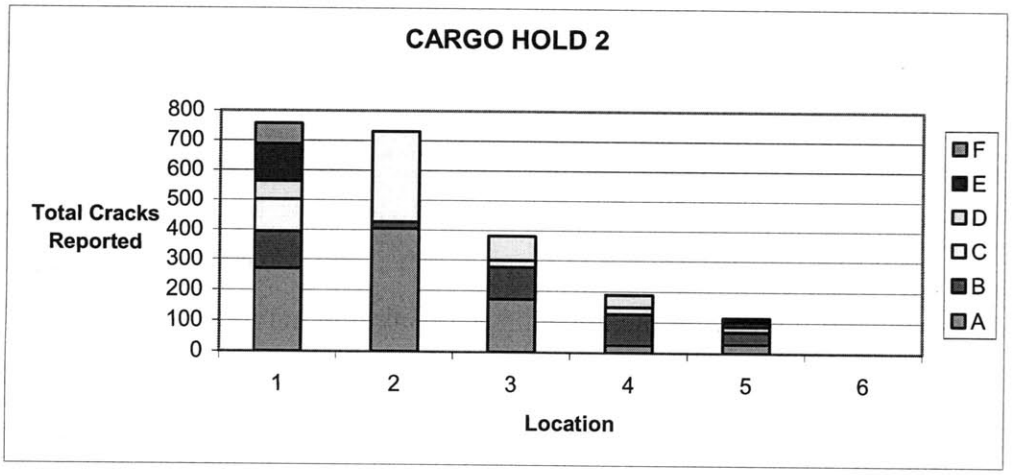


Fig. 4.2-19: Crack Distribution in Compartment 9

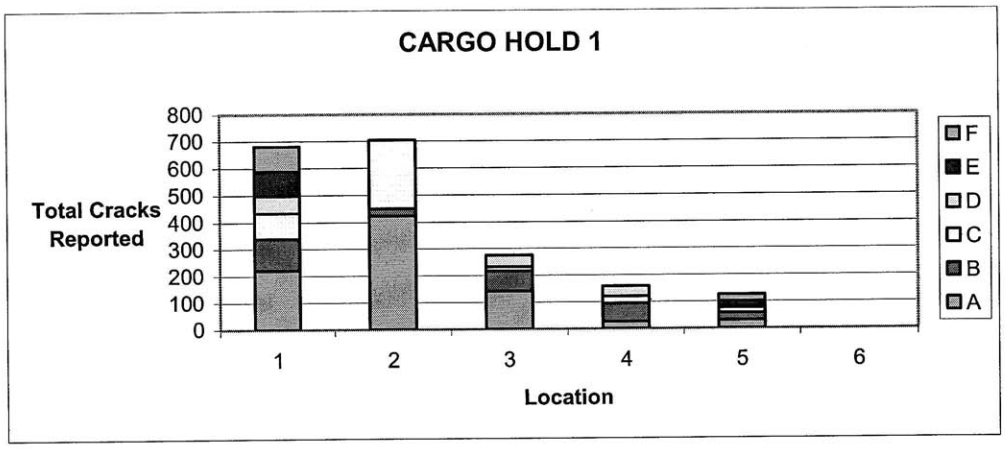


Fig. 4.2-20: Crack Distribution in Compartment 10

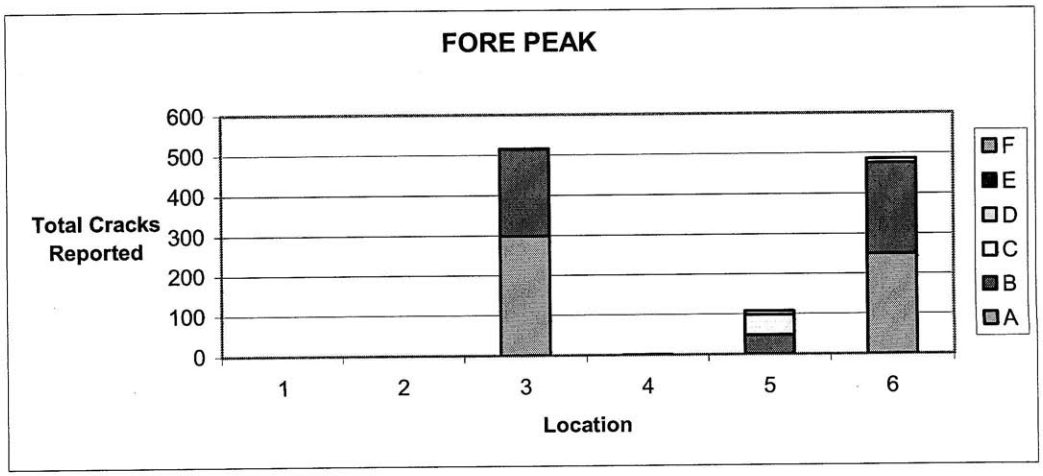


Fig. 4.2-21: Crack Distribution in Compartment 11

As shown in Fig. 4.2-10, the region with the highest crack frequency was the lower wing tank area (3) with a total of 9,290 cracks followed by 8,931 cracks in the Deck and upper wing tanks (1). Ballast tanks, combined, account for approximately 60% of all cracks. The crack distribution, however, varies significantly along the length of the ship as can be seen in the subsequent graphs (Fig. 4.2-11 to 4.1-21). The lower wing tank area shows a much higher number of cracks in the mid ship region (cargo holds 4-7) compared to the ship ends. The cargo hold region (shell and frames) also shows a relatively high number of cracks and appears to be the most vulnerable region in cargo hold 1 with 703 cracks out of the 1,942.

4.2.5.1.3.1 Region 1 – Deck & Upper Wing Tank (i = 1 to 6)

The deck and upper wing tank is the region with the most cracks in compartments 2, 3, 8 and 9 and ranks second in the remaining except for compartment 11. It is also second overall with a total of 8,931 cracks (30.2% of the total).

Cracks in region 1 develop mainly due to high local stresses but the whole region is also very vulnerable to corrosion. This is because the upper wing tanks undergo cycles of sea water and air exposure more than any other region in the ship (lower tanks must usually be full in order to ballast upper wing tanks). Therefore, many of the cracks develop by the mechanism of stress corrosion cracking.

The most vulnerable location appears to be that of the transverse web frames and stiffeners (1a), where a total of 3,312 cracks were recorded. Most of these were dealt with by increasing the plate thickness from say 12mm to 14mm. Initiation usually takes place at the 3 "corners" of the o-ring, most common being the lower and the inner (to the ship) corners. Fig. 4.2-22 shows the typical repairs which are carried out.

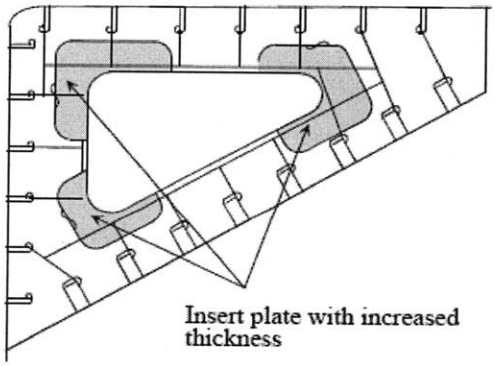


Fig. 4.2-22: Enhancement of Top Side Tank Web Frame with Brackets and Inserts [IACS 2004]

Cracks in this area develop both due to high stresses and stress corrosion cracking. The same applies to all scallops, small openings and man-holes on web frames which are vulnerable due to local corrosion at their edges.

The majority of scallop cracks were found on scallops of the deck and side shell rather than the slopping plate. Cracks at scallops on the slopping plate were mostly concentrated on the inner and upper region where thicker plating is often used. The most common solution was again increasing the thickness or adding a collar plate or doubler for strengthening. An area particularly vulnerable on the slopping plate is at the corners of the scallops where the web frame connects to the slopping plate. The solution to these cracks was usually either replacing the cracked piece or gouging/grinding and then welding it back. Cracking also initiates due to local stress at side shell longitudinals connecting with the tripping brackets of web frames. The face plate thickness in this case is usually increased.

The most common cracks on the deck are those at the corners of hatches. Cracks initiate due to stress concentration at the corners of hatch coamings from the inside and propagate outwards towards the deck. They are thus not visible from the side of the deck until they have propagated far enough. This can be seen in the right diagram of Fig. 4.2-23 where the crack is not visible from outside the hatch opening until it has propagated beyond the dotted line at the hatch corner. The particular problem has been long recognized and the plate thickness is increased at the corners by about 15% to account for this.

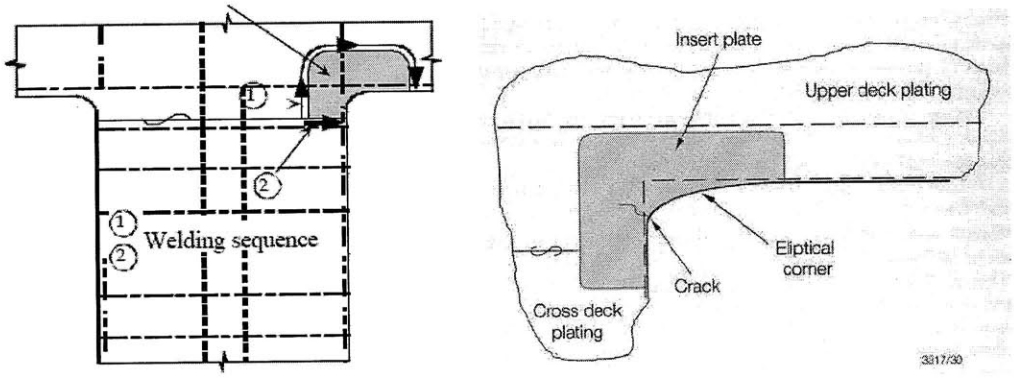


Fig. 4.2-23: Repair at hatch corners (left) [IACS 2004], and close-up (right) [LR 2005a]

Similar cracks develop on the deck at the corners of the accommodation and usually propagate outwards towards the shell. Another critical area on the deck is that of the cross deck (between the hatches) in which the plating is about 11mm compared to 25mm of the

remaining deck. The reason for this is that the side loads and torsional stresses carried taken by the cross deck were underestimated in early designs. Many cracks were also found on the stays around the hatch openings. Cracks usually initiate at the toes of hatch coaming brackets and the design is often modified to include a smoother bracket which weakens the hot spot (Fig. 4.2-24).

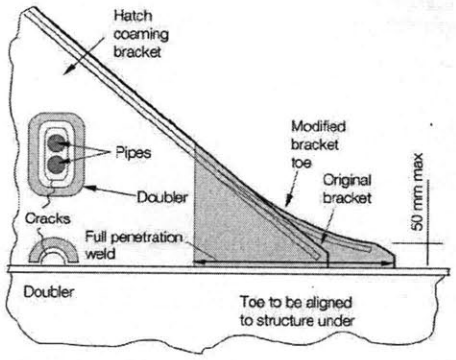


Fig. 4.2-24: Modification of hatch coaming brackets to reduce stresses on the deck [Ferguson et al 1993]

Besides cracking, the deck is also prone to mechanical damage from accidents during operation.

Many cracks were also reported on transverse hatch end beams (1e). These often arise from the high stress concentration at the connection with the longitudinal girder and are particularly dangerous for ballast water ingress from the wing tanks into the cargo hold. The thickness was usually increased locally in these cases during crack repairs.

No major modifications were reported in the repairs of cracks in 1d, 1e and 1f.

4.2.5.1.3.2 Region 2 – Cargo Hold Frames & Shell Plate (i = 7, 8 & 9)

A total of 6,353 were reported in the cargo hold frames and shell plate area which appears to be the most problematic region in cargo hold 1 (j = 10) and ranks second in compartments j = 2, 3 and 9.

Stresses increase with the distance from the neutral axis and they are consequently higher near the ends of the frames. Therefore, brackets are made thicker than the rest of the frame. Despite the increased thickness, the higher stresses combined with the high stress concentration factor and associated "hard spots" causes the majority of cracks to initiate at the toes (mostly the upper toes). They propagate along the welds towards the side shell.

Even though the lower region is more prone to corrosion and mechanical damage, the lower frames are larger and flexing is less severe. This, in combination with the increased fatigue in the topside tanks due to inertial effects, partly explains the increased occurrence of cracks in the upper toes. The overall frequency of these cracks along the ship length appears to be closely related to the stress distribution predicted by the wave induced and still water bending moments. When cracking was suspected to be caused by high stresses, the thickness was increased during repairs. When cracking was also found in locations of lower stresses, and was thus a consequence of poor design, a common approach was to modify the tips of bracket toes to make them smoother and rounder (sometimes also increasing thickness). Fig. 4.2-25 shows a lower bracket toe modification recommended by Lloyd's Register.

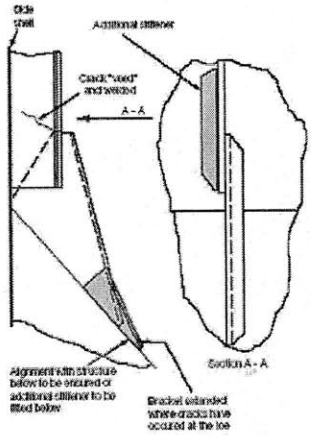


Fig. 4.2-25: Additional Stiffener and Bracket Extension [LR 2005a]

In agreement with past experience, cracks at brackets of an integral design, or in the absence of corrosion, were found to be contained in a localized area around the bracket toe. When corrosion was also reported, however, and in the case of a two-part bracket design (as depicted in Fig. 4.2-25), relatively larger crack lengths were recorded.

Most other cracks were found to be due to stress corrosion, inherent material and weld defects or mechanical damage. These were usually repaired by replacing the cracked plate with a new one of similar thickness. Examples include cracks in the middle region of frames, all of which without exception were found to propagate towards the shell plate. The shell plate on its own was very rarely found to crack away from connections. Cracks often initiate at weld defects in hopper tank transverse brackets and propagate along the shell due to fatigue. Some cracks were also reported along the edges of frames with the shell which was the result of wear and not stress.

Region 2 accounts for 306 cracks in cargo hold 9 (j = 2) and 703 in cargo hold 1 (j = 10), whereas the mean across the remaining cargo holds (j = 3 to 9) is 763. It should be noted that cargo holds 1 and 9 are different in design as the ship changes section towards the stern and bow. Frames are thus smaller in length and more curved so they are less vulnerable to cracking. Most of the stresses here are also taken by the bulkhead as opposed to the frames.

Even though still water bending moments are relatively low in this region, the frames in cargo hold 1 (j = 10) are subjected to weather induced dynamic loads and are enhanced accordingly. The side shell and frames, however, still appear to be the most vulnerable area of cargo hold 1. Some cracks in this region were found on the side shell near and on the connection to the collision bulk head. This design detail is expensive for shipyards to correct and is thus usually ignored, knowing that a few cracks will develop. Some large vertical cracks in the range of 1 to 2 meters have also been reported on the side shell in the region of the transverse bulk head between cargo holds 1 and 2.

It should be noted that the fore peak (j=11) is connected to the rest of the ship at about 10-15cm behind the collision bulk head and that this is the location where often ships split in two. The crack may initiate on the outer shell in the groove as a result of sea wave loading. Dynamic loads due to free surface effects within the fore peak also often translate to the shell via the bulk head and further propagate the crack. This phenomenon may also occur at the welding around the ship on the shell near the bulkhead between cargo hold 9 (j=2) and the Engine room (j=1). In this region, cracks often initiate on the main deck at the corners of the accommodation and propagate sideways towards side shell.

4.2.5.1.3.3 Region 3 – Lower Wing Tank (i = 10 to 13)

As shown in Fig. 4.2-10, the lower wing tank appears to be the most vulnerable area with a total of 9,290 reported cracks. The subsequent graphs (Fig. 4.2-11 to 4.1-21) show that the frequency of cracks in this region is much higher near the centre of the ship and decreases substantially towards the stern and the bow. Most cracks in the first double bottom (covering j = 2 and 3), result from wear and very rarely due to stress.

The most vulnerable location in the whole ship appears to be the bilge plate with its longitudinals (3b or i = 11) where a total of 3,785 cracks have been recorded. Most of these cracks initiate at the tripping bracket connections with the face plates and propagate down and through the frames towards the shell. About 80% of these were found to initiate at the inner corner of the tripping bracket and the rest initiated at the outer corner (the toe). The face plate thickness was usually increased during the repairs of these cracks. Another modification which was occasionally reported was to replace the bracket toe with a softer one and thus reduce the stress on the face plate at the corner as shown in Fig. 4.2-26.

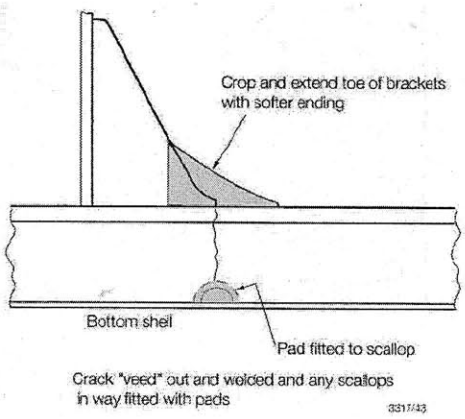


Fig. 4.2-26: Modification of Bracket Toe to Reduce the Stress on the Face Plate [Ferguson et al 1993]

The types of modifications which have been reported in this region are analyzed in greater depth in Section 4.2.5.1.4.

Cracks were occasionally reported on discontinuous bilge plates (3b, i = 11) at the corners where the sections end (on the outer side of the shell). The bilge keel sections were then replaced by one long bilge keel running throughout the length of the ship.

The location with the second largest number of reported cracks was bilge web frames (3a, or i = 10) with a total of 3,372. Unlike the top side tanks however, very few were reported at the o-ring "corners". Most were found to initiate at the corners of scallops and were relatively concentrated on the side shell compared to the hopper and bottom. After replacing, collar plates or doublers were often added for strengthening.

Only 386 cracks were found on the hopper plate and longitudinals (3c or i = 12). Stresses in this region are more uniformly distributed and cracks are usually only due to wear. Cracks were recorded at the connection with the tank top (inner bottom plate) from the side of the cargo hold. The plating thickness was often increased or additional intermediate brackets were added joining the hopper with the longitudinal girder. Very few cracks, however, were reported on the connection to the side shell. It appears more common for the frame brackets (toes) to fail instead.

A total of 1,747 cracks were recorded in the longitudinal girder and stiffeners (3d, i = 13). Many of these were on the longitudinal girder at manholes, air-holes and drain-holes as a result of stresses or wear at the edges. Cracks in manholes were often dealt with by replacing the plating with one of the original thickness and often adding a collar plate (doubler with a hole) as shown in Fig. 4.2-27. The face plate which is also recommended by IACS is probably less practical and was not reported in any of the repairs.

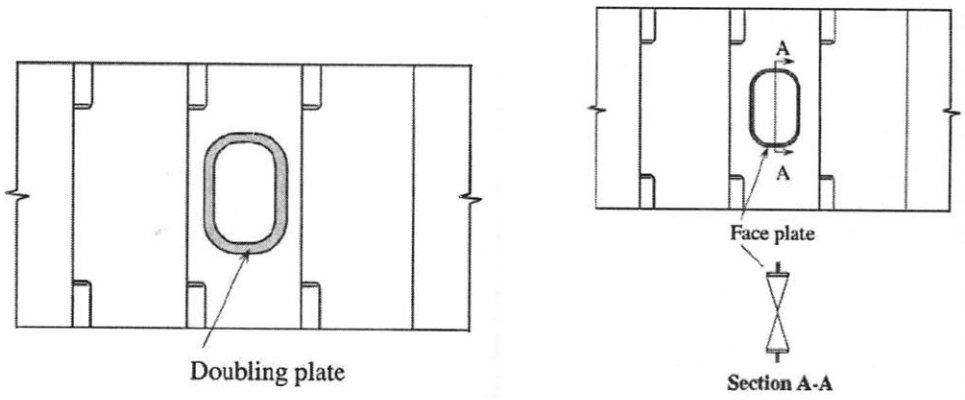


Fig. 4.2-27: Modification of Manholes with Collar plate (left) or (not reported) face plate (right) [IACS 2004]

During the repairs of cracks in drain holes or air holes, the plating thickness was usually increased. Cracks were also reported at the ends of stiffeners which are connected on the longitudinal girder. These are the result of poor design and thus the connection was usually modified to join more smoothly, or the length of the stiffener was increased so it ends at the floor. The thickness was generally increased when cracks appeared on the girder.

4.2.5.1.3.4 Region 4 – Double Bottom (i = 14 to 17)

A total of 2,411 cracks were reported in the double bottom region which is substantially lower than those in the lower wing tanks. This is partly explained by the fact that stresses are higher at the sides of the ship than close to centre-line. Again as with the lower wing tanks, the majority of cracks appear towards the centre of the ship and the frequency decreases towards the stern and bow. The static loads and buoyancy forces acting in this region vary significantly between loading conditions and the area is also very vulnerable to damages during cargo operations.

Most of the cracks recorded in the tank top (inner bottom plate) and longitudinals (4a, i = 14) were either due to mechanical damage or corrosion. These were just replaced with plating of the original thickness. Some cracks, however, were reported along the connection with the lower stool as a result of high stresses. In this case, the plating thickness was locally increased. Eventually, such cracks may propagate downwards across the girders and ultimately out to the shell but they are easy to detect due to the resulting ballast water ingresses into the hold.

The majority of cracks were reported on the transverse floors and stiffeners (4b, i = 15). Most of these were at the edges of manholes, scallops or drain holes as a result of stress and/or corrosion. The cracked plating was usually just replaced in most cases and a collar plate was often also added to cracked manholes as shown in Fig. 4.2-27. Cracks were also found at the connections of floors to girders due to the resulting stress concentration.

Relatively few cracks were reported in the bottom shell plate and longitudinals. Only a small number of bottom longitudinals was reported cracked. In these cases initiation took place at the corner of stiffeners which join the bottom longitudinals, the tank top longitudinals and the floors. These cracks propagate towards bottom shell. The thickness of the face plate was usually increased. Very few cracks were reported in the bottom shell. These were at the scallops of floors due to undercutting or at drain holes. The keel which is of thicker plating seems to be a crack-free region. Corrosion, however, may develop since this is where the ship rests when on dry dock.

A relatively high number of cracks were reported on the longitudinal girders and stiffeners (4d, i = 17). As with the side girder (3d, i = 13), cracks were found at the ends of stiffeners due to high stresses and stress corrosion cracking was found in drain and air holes. These were dealt with in the same way as in the side girder.

4.2.5.1.3.5 Region 5 – Transverse Cargo Hold Bulkheads (i = 18 to 23)

As can be seen in Fig. 4.2-11 to 4.1-21, the majority of cracks in bulkheads occurred in compartments j = 2, 5 and 6. These are the bulkhead between the engine room and cargo hold 9 and the two adjacent bulkheads of cargo hold 6 which is typically the heavy ballast hold. Cracking occurs even though the bulkheads adjacent to the heavy ballast hold are enhanced and often have a varying plate thickness to accommodate the hydrostatic loads. 1,989 cracks were reported in total and most are at the connections of bulkheads with surrounding structures, particularly hopper tanks and top side tanks.

The collision bulkhead suffers the greatest impact loads out of all bulkheads from the weather and due to slamming as a result of free surface effects from the partly ballasted fore peak tank. It is, however, enhanced with stiffeners, girders and stringers from the side of the fore peak tank in order to withstand these loads. There is also a gradual increase in its thickness from about 10mm at the top to 16 mm at the bottom in order to account for the hydrostatic forces imposed by about 20m of water from inside the fore peak. As a

consequence, fewer cracks are observed in the collision bulkhead and most are due to wear or corrosion rather than purely stress.

Besides the collision bulkhead, the aft bulkhead of cargo hold 2 (j = 9) has also been enhanced over the past several years as a result of reassessment and research. Similar problems thus often arise due to stiffness. A total of 107 cracks were reported on the collision bulkhead (j = 11) and similarly, 125 cracks were found in the cargo hold 2 bulkhead (j = 10). A large number of cracks (319 and 291 cracks respectively) were reported in the bulkheads of compartments j = 5 and 6 which are the two adjacent bulkheads of Cargo hold 6 (the typical heavy ballast hold). This is mainly due to the heavy ballast condition as discussed earlier.

288 cracks were also reported in the bulkhead of cargo hold 9 (j = 2). This is partly accounted for by the increased shear stresses which are witnessed at this location from the ANCO diagrams (Fig 3.9-5 to 3.9-9 in Section 3.9.4). Fatigue is also significant in this region since the engine room imposes a constant weight on the aft side of the bulk head while cargo hold 9 undergoes consecutive loading and discharging operations. High cycle fatigue due to vibration from the engine room also contributes to some extent.

Even though no cracks were found in the engine room bulkhead, it should be noted that this is a particularly critical area which is closely monitored. Since it separates the after peak tank with the engine room, any damage may lead to engine room flooding and have serious consequences. Furthermore, the bulkhead is subjected to thermal fatigue as a result of the heating from the side of the engine room and the alternate cooling from the continuous ballasting operations with cold sea water from the other. Cracks were reported, however, along the stiffener on the bulk head as a result of corrosion, flexing and due to the increased stiffness at the nodes.

About a quarter (24.8%) of the cracks in bulkheads were reported on the upper stool (5a, i = 18). Most of these were at the connection to the corrugated bulkhead or to the slopping plate particularly in the hold used for ballasting where stresses tend to be higher. These cracks are relatively easy to notice, however, particularly in the ballast hold due to the consequent water ingress to the adjacent holds. The solution for these cracks was usually gouging and then welding again. In some cases, intermediate tripping brackets were added inside the upper stool.

658 out of 1989 cracks in the bulkheads occurred in the upper corrugation (5b, i = 19). These were often the result of stress cracking at the connection of the corrugation to the slopping plates. Most of these cracks were reported to be gouged and welded. In some cases, tripping brackets are included between the corrugation and the upper stool for enhancement. Stress cracking was also witnessed in these and most cracks were found to initiate at the bottom of the tripping plate and propagate towards the stool. Repairs usually just included the replacement with thicker brackets.

The middle part of the corrugation was found to be much less vulnerable with almost no cracks except in cases with very much corrosion leading to stress corrosion cracks. Mostly other types of damages were reported in this region such as deformation, buckling, twisting etc.

The lower part of the corrugation showed crack distribution similar to that of the upper part. Cracks were reported at the connection with the lower stool and also at the connection with gusset plates and shedding plates. Most of these were stress cracks at the corners and bases but there were also some due to wear. Stress cracks were usually gouged and welded and in some cases, intermediate tripping brackets were included inside the lower stool for enhancement. Cracks due to corrosion were just replaced with plating of a similar thickness.

Most cracks in the corrugation overall were the result of high stresses. The best design to prevent this is that of curved shaped edges but it is far more expensive so the usual design consists of corners. In some cases it is of a square shape which is even worse in terms of stresses. The square design is less strong but it is cheaper and also cheaper and easier to repair when damaged. In addition to this, the corners rarely cracked, since they are welded from both sides and are, therefore, very strong. Some times, a totally flat sandwich structure (2 bulk heads with stiffeners in between) is used without a corrugation. This results in less cracking at the connections with the lower and upper stool. It is, however, more expensive and requires more steel.

In the lower stool (5e, i = 22), stress cracking was witnessed at the connection with the corrugation and with the tank top. Again gouging and welding was most common and intermediate brackets were occasionally added inside the stool. Other cracks due to corrosion were very few comparatively.

The ballast side trunk (5f, i = 23) is sometimes included in all cargo holds but is usually only present in every two. Cracks were usually recorded at the connection to the shell plate or at corner pointing inside the hold and most were near the mid region. These were usually gouged and welded and in some cases, carlings (web with rings) were included inside the trunk. Very few cracks were reported at the connection to the top side tank and hopper plates.

4.2.5.1.3.6 Region 6 – Other (i = 24 to 26)

The forepeak usually has two or three stringers (i = 24) but occasionally even six or more. These are platforms in the fore peak with scallops through which frames, stiffeners and sometimes girders (i = 25) pass. 227 out of the 1,109 cracks reported in the fore peak region were located at those girders. The fore peak design depends on whether it is constructed as one or two separate blocks. In the second case, one of the blocks ends at a stringer so the web frames, girders and vertical stiffeners within the fore peak are discontinuous and hence welded to the top and bottom of the stringer with brackets. In ships of this design, many cracks were located in the corners of these brackets at the connection with the stringer. If a single block design is adopted, this effectively introduces more scallops which are also prone to cracking as shown in Fig. 4.2-28.

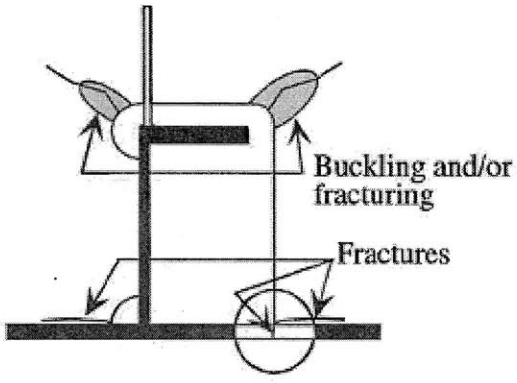


Fig. 4.2-28: Typical Cracks observed at Scallops [IACS 2004]

Cracks originating at scallops, often propagate to the shell and then appear from the other side as a bird spreading its wings, as shown in Fig. 4.2-29 and Fig. 4.2-30. That is how oil leaks often occur in tankers [Okumoto et al 2009].

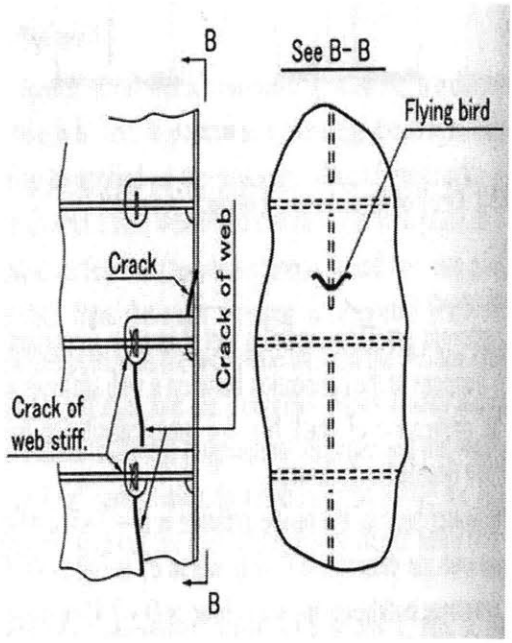


Fig. 4.2-29: "Fly bird" Crack on Side Shell, Originating at Scallop [Okumoto et al 2009]

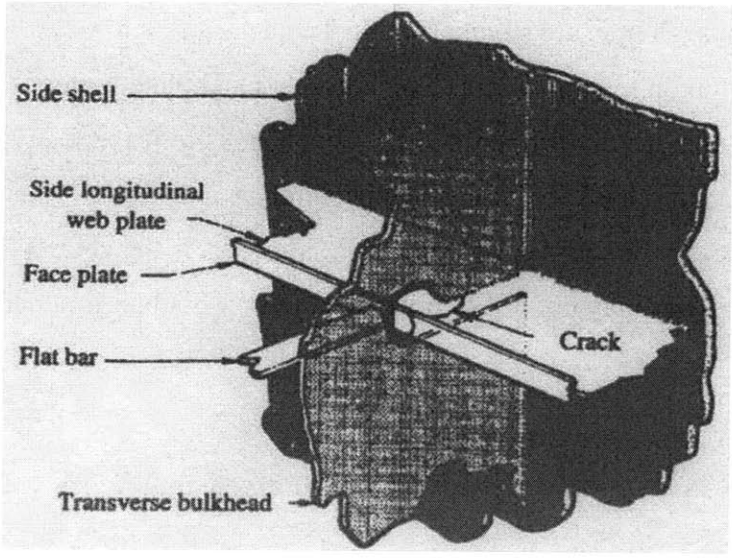


Fig. 4.2-30: Crack in Longitudinal at Connection to Transverse Web Frame [Hansen and Winterstein 1995]

Stringers (6a, i = 24) and girders (6b, i = 25) accounted for 275 and 216 cracks respectively. Most of the cracks were at scallops and the corners of brackets. Cracks at scallops were replaced and a collar or doubler was sometimes added. Cracks at the corners and along the edges of brackets were usually replaced with no modification but in some cases, the thickness was increased by say 2mm. Special attention was also paid to the welding and particularly at the bracket corners. Typically a specification includes the new bracket to be welded on both sides and also around the tip which is often neglected but is very important to avoid crack initiation.

17 cracks were reported in pillars and struts (6c, i = 26). Most of these were at pillar connections with brackets at the ends of the pillars. This involved cracking of brackets rather than the pillars so the brackets were just replaced.

4.2.5.1.4 Design Conclusions

As can be observed in the previous sections, there is a particular trend in the way in which repairs and design changes are carried out depending on the origin of the crack. The general solutions adopted are summarised in Table 4.2-6.

It is common to simply replace a stress-cracked plate with one of increased thickness while not carrying out any further modification. This is for example typical on the deck at the corners of the accommodation or the hatch coamings.

If cracks are due to wear or corrosion, an insert is the correct and final method but in situations where this may not be possible, a temporary doubler is added.

GENERAL REPAIR SOLUTIONS	
CRACK TYPE	**SOLUTION**
STRESS	INCREASE PLATE THICKNESS
CORROSION AND WEAR	DOUBLER - TEMPORARY INSERT - PERMANENT
POOR DESIGN	MODIFY PART ACCORDINGLY
CYCLIC GLOBAL DEFLECTION	ADDITIONAL REINFORCEMENT OF STRUCTURE
VIBRATION (Usually in AP + ER)	DAMPING / SUPPORT WITH STIFFENER/BRACKET(S)
SMALL CRACKS (10-22mm)	GRIND & WELD

Table 4.2-6: General trend in repairs and modifications depending on crack origin

Design changes are also often required depending on the situation and there may be a range of possible solutions. A typical example includes tripping brackets which connect web frames to the longitudinals. The great majority of cracks were found to initiate at their corners due to the associated "hard spots" and propagation was through the face plate of the longitudinal towards the outer shell. Approximately 80% of the cracks were reported to initiate at the inner corner. The most immediate solution in this case was to increase the radius of curvature at this location where cracks tend to initiate. If this proved inadequate, or if cracks initiated at the outer corner (about 20% of cracks), the most common solution was to increase the face plate thickness. In cases where this did not eliminate cracks initiating at the outer corner (the toe), a common solution was to replace the bracket with a more curved one, which weakens the "hard spot" and provides a more even distribution of the stresses along it. Ultimately, if cracks anywhere on the bracket persisted, a secondary tripping bracket was provided on the other side of the web frame as shown in Fig. 4.2-31.

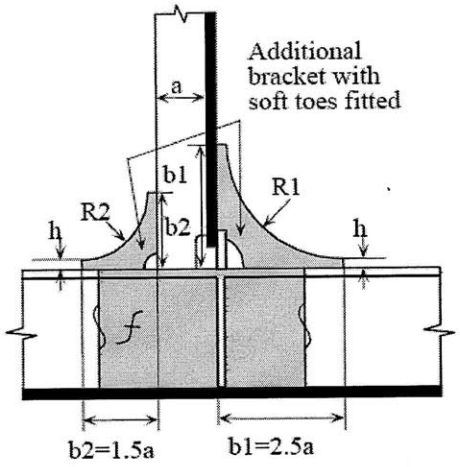


Fig. 4.2-31: Tripping bracket modifications along with the principal dimensions [IACS 2004]

If cracks develop due to large global deflections such as the whole double bottom, then reinforcement of the whole structure is required in addition to renewal and possible design changes of the fractured part. Fig. 4.2-32 shows frames without tripping brackets that have deformed under large global deflection and Fig. 4.2-33 shows tripping brackets between frames which counteract the problem.

Fig. 4.2-32: Deformation of Side Shell Frames Under Global Deflection [IACS 2004]

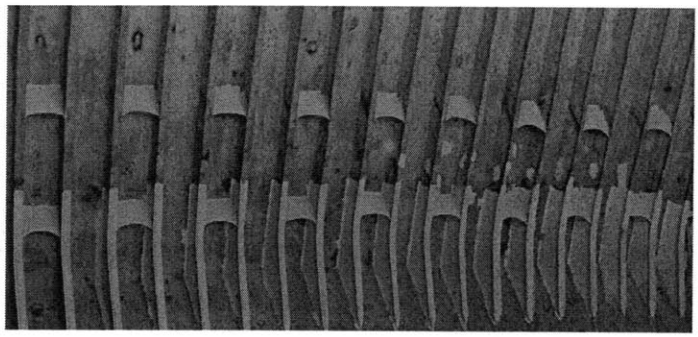


Fig. 4.2-33: Tripping brackets between side Shell frames [LR 2005a]

In some cases, cracks develop due to design flaws which are known already from the design stage. Construction costs, however, very often outweigh the benefits and a sacrifice is made. As a result, design changes have to be made once cracking appears in order to solve the problem permanently. One of the most typical examples is that of the scallops. These are there for no other reason other than the fact that they are needed for the assembly of the blocks in construction. The associated problems regarding cracking in scallops as shown in Fig. 4.2-34 and 4.2-35 are well understood.

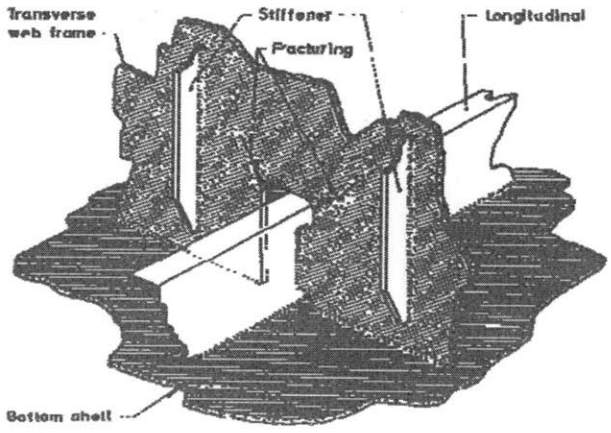


Fig. 4.2-34: Associated cracking problems with scallops [Pedersen et al 1996]

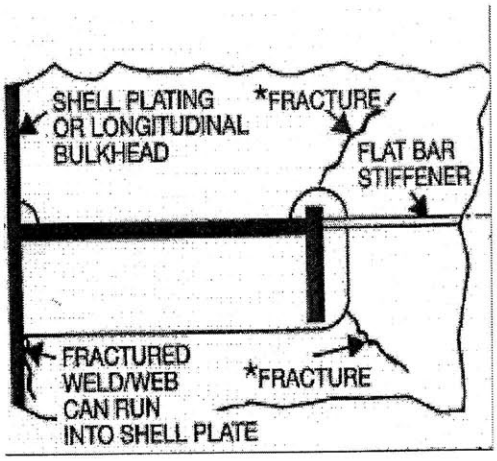


Fig. 4.2-35: Associated cracking problems with scallops

Scallops can be enhanced by a doubler or a collar plate which helps reduce cracking. Including this to all the scallops at the construction stage, however, is too expensive and thus they are designed knowing that the area will develop say 50 cracks over a course of 30 years. Consequently, these solutions serve as modifications after the problem starts off. Fig. 4.2-36 shows typical scallop modifications as proposed by IACS.

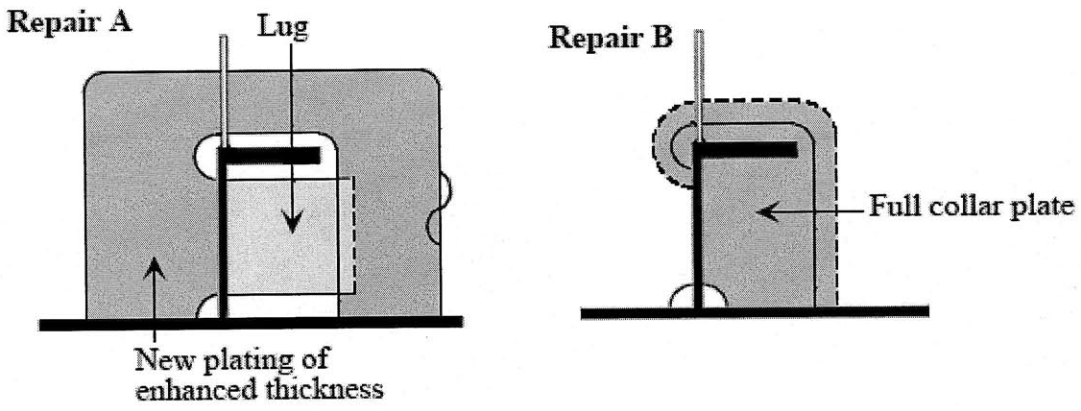


Fig. 4.2-36: Scallop Modifications [IACS 2004]

Design consequently plays a major role in the number and locations of cracks which appear throughout a ship's life. The effects of design are witnessed during the very early

stages where cracks due to design faults may appear but also during the later life as some designs age better than others.

During the survey, great similarities were witnessed between sister ships. Furthermore, ships from particular building shipyards or countries also often share the same problems and weaknesses. For example, 5 Taiwanese sister ships in the database showed almost consistently the same distribution of cracks. Romanian ships on average showed a much higher number of cracks which shows partly why they are viewed as inferior and are valued significantly lower in the market. Japanese ships are considered to be of the highest quality and are generally the most expensive. These develop many cracks, however, which are associated with the extensive use of high tensile steel particularly as ships age. There is a great number of Korean ships and these are generally of good quality but they are being overtaken in number as shipbuilding capacity in China is increasing radically. The quality of Chinese ships seems to vary significantly between the numerous shipyards and there is great development going on.

4.2.5.1.5 Comparisons with Previous Research

A similar analysis has been carried out by GL in their 2005 damage survey on Bulk Carriers [GL 2005b Private Correspondence]. This included 145 ships, out of which 72 were classed by GL. The 783 damages were found to be distributed as shown in Fig. 4.2-37.

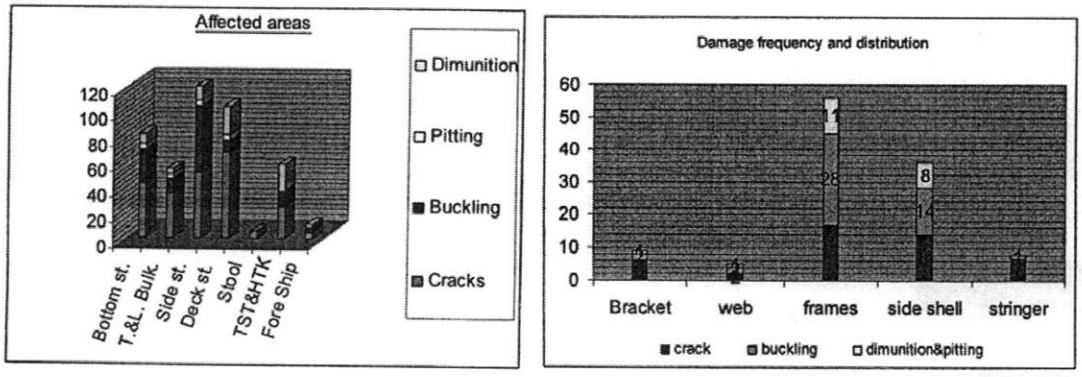


Fig. 4.2-37: GL Bulk Carrier Damage Survey Results [GL 2005b Private Correspondence]

Cracks were mostly reported at the connections of bulk heads to other members such as wing tanks or at the connections between shelf plates and shedder plates with the stool. They were mainly focused in the lower region of the bulk heads. Many cracks were also found at side frames and in the upper regions mainly at stays, face plates and hatch side coamings. Cracked girders were also common and this was believed to be the result of bad workmanship and overstressing loading to high local or global stresses.

Though cracks were found to develop in similar regions to our survey, the distribution of these is significantly different. Surprisingly, only a few similarities such as the relatively low number of cracks at the fore ship (fore peak) can be observed in the distribution of cracks as shown in Fig. 4.2-37 compared to Fig 4.2-6.

Slightly more similar results were obtained in the distribution of cracks when focusing in the bottom and upper ship areas. The crack distribution by the GL bulk carrier damage survey at these locations is given by Fig. 4.2-38.

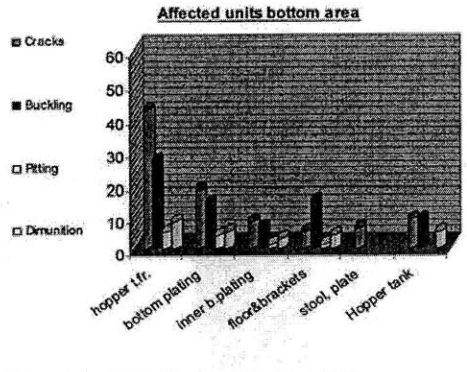


Fig. 4.2-38: GL Bulk Carrier Damage Survey Results in Bottom Area [GL 2005b Private Correspondence]

As in the current survey, many cracks have been reported in the hopper transverse frames (web frames) which corresponds to location i = 10 (3a). The second most popular region is the bottom plating corresponding to location i = 16 (4c) which in the current project has relatively few cracks. It should be noted, however, that the bilge plate may also be

included here since it is not quoted elsewhere. This corresponds to location i = 11 (3b) where more cracks than any other region have been reported (3,785).

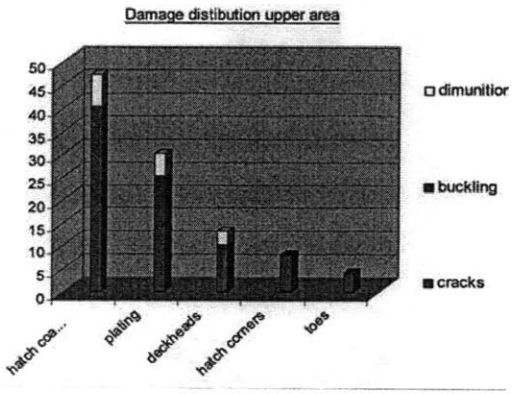


Fig. 4.2-39: GL Bulk Carrier Damage Survey Results in Upper Area [GL 2005b Private Correspondence]

As can be seen, most cracks in the upper area have been reported in the hatch coamings and also in the deck plating. These correspond to locations i = 5 and 6 (1e and 1f) respectively, but it should be noted that our location 1 also includes the upper wing tank which has a high density of cracks. This explains why our locations i = 5 and 6 (1e and 1f) account for a smaller fraction of the total number of cracks.

A similar damage survey by GL was also carried out on 193 tankers where a total of 1,201 damages were reported. The main results regarding cracking are shown in Fig. 4.2-40.

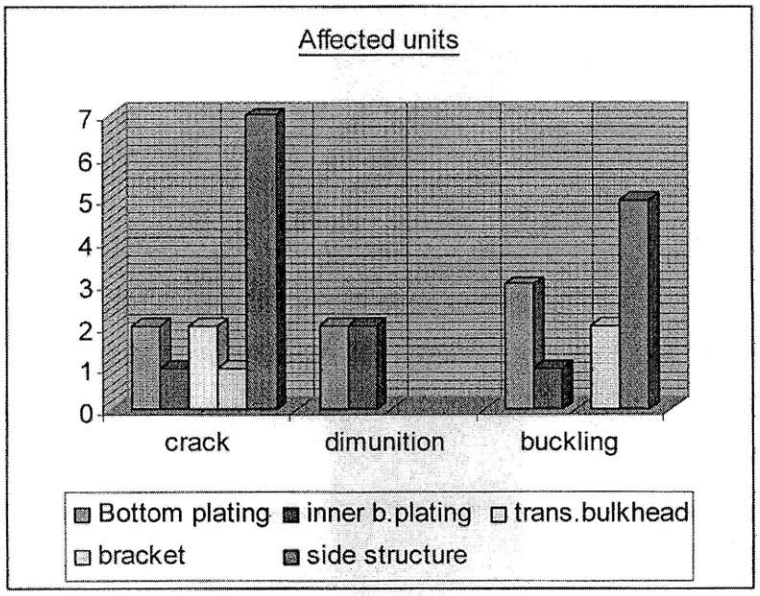


Fig. 4.2-40: GL Bulk Carrier Damage Survey Results [GL 2005b Private Correspondence]

A similarity with these results was that many side frames were found cracked, particularly at connections with lower brackets. As can be seen by comparing to Fig. 4.2-10 however, there are significant differences in the crack distribution. The major example is the inner bottom plating which appears to be the most critical area while hardly any cracks were reported at that location in the current survey.

A damage survey was carried out in by DNV in 2002 and the results regarding the distribution of damages in capes are illustrated in Fig. 4.2-41. These include 221 cracks out of 304 damages.

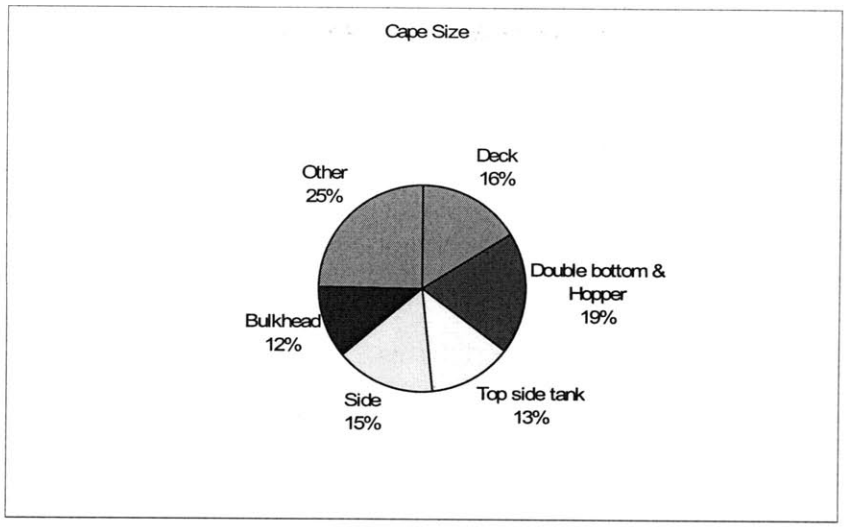


Fig. 4.2-41: Damage Distribution in Capes where 221 out of the 304 Damages are Cracks from the DNV Database [DNV 2002 Private Correspondence]

Even though many damages other than cracking are included, these results seem somewhat more similar to those of the present survey. Table 4.2-7 summarizes the results of various surveys compared to those of the current project.

LOCATION	CODES	CURRENT (Capes - %Cracks)	DNV (Capes - %Damages)	LR (Bulkers %Damages)	ABS (Bulkers - %Damages)
DECK	1(e-f)	7	16	21	36.5
D.BOTTOM & HOPPER	3(a-d) & 4(a-d)	40	19	16	33.7
TOP SIDE TANK	1(a-d)	23	13	36	-
SIDE	2(a-c)	21	15	27	29.8
BULKHEAD	5(a-f)	7	12	-	-
OTHER	6(a-c)	2	25	-	-

Table 4.2-7: Crack distribution in current survey compared to damage defect distribution from the DNV, LR and ABS surveys [DNV 2002 Private Correspondence, LR 1999 Private Correspondence, ABS 1976]

As shown in the Table 4.2-7, cracks have a significantly different distribution compared to other types of damages and also the ship type plays a major role. This emphasizes the importance of projects which are specific on a certain type of damage and vessel. It is also important to keep in mind the way each location is defined when comparing results across different surveys. [Schulte-Stratause 1991], for example, reports 42% of all fatigue cracks on the side shell and its longitudinals. This percentage exceeds the corresponding value in all the other databases considered. His definition of side shell, however, may also include areas which are classified under the double bottom or topside tanks in other surveys.

4.2.5.2 Crack Sizes

Starting with the 3-D matrix $\tilde{C}$, we sum across "i" and "j" and reduce it to a 1-D matrix which gives us the number of cracks under each size (50 to 8000mm in increments of 50mm) irrespective of their location on the ship. By dividing each element in the matrix by the total number of cracks in the database, the Probability Density Function (PDF) of crack size was constructed and is presented in Fig. 4.2-42. This shows the probability of a crack lying within every given size range irrespective of its location.

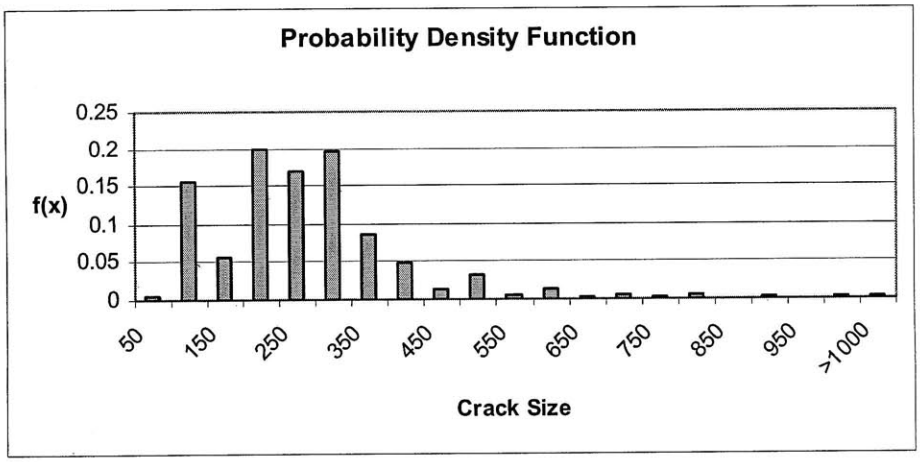


Fig. 4.2-42: Probability Density Function of Crack Size

From this, the Cumulative Distribution Function (CDF) of crack size was plotted which shows the probability of a crack being up to a given size (Fig. 4.2-43).

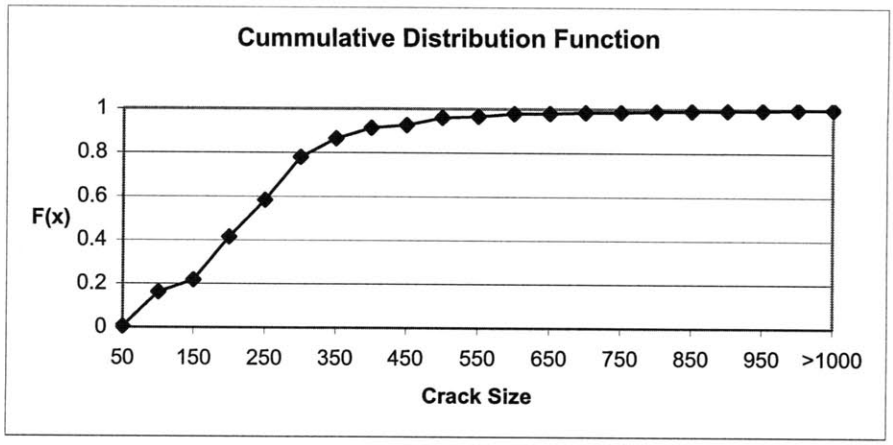


Fig. 4.2-43: Cumulative Probability Function of Crack Size

While the crack size range is very wide, the inter-quartile range of the cumulative distribution function shows that 50% of all cracks observed were between 158mm and 292mm long (using linear interpolation). The c.d.f. at a crack length of 1m is equal to 99.8% so larger cracks are very rare (51 in our database). Occasionally cracks of over 2 meters were recorded. Examples of these include vertical cracks on the side shell in way of the cargo bulk head between cargo holds 1 and 2 (j = 10). The shape of the graph in Fig. 4.2-42 seems to be somewhat irregular showing a significantly higher number of cracks at sizes which are multiples of 100 compared to intermediate values. This is because surveyors often have a tendency to record crack sizes in round numbers. Very similar graphs were produced by [Antoniou, 1977] based on his survey of cracks in oil tankers under repairs. These are shown in Fig. 4.2-44.

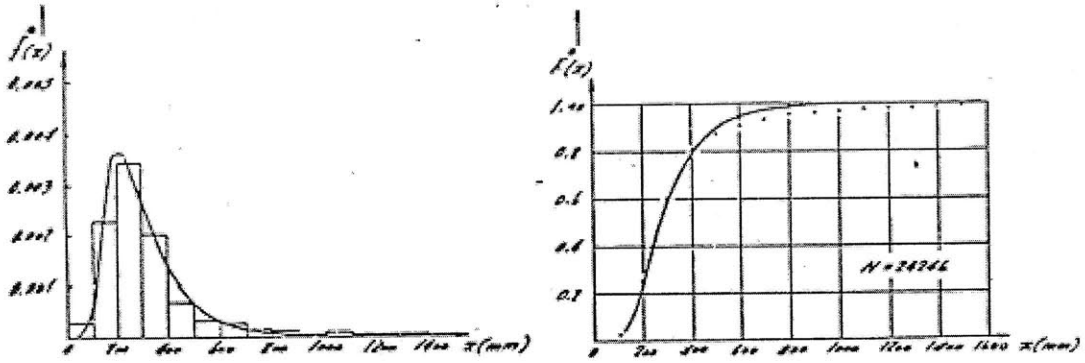


Fig. 4.2-44: Marginal Distribution Density and Marginal Distribution of Crack Size Irrespective of Age [Antoniou, 1977]

Evidently as [Antoniou, 1977] also predicted, the majority of cracks (approximately 60%) are up to 300mm which appears to be the size limit considered important to be reported by classification society surveyors. In our database, c.d.f. at 300mm is approximately 78% (as opposed to 60%) and c.d.f. is equal to 60% for approximately 254mm cracks (using linear interpolation). This suggests that surveyors are on average reporting a slightly larger fraction of smaller cracks today in capesize bulk carriers compared to what was reported in tankers in the 1970s.

4.2.5.3 The Effect of Age

The average number of cracks per ship from the current survey was found to be 123. This may sound shocking for people outside the marine community but it proves the fact that ships can travel perfectly safe with a large number of cracks. Similar Japanese investigations in 1973 have suggested an average of about 200 cut out damages per vessel [ISSC 1973] while the findings of the latter survey carried out by the Ship Structural Committee suggests a rate well in excess of 100 failures per vessel [SSC 1980]. The findings of Exxon Corporation from the surveys carried in tankers of its fleet in the early 1980s also suggest the number of fractures being of the order of hundreds in a typical vessel [Exxon 1983 - Private Correspondence]. The survey carried out by Prof. Antoniou in 1977 showed an average of

110 cracks per tanker [Antoniou 1977]. This proves the earlier point made that only a small percentage of cracks are reported by surveyors if they are considered dangerous and warrant further investigation. It is also evident from the frequency and size of cracks in similar surveys carried out by classification societies, that only large damages and cracks were considered.

The variation of the number of cracks per ship with ship age and its cumulative total have been computed and are presented in Fig. 4.2-45 and 4.2-46. The first graph is created by compressing the 29 2-D $\tilde{N}_A$ matrices into one number (each) by summing across the "i" and "j" components, and then plotting the resulting numbers against "A". The second graph is just the cumulative of the first.

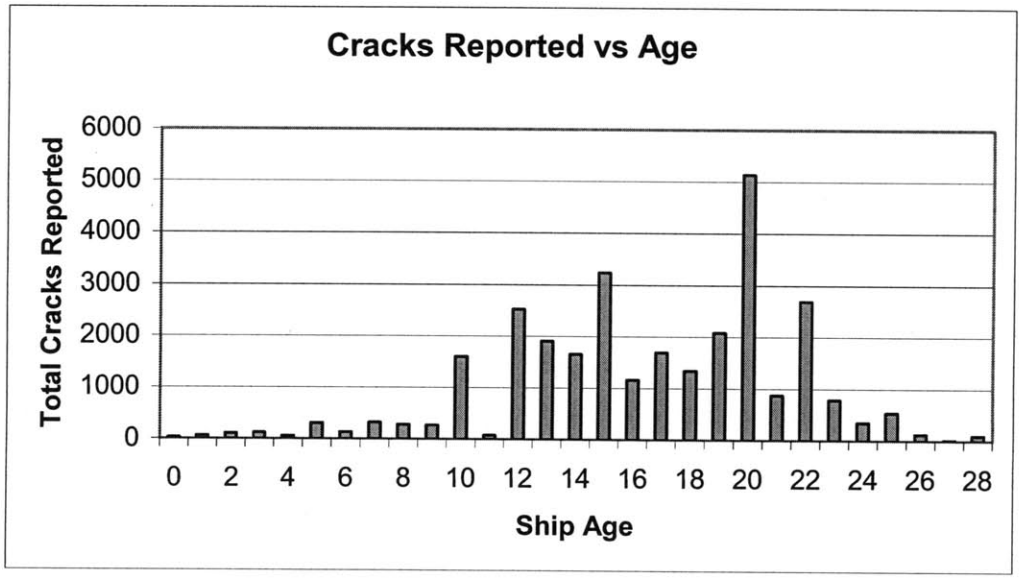


Fig. 4.2-45: Average Number of Cracks per Ship with respect to Age

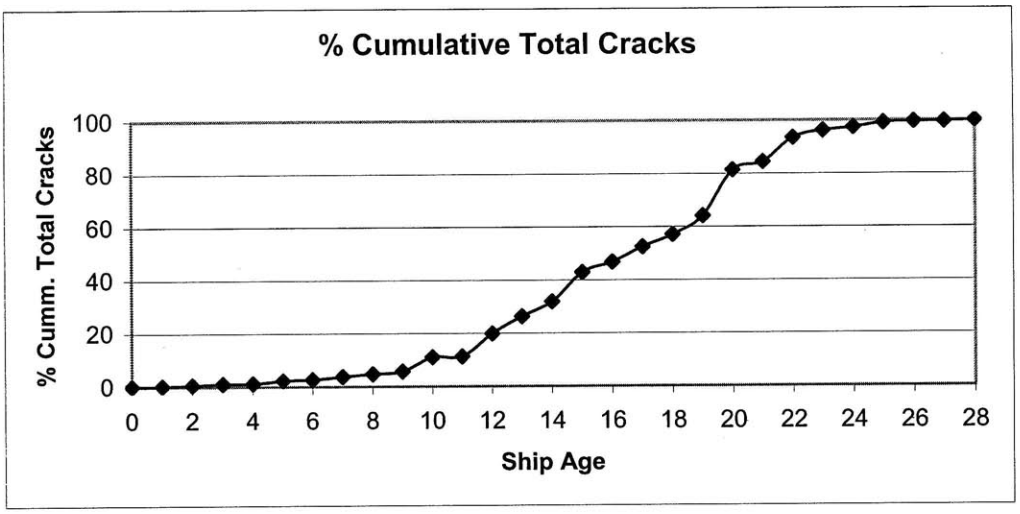


Fig. 4.2-46: Cumulative Average Number of Cracks per Ship with Age

By considering the inter-quartile range in Fig. 4.2-46, it can be seen that 50% of all the cracks that develop throughout the ship's life, occur between the age of approximately 12.8 and 19.6 years old (using linear interpolation).

An interesting pattern is observed in the number of cracks per ship as a function of ship age. It can be seen that the average number of cracks generally increases until the age of about 20 years after which they start declining again. Periodic cycles can also be observed in relation to this trend. The number of cracks show high peaks at the ages of 10, 15 and 20 which are the years when special surveys are normally passed. Additional peaks are observed at the ages of 12, 13, 17 and 22 which are common years for passing intermediate surveys. During the subsequent years following major surveys such as year 11, the number of cracks reported is significantly reduced since it takes a while again for the ship condition to deteriorate. A similar analysis was also performed by [Yamaguchi, I. 1968] on NKK ships in 1968. Fig. 4.2-47 shows the crack frequency with respect to age for 97 NK class built vessels between 1950 and 1962.

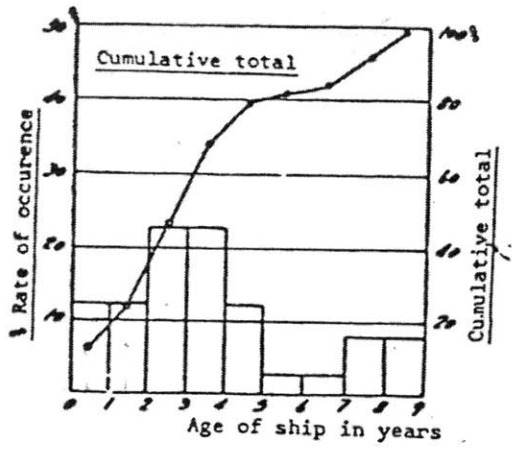


Fig. 4.2-47: Rate of Crack Occurrence with respect to Ship Age
[Yamaguchi, I. 1968]

This graph shows that damages peak at the age of about 2 to 4 years old. It only covers, however, a very small fraction of the ships' service life. [LR, ABS and DNV 2006] provide some results on defects found in 224 double hull bulk carriers, that can be analyzed to produce similar results. They provide the results shown in Table 4.2-8. Using their total number of defects (1,323) and total number of ships (224), the results shown in Table 4.2-9 can be inferred.

Age	Cracks	Defects (Including Cracks)	Ships
<5	18.98%	23.60%	51%
5 to 9	29.04%	36.84%	29%
10 to 14	11.39%	21.65%	13%
15 to 19	3.23%	11.75%	4%
20 to 24	0.41%	0.41%	1%
25+	4.82%	5.75%	2%
Total (%)	67.88%	100.00%	100%

Table 4.2-8 Results of [LR, ABS and DNV 2006]

Defects	Cracks	Ships	Cracks/Ship
460	370	114	3.245614
718	566	65	8.707692
422	222	29	7.655172
229	63	9	7
8	8	2	4
112	94	5	18.8
1949	1323	**224**	

Table 4.2-9 Inferred Results of [LR, ABS and DNV 2006]

Fig. 4.1-48 shows a plot of Cracks per ship against age group, using the results of Table 4.2-9 and Fig. 4.2-49 shows the same chart using the results of the current database.

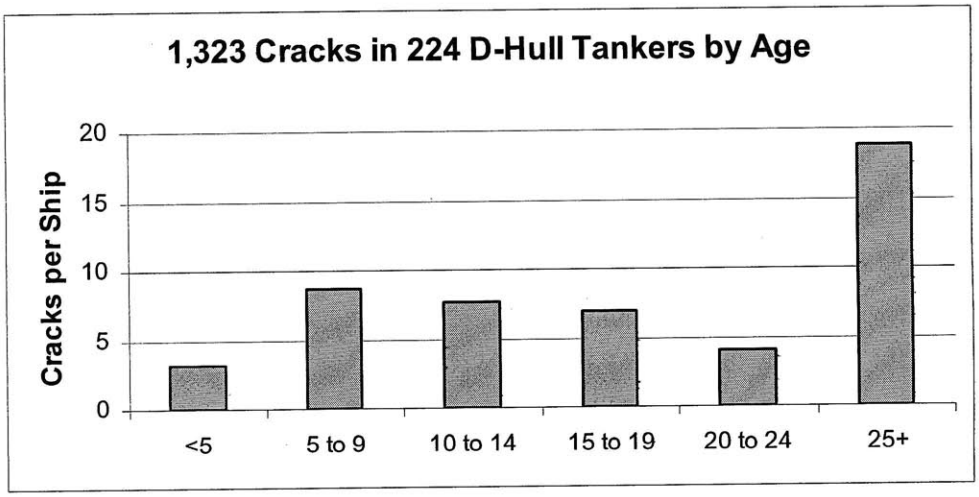


Fig. 4.2-48 Inferred Results of [LR, ABS and DNV 2006]

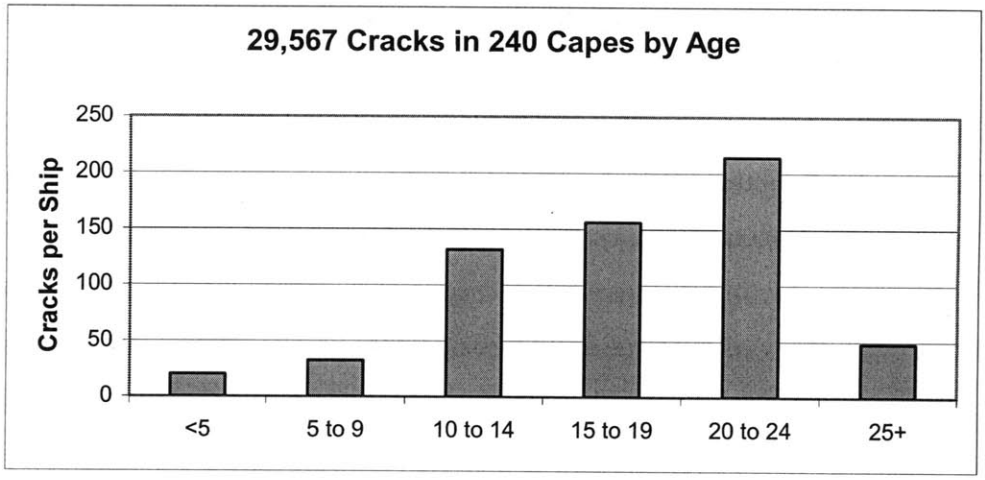


Fig. 4.2-49: Average Number of Cracks per Ship with respect to Age

There is a clear difference between the trend of our results and that of [LR, ABS and DNV 2006]. However, the most striking part is the scale on the ordinate axis. The average number of cracks is 123.2 in our database and only 5.9 in [LR, ABS and DNV 2006]. This indicates that there is a clear difference in scope between the two surveys besides the difference in ship type and size.

It is interesting to note that Prof Antoniou concludes from his data on tankers that with an average of 110 cracks per ship (compared to 123 in the current survey) "the average number of probable cracks during a ship's life time of say 22 years is about 2000". An estimated cost of repairing these cracks with today's prices would be around \$1m. It should be noted, however, that this is a very vague estimate as a crack may only cost about \$50 to repair in a shipyard in China during repairs whereas it may cost hundreds of thousands if for example it requires dry docking or delays a ship.

The final result is the relation of crack size with ship age. We compress the 2-D matrices $\tilde{L}_A$ and $\tilde{N}_A$ into one number by summing across their "i" and "j" components. For each ship age "A", this gives us the total crack length and total number of cracks respectively. Dividing to total crack length by the total number of cracks gives us the mean crack size for each ship age.

The computation of the median is significantly more complex. Starting with the 3-D matrices $\tilde{C}_A$, we compress it into a 1-D matrix by summing over the "i" and "j" components. The result is 29 (1x16) matrices (one for each age) which gives the total number of cracks for

each size. By plotting the c.d.f. and determining the crack size for which c.d.f. = 50%, we determine the median crack size for that respective ship age.

The mean and median crack sizes have been computed for each age and are presented in Fig. 4.2-48. The Weibull distribution is often used to describe phenomena which result from two independent mechanisms, typically one short term and one long term cause as is the case with wear or fatigue in bearings. In this case, early design problems result in short term high crack growth rates while fatigue and corrosion is the cause of long term cracks of lower growth rates and consequently smaller crack sizes by the time of the inspection. It is reasonable, therefore, to assume that both the mean and median crack size may be characterized by a Weibull distribution.

The PDF f(t), and the CDF F(t) of the two parameter Weibull distribution are given by:

$$f(T) = \frac{\beta}{\eta}\left(\frac{T}{\eta}\right)^{\beta-1} e^{-\left(\frac{T}{\eta}\right)^{\beta}} \tag{4.2-7}$$

$$F(T) = 1 - e^{-\left(\frac{T}{\eta}\right)^{\beta}} \tag{4.2-8}$$

The c.d.f. was linearized by taking natural logarithms (twice):

$$\begin{aligned} e^{-\left(\frac{T}{\eta}\right)^{\beta}} &= 1 - F(T) \\ \left(\frac{T}{\eta}\right)^{\beta} &= -\ln\left[1 - F(T)\right] \\ \beta \ln\left[\left(\frac{T}{\eta}\right)\right] &= \ln\left[-\ln\left[1 - F(T)\right]\right] \end{aligned} \tag{4.2-9}$$

Then, the least squares method was used to evaluate the distribution parameters β and η. This can be done by setting the derivative of the sum of the errors with respect to β and η

simultaneously to zero and then examining the second derivatives to verify that it is a minimum. The Weibull distribution parameters are shown in Table 4.2-10 and the two Weibull functions, (one through the mean values and one through the median values), are shown along with the data points in Fig. 4.2-50.

WEIBULL DIDTRIBUTION PARAMETERS		
	MEAN CRACK SIZE	MEDIAN CRACK SIZE
B	1.41	1.40
H	15.8	14.6

Table 4.2-10: Weibull Distribution Parameters

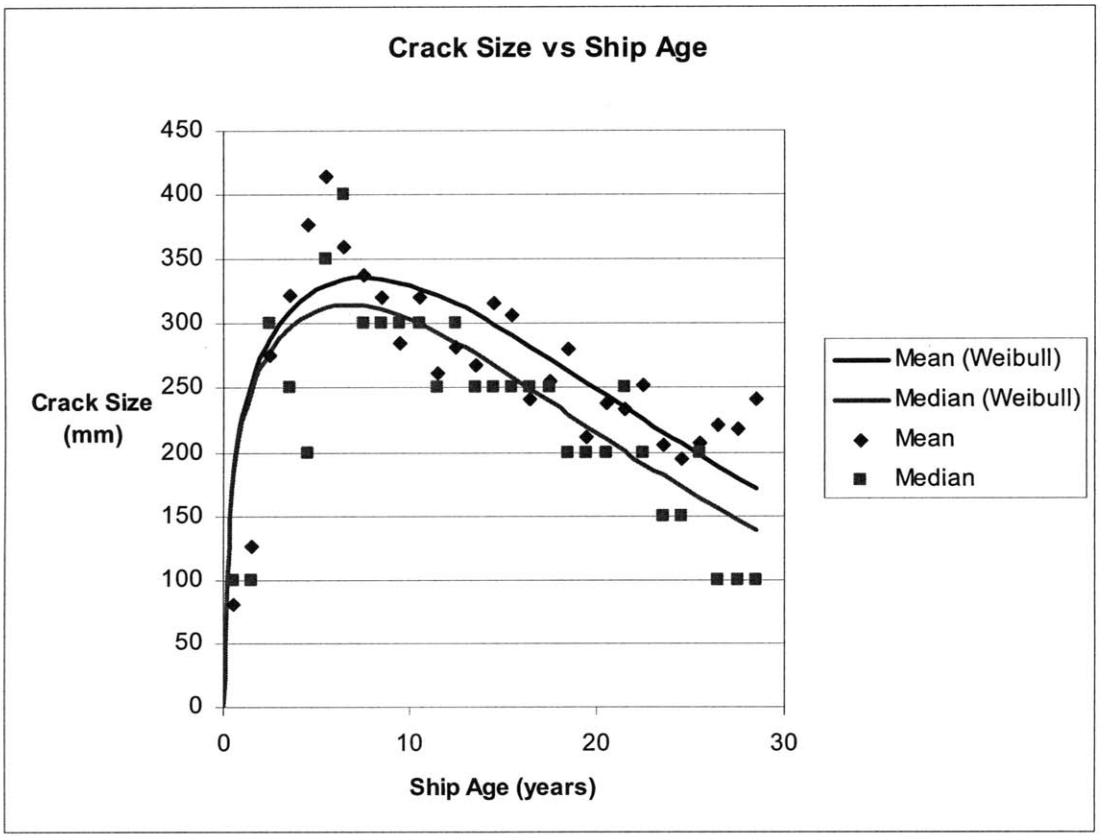


Fig. 4.2-50: Mean and Median Crack Size with respect to Ship Age

Both the mean and median crack size increase during the early life and peak at the age of about 5 years which is when the first special survey is passed. They then continuously

decrease with age. Similar Japanese investigations in 1973 have also suggested that the occurrence of cracking peaks at about 3 to 4 years [ISSC 1973].

It is also interesting to note that the mean is above the median throughout the ship's lifetime. This implies a negative skew of the data (in a plot of crack frequency against size) which is also evident in Fig. 4.2-42. The Weibull parameterization function seems to be a fairly accurate representation of the data for both the mean and median, but it predicts a slightly high value for the age at which the mean crack size peaks.

The same analysis was carried out by [Antoniou, 1977] where a similar trend has been obtained excluding the initial increase during the early years. The graph is presented in Fig. 4.2-51.

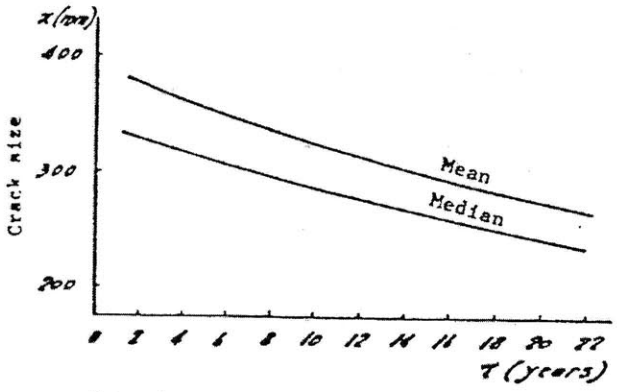


Fig. 4.2-51: Mean and Median of Crack Size versus Age of Ship [Antoniou, 1977]

The first year of a ship's life is not predictable in terms of cracking and it is covered by the shipyard's guarantee. There are consequently frequent inspections by the owners who make an effort to discover any problems for the shipyard to fix without charge. After the end of the guarantee period when the ship is one year old and up until the age of about five, there are no major repairs and the surveys are generally less stringent. This allows cracks to grow to a large size before they are discovered.

The early years of a ship's life are characterized by design related cracks. Any defects or faults from design which result in high stress concentrations or overstressed areas, lead to the initiation of cracks which propagate at a relatively high rate. This, combined with the less frequent and stringent inspections, leads to the mean and median crack size being relatively

large when cracks are recorded. Typical cracks during the early life include the classic cracks at hatch corners.

[Barltrop et al. 1992] show the predicted distribution of crack sizes with time during the first few years in Fig. 4.2-52 based on fracture mechanics. These are approximately an order of magnitude below our results, presumably because real world effects such as unexpected impacts and bending moments or stress concentrations due to design and manufacturing imperfections have not been considered in the theoretical predictions. Nevertheless, it clearly illustrates how the distribution of crack sizes may evolve over time.

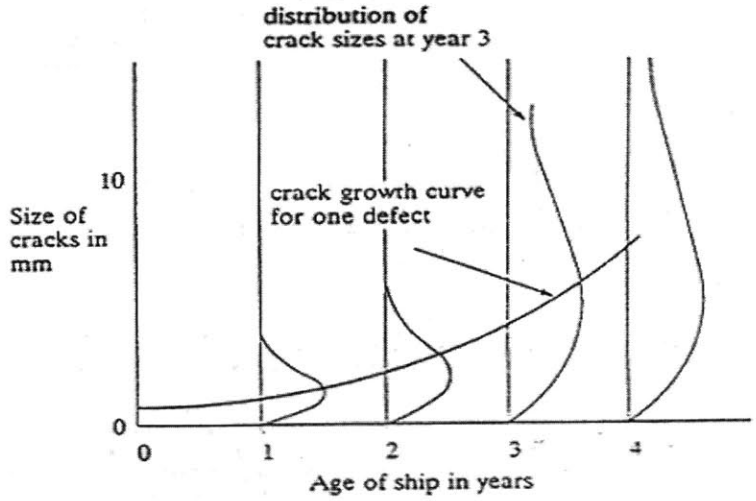


Fig. 4.2-52: Changes in Distribution of Crack Sizes with Time

Following the first special survey at the age of about 5 years, most design problems are corrected as cracks emerge and the design continuously improves during the subsequent repairs throughout the ship's life. As a consequence, more and more of the cracks appearing as the ship ages are due to fatigue which are generally much smaller when reported as they propagate at a much lower rate. Along with the design improvements, surveys become more regular and extensive as ships age and consequently there is a greater chance of detecting cracks. This explains the decrease in the mean and median crack size with age after the peak at about 5 years old.

The survey carried out by NK in 1976 showed that cracks due to structural discontinuities were relatively small (nearly half were less than 100mm) whereas cracks due to faults in fabrication and/or material were much larger (some greater than 500mm).

Furthermore, almost all such cracks which were greater than 500mm initiated within the first 8 years of operation [NK 1976].

It should be noted that the ship condition, and consequently the frequency and size of cracks at any given age, is highly dependent on the design and ship builders, but also on the owners. For example, some owners (typically Japanese and Norwegians until a few years ago), operate ships until the age of about 10 years and then plan on selling them. These ships are not only built accordingly, with a higher percentage of high tensile steel, but they are also repaired less extensively as they approach the age of 10 years. Both these parameters play a great role in the future cracking behavior of the ship.

4.2.5.4 Database Validation and Revision

The analysis that will follow in the next chapters requires significantly more detailed data in terms of the exactness of crack locations and individual sizes for all cracks. Though this has not been an impediment so far, a significant amount of the data, particularly that which was not verified with data from owners, will have to be discarded for the remaining analysis. The analysis so far was repeated for the revised database in order to check the consistency between the data. The results are summarized in Fig. 4.2-53 to 4.1-72.

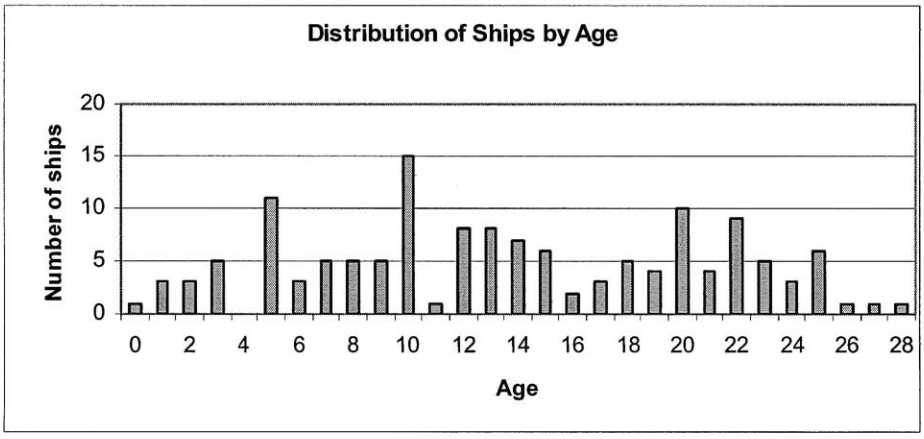


Fig. 4.2-53: Distribution Crack-Database Ships by Age

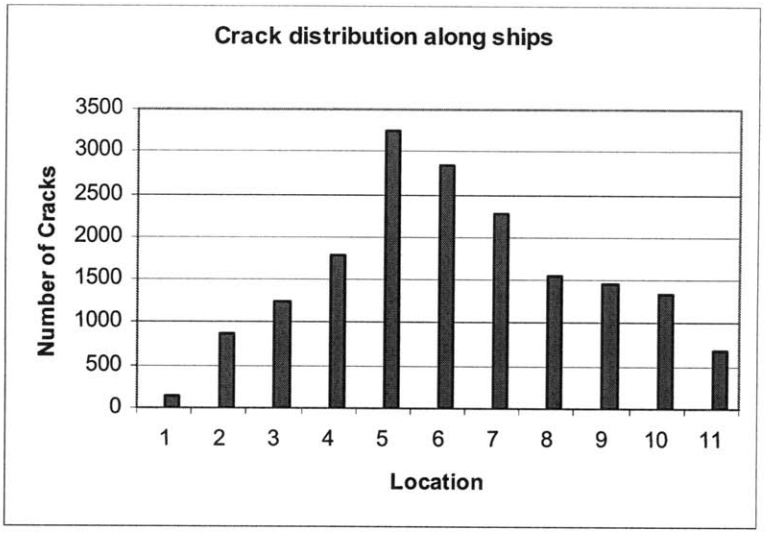


Fig. 4.2-54: Crack Distribution along Ship Length

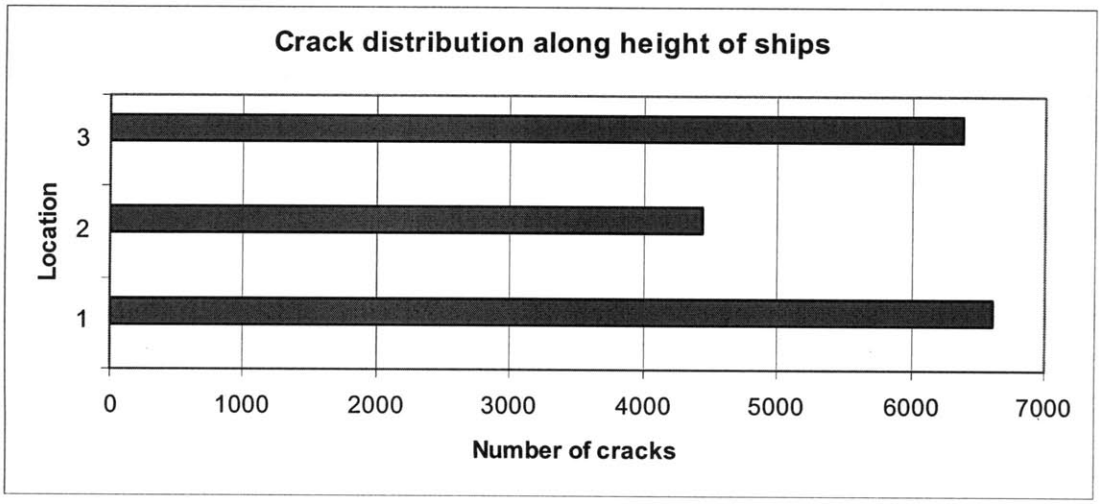


Fig. 4.2-55: Number of Cracks along Ship Height

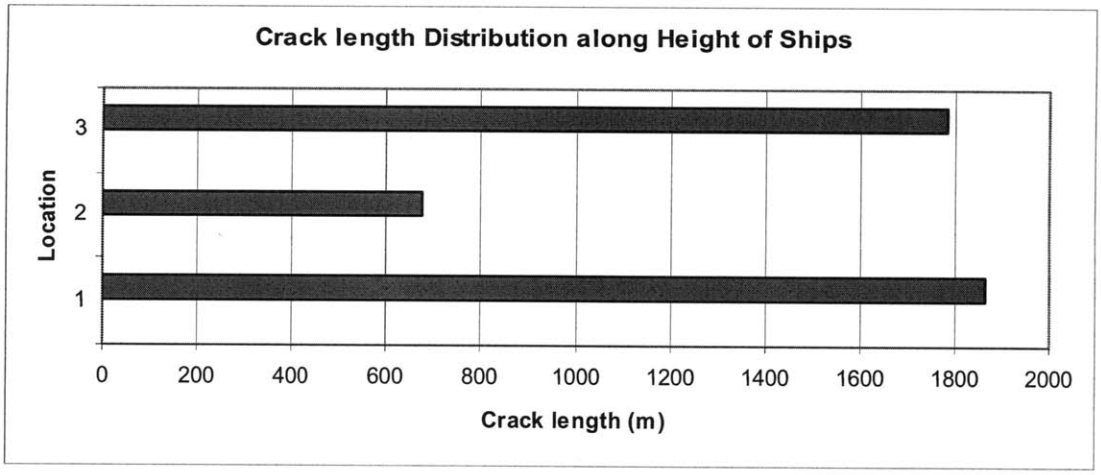


Fig. 4.2-56: Total Crack Length distribution along ship Height

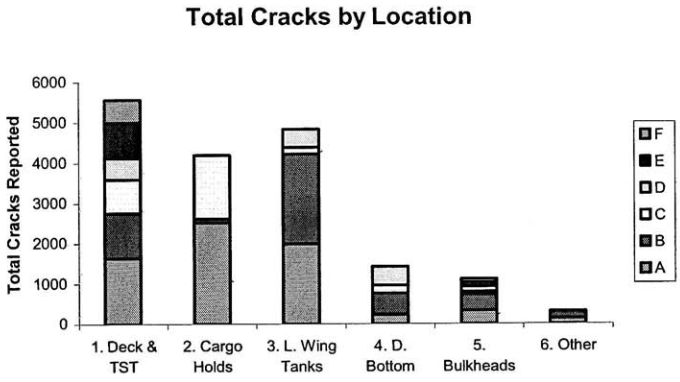


Fig. 4.2-57: Total Crack Distribution in the various Locations

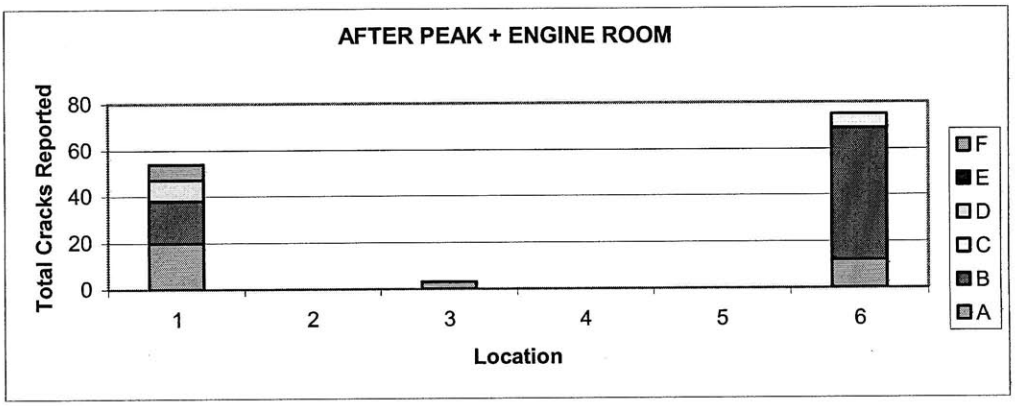


Fig. 4.2-58: Crack Distribution in Compartment 1

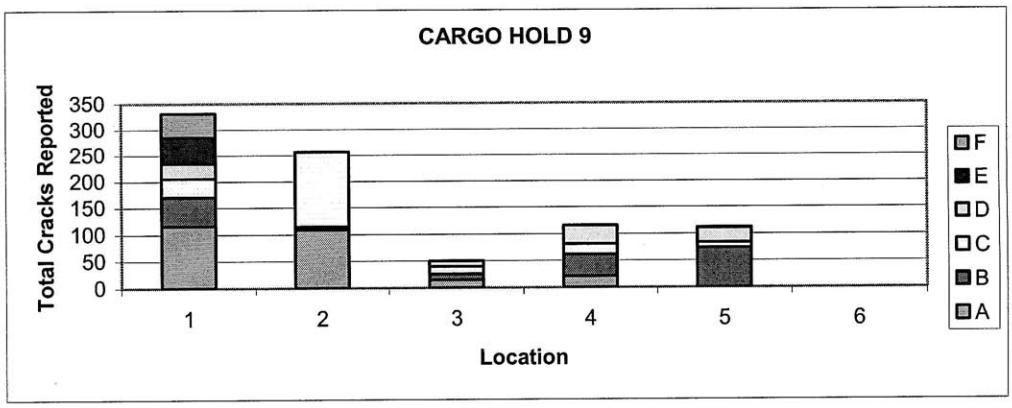


Fig. 4.2-59: Crack Distribution in Compartment 2

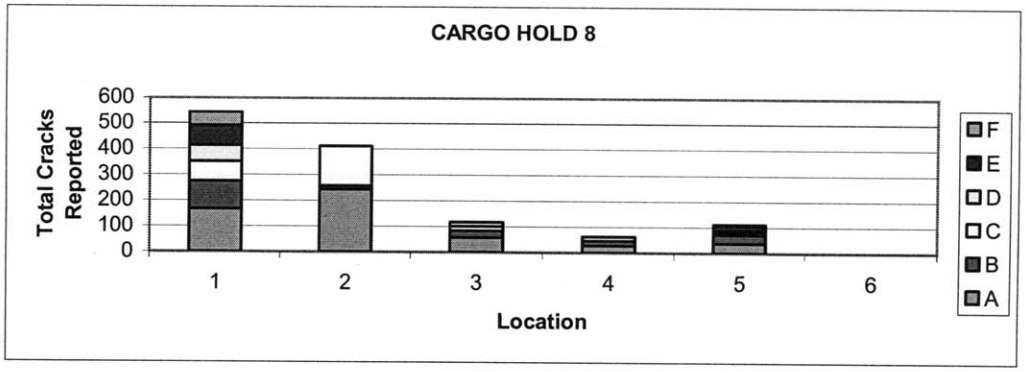


Fig. 4.2-60: Crack Distribution in Compartment 3

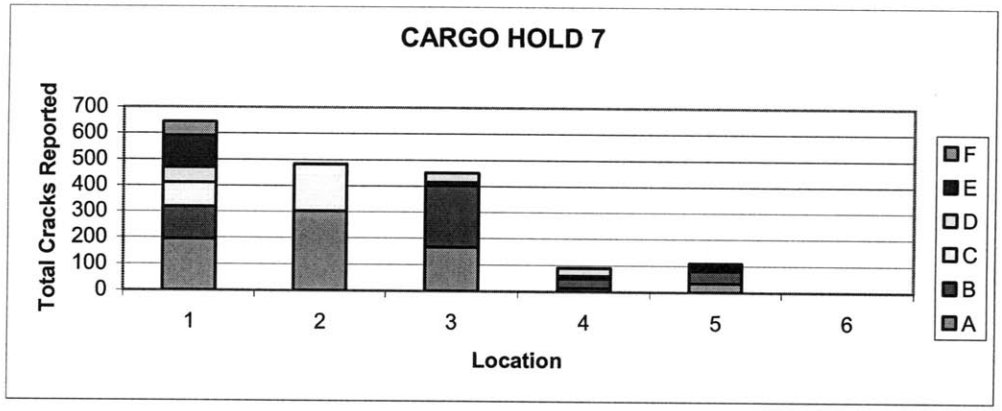


Fig. 4.2-61: Crack Distribution in Compartment 4

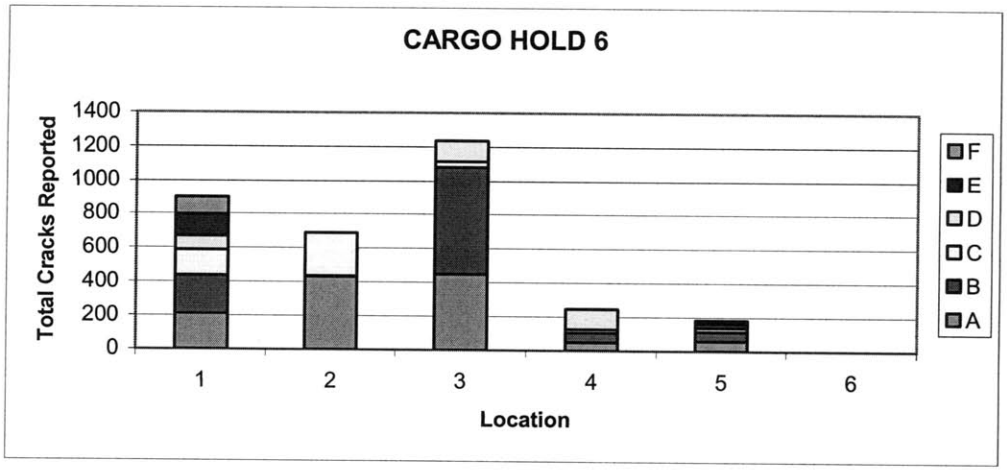


Fig. 4.2-62: Crack Distribution in Compartment 5

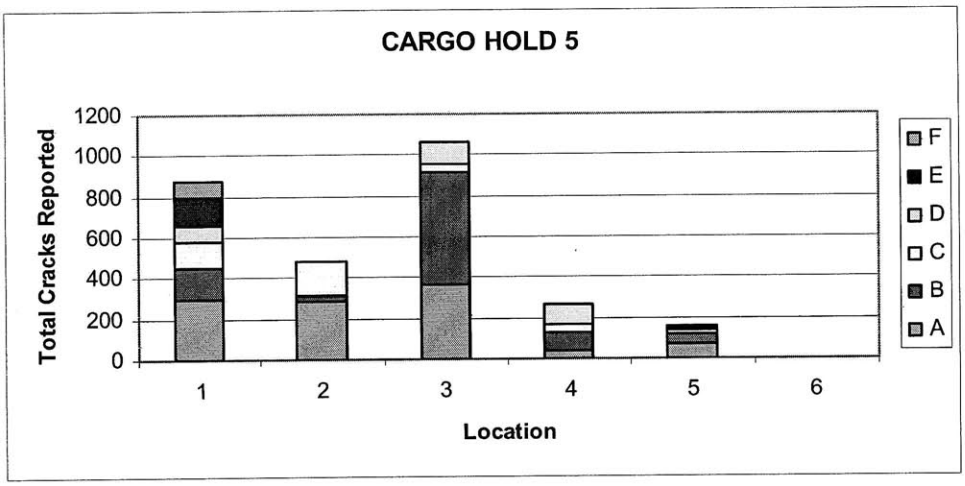


Fig. 4.2-63: Crack Distribution in Compartment 6

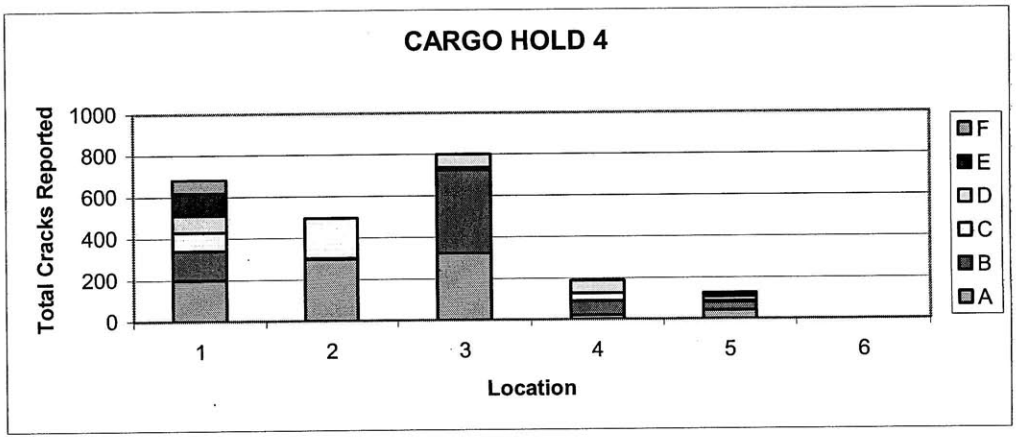


Fig. 4.2-64: Crack Distribution in Compartment 7

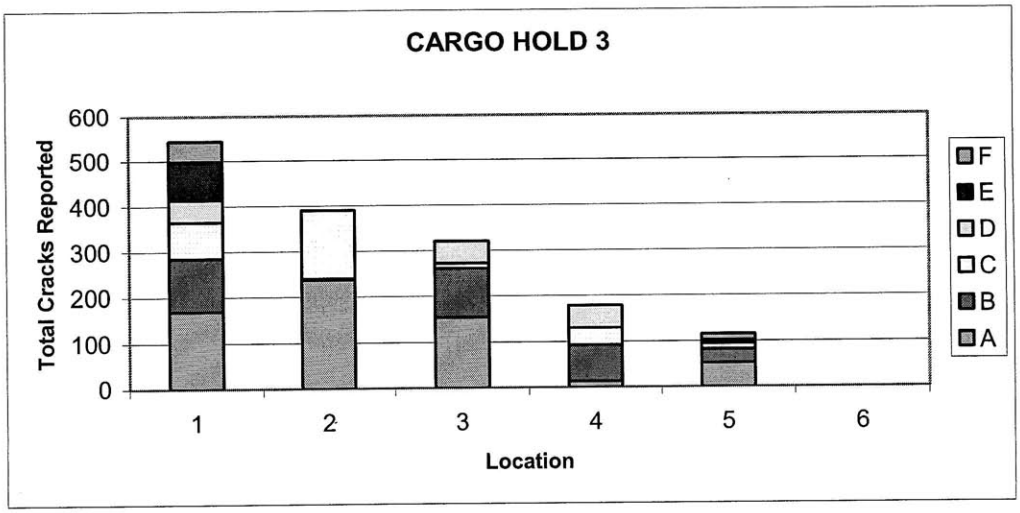


Fig. 4.2-65: Crack Distribution in Compartment 8

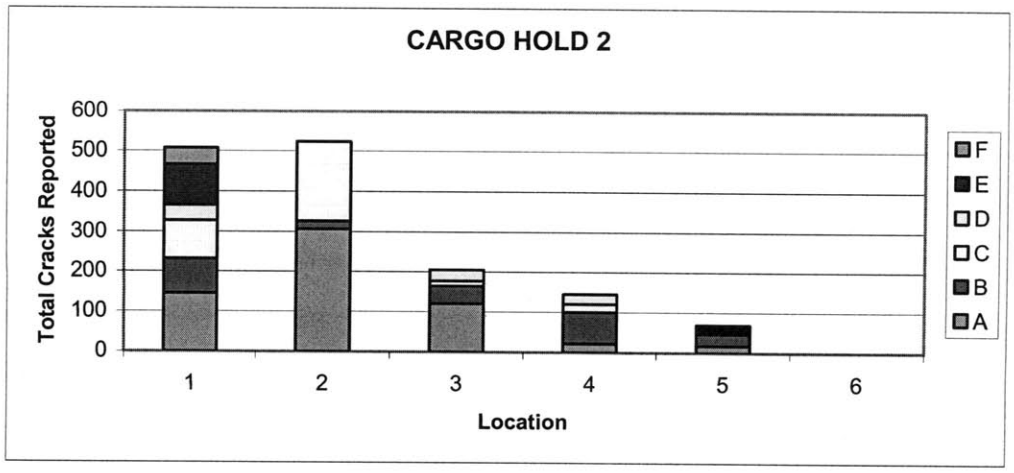


Fig. 4.2-66: Crack Distribution in Compartment 9

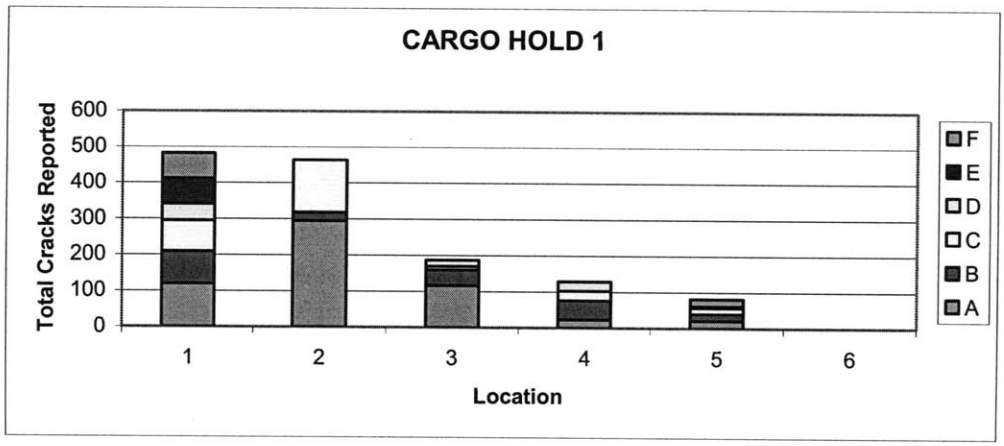


Fig. 4.2-67: Crack Distribution in Compartment 10

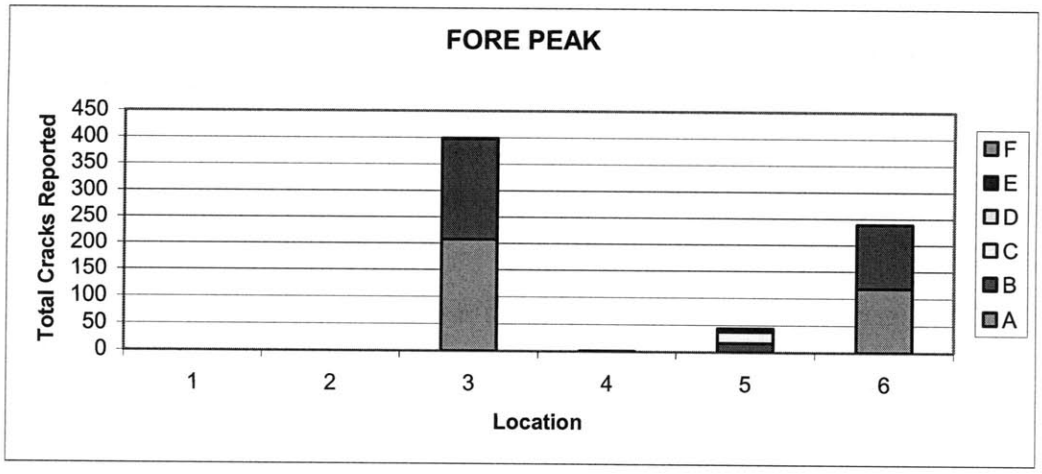


Fig. 4.2-68: Crack Distribution in Compartment 11

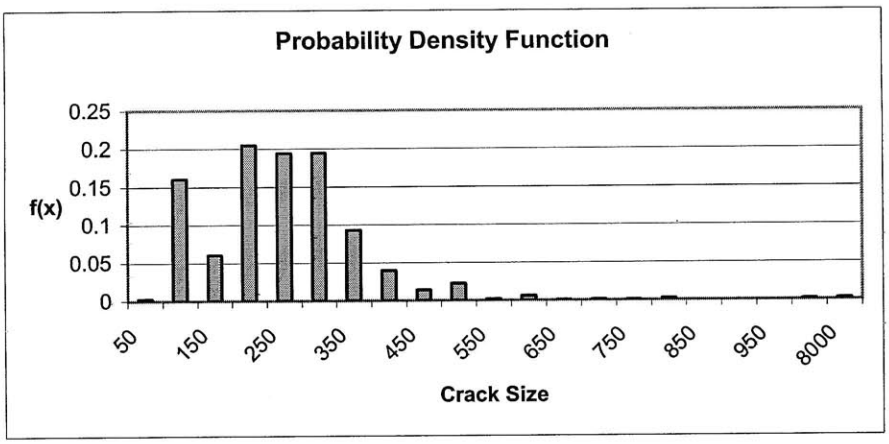


Fig. 4.2-69: Probability Density Function of Crack Size

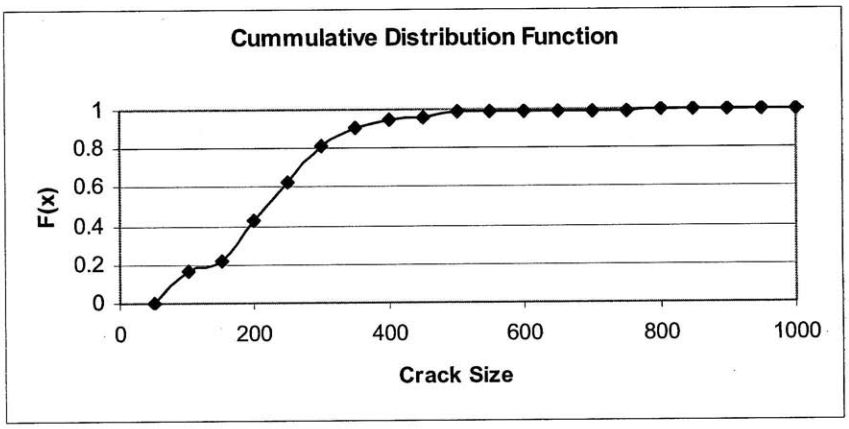


Fig. 4.2-70: Cumulative Probability Function of Crack Size

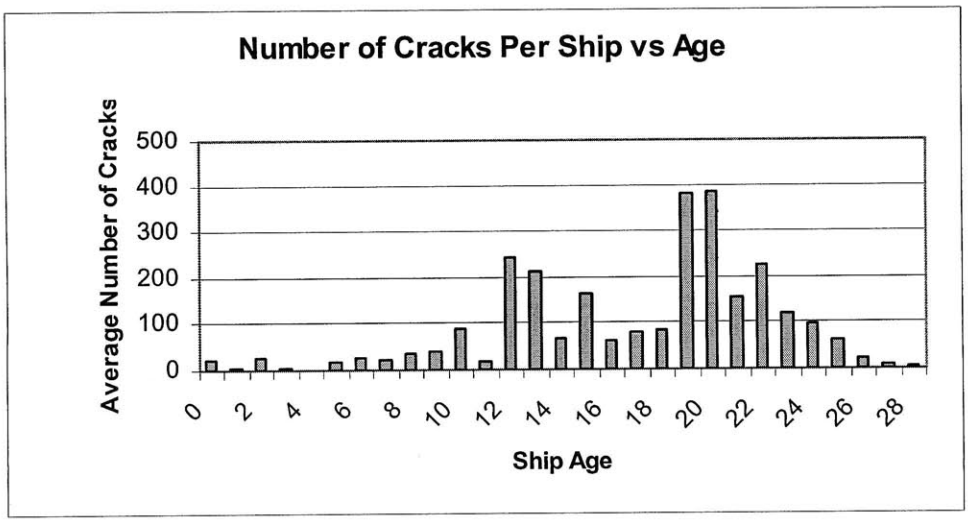


Fig. 4.2-71: Average Number of Cracks per Ship with respect to Age

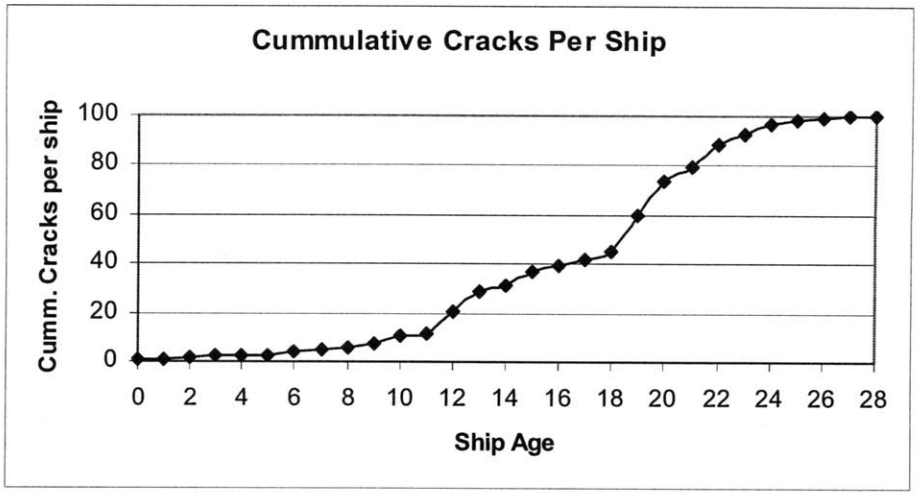


Fig. 4.2-72: Cumulative Average Number of Cracks per Ship with Age

Table 4.2-11 summarizes the main statistics.

DATABASE STATISTICS AND COMPARISON		
Database	INITIAL	REVISED
Total Number of Ships (entries)	240	140
Total Number of Cracks	29,567	17,435
Total Crack Length (km)	7.82	4.32
Mean Crack Size (mm)	264	248
Mean Number of Cracks per Ship	123	125
Mean Total Crack Length per Ship (mm)	32,582	30,875

Table 4.2-11: Revised Data Sample

The similarity between the two databases, particularly in terms of number of cracks and total crack length per ship, shows that the data is sufficiently consistent within itself. The same conclusion can be reached by comparing the graphs of the two databases. This result, and the large size of the database relative to the world fleet give confidence that the database is a representative sample.

4.2.5.5 Comments and Conclusions

Cracks were shown to generally appear at the highly stressed regions as predicted from the wave induced bending moments. However, many other causes of cracking have been identified. These, in combination with the enhancement of highly stressed areas, tend to weaken the link. Examples of other cracking causes include corrosion or damages induced during cargo discharge. An arbitrary location may also be overstressed during cargo operations at high rates due to a deviation from the plan, which is very likely to occur. These and other factors result in additional cracks in regions where the still water or wave induced bending moments are relatively low.

An important observation is that even though a great amount of research has been directed towards improving ship design against cracking in the critical areas, evidently, cracks are still generally observed in the highly stressed regions exactly where they are expected. This to some extent resembles the aircraft industry where continuous research is focused in minimizing stress concentrations and improving design, but cracks still initiate at highly stressed points which go unnoticed. One of the main reasons for this outcome in ships, is that sacrifices are purposely made regarding cracking, in order to keep manufacturing costs within acceptable limits.

Due to the numerous factors involved, and the differing views and interests of the various parties, it is difficult to predict the future with respect to cracks in capes. Ship owners take the view that the unified rules (common rules) should be stricter regarding ship design and construction of vessels, in order to minimize cracking and subsequent repair and maintenance costs. Furthermore, they favor lower loading rates for easier monitoring and adherence to the loading sequence in order to avoid overstressing of the hull. Terminals on the other hand strive to maximize loading rates in order to minimize congestion and facilitate the higher export and import of cargo.

Shipyards are generally focused on introducing new designs to create a new market and increase business for the shipbuilding industry. They also have an interest in delaying the initiation of any problems including cracking beyond the twelve month guarantee period.

Classification societies recognize the need for stronger ships and they introduced the unified rules in order to avoid pressure from shipyards and unfair competition amongst

themselves. Port State Control has also shown a greater interest and has introduced the "*Bulk Carrier Inspection*" which entails the internal inspection of the bulk carrier hull condition and survey for cracks.

Cargo owners and charterers who are most concerned about damages and delays, are dependent on cargo terminal operators and are trying to tackle the issue by imposing an age limitation. For this purpose, they introduced a 25 year age limit for ships which are allowed to transport iron ore. Similarly, underwriters who understand the potential risks of cracking, have responded by quoting higher premium rates for older vessels.

The IMO is mostly concerned with safety aspects of both the crew and the environment. They turned down the double-hull legislation attempt of shipyards for a new design, in favor of stronger single-hull bulk carriers. However, they have not yet taken any effective measurements regarding the high loading and discharging rates.

This is the largest ship cracking survey in terms of the number of cracks considered, out of those identified in a comprehensive literature research. It is also the only one focusing particularly on capes which lie at the core of the problem. The number of ships considered account for a substantial portion of the world fleet.

Though cracks in the current investigation stem from a variety of causes, ship design seems to have a major influence. There was a case of 5 Taiwanese sister ships within the data sample, which all showed similar crack patterns. Furthermore, crack sizes were found to continuously decrease after approximately the first special survey while a number of cracks per ship was observed to rapidly decline after around the fifth survey. These results suggest that, contrary to popular belief, the design of a vessel and the way in which it is maintained and repaired can be of much greater importance than the age regarding the frequency of cracking.

Design related cracks with high growth rates occur during the early years of a ship's life at highly stressed locations. Those are gradually eliminated by design modifications and appropriate reinforcement during repairs. Fatigue cracks generally appear more randomly during the later stages of a ship's life. Factors contributing to fatigue include dynamic loads and overstressing due to high loading rates or bad weather including storms; wave induced cyclic loads; slamming loads during ballasting; low cycle stressing due to consecutive loading, discharging, ballasting and de-ballasting operations; high cycle fatigue due to

vibrations e.g. from the engine, shaft, propeller, bulkheads or rudder; thermal fatigue due to ballasting operations (particularly in the after peak which is adjacent to the engine room); and other random loads during operation that are difficult to quantify.

Due to the complexity of the bulk carrier structure, it is impossible to guarantee that no cracking will occur. Cracks up to a few meters long are common, and develop due to many reasons including fatigue, wear, bad design, damage etc. The results suggest that a typical cape may have hundreds of cracks at any one time, while the number developed throughout its lifetime is approximately two thousand. Many of these are not recorded by classification societies during regular surveys.

The mean number of 123 cracks recorded per ship, and the scatter of the data, demonstrate that ships can operate safely with hundreds of cracks. Though there is little evidence to suggest that fatigue cracks pose a significant threat to the overall structural integrity of a ship, they are repaired whenever possible. Many cracks cannot be identified during routine hull maintenance so focused surveys after cleaning and preparation are carried out during dry-dock. It is also important, for inspections to be carried out during operation, particularly after a high stress situation such as a fast cargo operation or after a storm. Cracks, which have grown to a large size, can then be easily identified and repaired before they impose a danger.

Though information regarding the design and shipyard in which the vessels were built was only available for a limited portion of the data, it is observed that some yards build ships that are more crack resistant than others. Romanian ships, for example, consistently had more cracks that those from the Far East. The shipyard, and consequently the construction quality and manufacturing methods adopted, seem to have a major influence on the stage at which cracks initiate during the ship's lifetime. This is generally due to the smaller defects that are present to start with, the lower residual stresses after the effective stress relief of welds, lower stress concentrations after careful finishing etc. Design on the other hand seems to influence the rate at which deterioration progresses after initiation. This is partly due to the avoidance of "hard spots" and other measures which can be taken at the design stage to reduce the local stress range. A more comprehensive and focused study would be required to derive substantiated conclusions regarding this matter.

4.3 Crack Growth Rates

4.3.1 Introduction - Purpose

In Chapter 4.2, the final result showed the mean and median crack size as a function of ship age. After the age of about 5 years, crack size was found to steadily decrease with age. Two factors causing this outcome were discussed. One is that as a ship ages, fast growing stress cracks are repaired with design changes that eliminate their recurrence, while slow growing fatigue cracks become more prominent. The other reason is that as ships age, inspections become more frequent and stringent, thereby not giving enough time to the cracks to grow to a large length.

In order to separate the impact of those two effects on the final result, growth rates need to be examined as a function of ship age. Average crack growth rates for each location and ship age are also required to assess the safety implications of the various cracks.

4.3.2 Paris Law

Paris Law is the most common procedure used to determine crack growth rates in structures such as ships. Some of the most advanced research on ship structural reliability to date, carried out jointly by the Pusan National University (PNU), the American Bureau of Shipping (ABS) and Chevron, apply Paris Law to determine crack growth rates throughout the hull and its implications on longitudinal strength [Paik et al 2003a, Paik et al 2003b].

Our analysis of crack growth rates, therefore, begins by applying the Paris Law and checking its consistency with the data. The Paris Law, which expresses the crack growth rate in a differential equation, can be integrated to give the final crack size in terms of the initial

crack size a_0, the number of stress cycles N, material parameters A and m and geometric parameter Y as follows:

$$\frac{da}{dN} = A(\Delta K)^m = A\left(Y\Delta\sigma\sqrt{\pi a}\right)^m$$

$$\int_{a_0}^{a} a^{-\frac{m}{2}} da = A\left(\Delta\sigma Y\sqrt{\pi}\right)^m \int_0^N dN$$

$$\frac{2}{2-m}\left[a^{\frac{2-m}{2}}\right]_{a_0}^{a} = NA\left(\Delta\sigma Y\sqrt{\pi}\right)^m \qquad (4.3\text{-}1)$$

$$a = \left[a_0^{\frac{2-m}{2}} + \left(\frac{2-m}{2}\right)NA\left(\Delta\sigma Y\sqrt{\pi}\right)^m\right]^{\frac{2}{2-m}}$$

Because of the way Paris Law is designed, a_0 has to be small (of the order of a millimeter) in order to get meaningful results. After ongoing research in the field, the method of applying Paris Law to ship components is standard and tabulated results exist for the parameters required (such as geometric factors).

The effective stress amplitude of location "i" $\Delta\sigma_i$, is obtained by

$$\Delta\sigma_i = 2\frac{M_w y_i}{I} * SCF_i * k_f \qquad (4.3\text{-}2)$$

M_w is the global bending moment which can be obtained from MIT Sea-keeping tables USAS-L program for the trade routes in which capes typically sail and from loading manuals for cargo operations. I is the second moment of area of the cross section which may vary slightly between compartments (particularly at the ends) but not so much between ships. SCF_i are stress concentration factors for locations "i" and have been tabulated by ABS. y_i is the vertical distance of the crack from the neutral axis. k_f is a knockdown factor (0.25) to account for dynamic stress cycles.

The number of stress cycles "N" per year can be approximated assuming an average wave period of 8 seconds which is commonly used and corresponds to a wavelength of 100m according to the deep water dispersion relation (Eq. 4.3-4). The analysis was repeated with a wavelength of 12 seconds (corresponding to a 225m wavelength) and this had no impact on the conclusions. The wave encounter frequency is given by:

$$\omega_e = \omega + kV\cos\mu \tag{4.3-3}$$

where the ship velocity is V, the wave number is $k = \frac{2\pi}{\lambda}$, the wave frequency is $\omega = \frac{2\pi}{T}$, the wave period is T=8s, and μ is the angle of wave propagation using a body-fixed coordinate system. One can use the dispersion relation to solve for the encounter frequency using a typical ship travel speed of 14 knots.

$$\omega^2 = gk\tanh(kh) \xrightarrow{DeepWater} gk \tag{4.3-4}$$

On average, however, traveling in both directions relative to the waves, the encounter frequency will average out to be approximately equal to the wave frequency. Therefore, we can simply use ω. In practice, the ship makes short stops for loading operations which involve a lower loading frequency and higher loading amplitude but this effect is not considered in the analysis. If anything, however, this assumption should make the results of Paris Law less conservative (because of the damage during cargo operations).

4.3.3 Over-Conservative Results

Using tabulated values and data available in the open literature, the above procedure was applied to various locations in order to compare to the data. In agreement with some of

the more recent research, the results were found to be over-conservative over a wide range of locations. The shell frame brackets are chosen as an example to demonstrate this because of the large number of cracks over a wide range of ship ages. $\Delta\sigma_i$ for upper (i = 7) and lower (i = 9) shell frame brackets amidships correspond to 125 MPa and 32 MPa respectively. Table 4.3-1 summarizes the numbers that go into Paris law for lower shell frame brackets amidships:

Shell Frame Parameters	
α_0 = 1 mm	Y = 1.33
A = 6.94E-12	m = 3.07
$\Delta\sigma$ = 32 MPa	N = 3,942,000 Cycles/yr

Table 4.3-1: Paris Law Data for Lower Shell Frame Brackets [Paik et al 2004, ABS 2002a]

Paris law was applied numerically for 63,990,486 stress cycles (16.233 years) and the results of crack size over time is shown in Fig. 4.3-1.

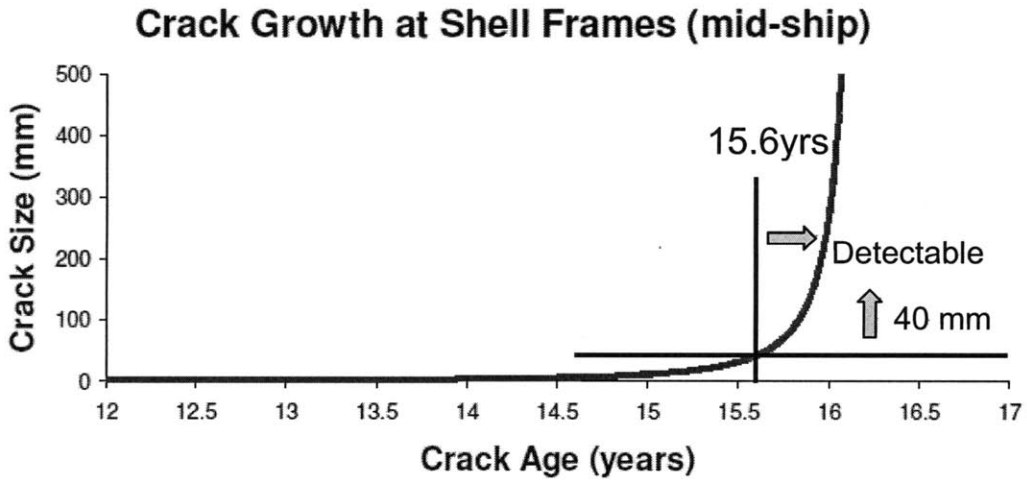


Fig. 4.3-1: Paris Law Crack Growth for Shell Frame Brackets

According to the results, Paris Law suggests that it would take approximately 15.6 years for a 1mm shell frame bracket crack to grow to a detectable size (~40mm) for a

standard inspection. After it reaches 40mm, however, the growth rate increases rapidly. Table 4.3-2 shows some tabulated values derived from Fig. 4.3-1 with time measured from the point when the crack is 40mm.

Crack Length (m)	Time (Months)
0.04	**0.0**
0.5	5.9
1	6.5
5	7.3
10	7.5
25	7.6
175	**7.8**

Table 4.3-2: Paris Law Growth for Lower Shell Frame Brackets

The perimeter of a capesize bulk carrier is approximately 140m. Paris law predicts that a barely detectable bracket crack (at 40mm) grows all the way around the ship in less than 8 months, which is less than the shortest scheduled inspection interval (annual surveys). If that were the case, each time an inspector missed a 40mm crack, the ship would be expected to break in two before the next inspection.

Evidently, Paris Law is extremely over-conservative. This has also been observed in some of the most recent fracture mechanics research on ships. In fact, ABS is currently working on a project where they examine the progress of cracks on small tankers between voyages without repairing them. They are finding much slower crack growth than that predicted by Paris Law and in some cases, cracks are found to stop growing after they reach a certain size.

The reason why Paris Law is conservative is that as a crack grows, the structure becomes more flexible. A lot of the stress is then transferred to the surrounding members and the stress that is driving the crack growth decreases.

4.3.4 Proposed Paris Law Modifications

Three modifications of the Paris Law were proposed and tested. The constant stress amplitude term is replaced by one that is a function of crack length, and thereby decreases with time. This will cause the predicted crack size at any point in time to be smaller and thereby less conservative.

1). The first modification is to replace $\Delta\sigma$ with $\Delta\sigma\left(1-\frac{a}{a_f}\right)$ where a_f is a "final" crack length. In this case a_f is chosen to be the size of the bracket. This means that when $a = a_f$, the bracket is cut and the crack has reached the side shell.

Modified Paris Law 1 becomes:

$$\frac{da}{dN} = A\left[Y\Delta\sigma\left(1-\frac{a}{a_f}\right)\sqrt{\pi a}\right]^3 \qquad (4.3\text{-}5)$$

As before, integrating from the initial to the current crack length gives a function that relates the crack size "a" and the number of stress cycles "N":

$$\left[\frac{1}{4a_f^{\frac{7}{2}}\left(a_f-a\right)^2}\left[\sqrt{aa_f}\left(25a_f^3-15a^3-8\frac{a_f^5}{a}\right)+15\arctan h\left(\sqrt{\frac{a}{a_f}}\right)\left(a_f^2-2a_fa^3+a^5\right)\right]\right]_{a_0}^{a}$$
$$= A\left(\frac{Y\Delta\sigma\sqrt{\pi}}{a_f}\right)^3 N \qquad (4.3\text{-}6)$$

2). The second modification is to replace $\Delta\sigma$ with $\Delta\sigma\left(1-\frac{a}{a_f}\right)^2$ where again a_f is chosen to be the size of the bracket.

Modified Paris Law 2 becomes:

$$\frac{da}{dN}=A\left[Y\Delta\sigma\left(1-\frac{a}{a_f}\right)^2\sqrt{\pi a}\right]^3 \tag{4.3-7}$$

Integrating in this case yields:

$$\left[\frac{15}{a_f^{\,7}\left(a_f-a\right)}+\frac{5}{a_f^{\,6}\left(a_f-a\right)^2}+\frac{2}{a_f^{\,5}\left(a_f-a\right)^3}+\frac{3}{4a_f^{\,4}\left(a_f-a\right)^4}+\frac{1}{5a_f^{\,3}\left(a_f-a\right)^5}+\frac{21\left[\ln a-\ln\left(a-a_f\right)\right]}{a_f^{\,8}}-\frac{6}{a_f^{\,7}a}-\frac{1}{6a_f^{\,6}a^2}\right]_{a_0}^{a}=A\left(\frac{Y\Delta\sigma\sqrt{\pi}}{a_f^{\,2}}\right)^m N \tag{4.3-8}$$

3). The third modification involves the replacement of $\Delta\sigma$ with $\Delta\sigma\left(\frac{1}{1+Ka}\right)$ where "K" is a geometric constant that can be adjusted to produce a good fit with the experimental data. This constant accounts for the fact that the cracked component becomes more flexible with crack growth and stresses are transferred to the surrounding members, so its value depends on the surrounding geometry. Note that the constant "K" is defined for the crack length "a" in meters (to be consistent with S.I. units).

Modified Paris Law 3 is becomes:

$$\frac{da}{dN} = A\left[Y\Delta\sigma\left(\frac{1}{1+Ka}\right)\sqrt{\pi a}\right]^3 \qquad (4.3\text{-}9)$$

Integrating this time gives:

$$\left[\frac{2K^3}{5}a^{\frac{5}{2}} + 2K^2a^{\frac{3}{2}} + 6Ka^{\frac{1}{2}} - 2a^{-\frac{1}{2}}\right]_{a_0}^{a} = A\left(Y\Delta\sigma\sqrt{\pi}\right)^3 N \qquad (4.3\text{-}10)$$

It is clear from Eq.4.3-6, 4.3-8 and 4.3-10 that even small modifications to the original Paris Law complicate results to the point where it is impossible to solve for the crack length as a function of the number of stress cycles and the initial crack length. Again, we have to resort to numerical integration of the above equations to overcome this problem.

In order to compare the original Paris Law, the three modified laws and the experimental data (from the database), we have to plot them all with the abscissa beginning at the same point. That point is chosen to be when the crack length is equal to the detectable size (40mm). Crack length is, therefore, plotted against the time since the crack was 40mm (t'). The independent variable, therefore, becomes:

$$t' = t - t_{a=40mm} \qquad (4.3\text{-}11)$$

In order to obtain comparable points from the data, we have to consider the size of cracks in the given location and the inspection intervals. Shell frame brackets amidships are inspected every 2.5 years (at dry docks) until the age of 20, after which they are usually inspected once a year. No frame cracks were identified in ships under 5 years of age.

We assume that cracks reach 40mm evenly throughout the inspection interval. It follows that on average they grow from 40mm until the inspection over half the inspection interval. The value of t' for cracks observed is set to half the inspection interval. We can then deduce three data points from the data as follows:

For t'=0: $$\overline{a}_{t'=0} = a_0 = 40mm$$

For t' = 0.5years: $$\overline{a}_{t'=0.5} = \frac{\sum_{A>20}\sum_{j=5}^{7}\left[\tilde{L}_A\right]_{i=7,j}}{\sum_{A>20}\sum_{j=5}^{7}\left[\tilde{N}_A\right]_{i=7,j}} \qquad (4.3\text{-}12)$$

For t' = 1.25 years: $$\overline{a}_{t'=1.25} = \frac{\sum_{A\leq 20}\sum_{j=5}^{7}\left[\tilde{L}_A\right]_{i=7,j}}{\sum_{A\leq 20}\sum_{j=5}^{7}\left[\tilde{N}_A\right]_{i=7,j}} \qquad (4.3\text{-}13)$$

The original Paris Law is plotted along with the three modifications and the data points on a graph of Crack Size against t'. The constant "K in the third modification is adjusted to K= 4.7 in order to fit the data.

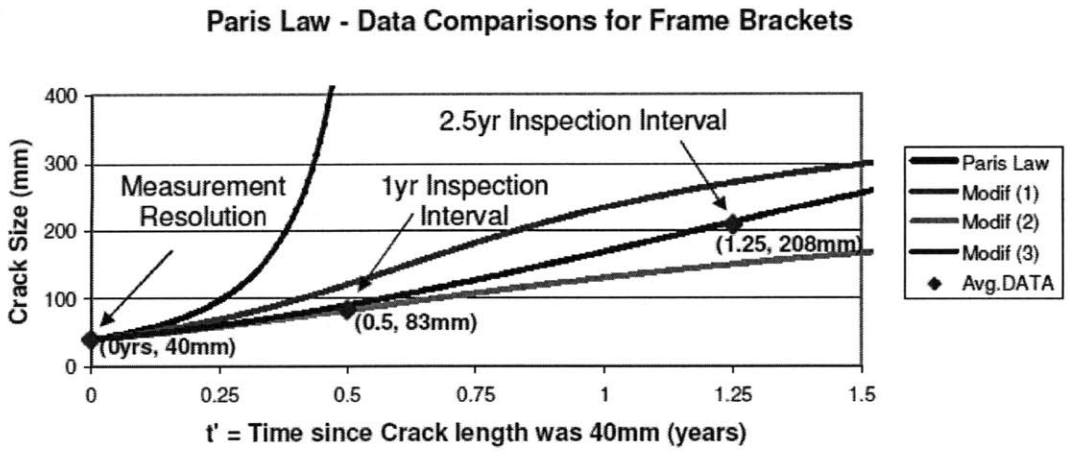


Fig. 4.3-2: Paris Law, Modifications and Data comparisons of Crack Growth in Frame Brackets

Over the range considered, we can see that the original Paris Law is extremely conservative, the first modification is less but still too conservative, the second modification underestimates the crack growth rate and the third modification is adjusted to fit the data.

If we were to adopt this approach, the only viable option would be the third modification. This, however, would require calibrating the constant "K" for all locations on the ship. The amount of effort required to accomplish this would be analogous to that of ABS and other organizations who produced tabulated results of the stress intensity factors throughout the ship hull over decades.

Over the range of crack sizes that we are considering, we can see that the crack growth is approximately linear. Considering the example of shell frame brackets in Fig. 4.3-2, the error of approximation by assuming linear growth is only 0.146%. Therefore, it is more appropriate for our purposes to approximate crack growth as described in Section 4.3.5 that follows.

4.3.5 Crack Growth Rate Approximation

The crack growth rate has to be approximated for each location and each ship age. The mean crack size for each location and each age can be deduced from the data. A two dimensional matrix $\tilde{\bar{a}}_A$ is defined for each age A as the Hadamard division of matrix $\tilde{L}_A$ by matrix $\tilde{N}_A$:

$$\tilde{\bar{a}}_A = \frac{\tilde{L}_A}{\tilde{N}_A} \tag{4.3-14}$$

In other words, using the Hadamard division, its elements are calculated as follows:

$$\left[\tilde{\tilde{a}}_A\right]_{i,j} = \frac{\left[\tilde{L}_A\right]_{i,j}}{\left[\tilde{N}_A\right]_{i,j}} \tag{4.3-15}$$

Similarly, matrix $\tilde{\tilde{a}}_S$ is defined for each ship and matrix $\tilde{\tilde{a}}$ for the whole database using the relevant matrices.

The inspection interval for each location, for every ship age is available in rules of IACS member classification societies. Some assumptions and approximations have to be made to account for differences in rules and for cases where freedom of choice is given to surveyors. The values are summarized in Table 4.3-3.

"i"	Location Letter	a^r (mm)	T^I (years) (AGE<5)	T^I (years) (AGE<20)	T^I (years) (AGE>20)
1	1a	40	AGE	2.5	1
2	1b	40	AGE	2.5	1
3	1c	40	AGE	2.5	1
4[2]	1d	40	j = 5,10: 1 j ≠ 5,10: AGE	j = 5,10: 1 j ≠ 5,10: 2.5	1
5*	1e	40	j = 5,10: 1 j ≠ 5,10: AGE	j = 5,10: 1 j ≠ 5,10: 2.5	1
6*	1f	30	j = 5,10: 1 j ≠ 5,10: AGE	j = 5,10: 1 j ≠ 5,10: 2.5	1
7*	2a	40	j = 5,10: 1 j ≠ 5,10: AGE	j = 5,10: 1 j ≠ 5,10: 2.5	1
8*	2b	40	j = 5,10: 1 j ≠ 5,10: AGE	j = 5,10: 1 j ≠ 5,10: 2.5	1

[2] The minimum requirement for annual surveys is the inspection of Cargo Hold 1 (j=10) and an additional cargo hold chosen by the surveyor, usually Cargo Hold 6 (j=5), which is the ballast hold amidships. The values in the table are only typical. In practice, when the previous annual survey of a ship was available, it was used to identify the inspection interval of a particular crack/location

9*	2c	40	j = 5,10: 1 j ≠ 5,10: AGE	j = 5,10: 1 j ≠ 5,10: 2.5	1
10	3a	60	AGE	2.5	1
11	3b	60	AGE	2.5	1
12	3c	60	AGE	2.5	1
13	3d	60	AGE	2.5	1
14	4a	60	AGE	2.5	2.5
15	4b	60	AGE	2.5	2.5
16	4c	60	AGE	2.5	2.5
17	4d	60	AGE	2.5	2.5
18*	5a	80	j = 5,10: 1 j ≠ 5,10: AGE	j = 5,10: 1 j ≠ 5,10: 2.5	1
19*	5b	80	j = 5,10: 1 j ≠ 5,10: AGE	j = 5,10: 1 j ≠ 5,10: 2.5	1
20*	5c	80	j = 5,10: 1 j ≠ 5,10: AGE	j = 5,10: 1 j ≠ 5,10: 2.5	1
21*	5d	80	j = 5,10: 1 j ≠ 5,10: AGE	j = 5,10: 1 j ≠ 5,10: 2.5	1
22*	5e	80	j = 5,10: 1 j ≠ 5,10: AGE	j = 5,10: 1 j ≠ 5,10: 2.5	1
23*	5f	80	j = 5,10: 1 j ≠ 5,10: AGE	j = 5,10: 1 j ≠ 5,10: 2.5	1
24	6a	40	AGE	2.5	1
25	6b	40	AGE	2.5	1
26	6c	40	AGE	2.5	1

Table 4.3-3: Detectable crack sizes and Inspection Time Intervals

A two dimensional matrix $\tilde{T}_A^I$ is constructed for each ship age "A" with elements $\left[\tilde{T}_A^I\right]_{i,j}$ giving the inspection interval of location "i" in compartment "j".

The detectable crack size for each location can be estimated from the cracks reported in the database, previous research on the probability of crack detection with respect to size and other parameters, and by consulting with experienced surveyors and engineer superintendents. The values can be found in Table 4.3-3 and range is between 30mm and 80mm. Arguments could be made why the measurement resolution should increase with age, but there are also counter arguments. An older ship is inspected in more detail and often by more surveyors so one could argue for a higher resolution. On the other hand, an older ship has more to be reported including more wastage, damages and possibly more cracks, so arguably, there is less time to inspect per crack, indicating a lower resolution. Therefore, this variable was neglected for simplicity. A single 2-D matrix $\tilde{a}^r$ was constructed with elements $\left[\tilde{a}^r\right]_{i,j}$ giving the crack measurement resolution for location i,j irrespective of ship age.

Using the above matrices, a matrix of crack growth rates can then be constructed. A 2-D matrix $\tilde{R}_A$ is constructed for each ship age "A" with elements $\left[\tilde{R}_A\right]_{i,j}$ giving the crack growth rate that corresponds to the location "i" in compartment "j" for ship age "A". Using Hadamard division:

$$\tilde{R}_A = \frac{\tilde{\tilde{a}}_A - \tilde{a}^r}{\frac{1}{2}\tilde{T}_A^I} \tag{4.3-16}$$

Its elements are calculated as follows:

$$\left[\tilde{R}_A\right]_{i,j} = \frac{\left[\tilde{\tilde{a}}_A\right]_{i,j} - \left[\tilde{a}^r\right]_{i,j}}{\frac{1}{2}\left[\tilde{T}_A^I\right]_{i,j}} \tag{4.3-17}$$

Similarly, matrix $\tilde{R}_S$ is defined for each ship and matrix $\tilde{R}$ for the whole database using the relevant matrices.

This approximation of the crack growth rate follows the same method used in comparing the Paris Law and its proposed modifications with growth rates implied by the data. Cracks are assumed to grow, on average, from the resolution length to their final length (at which they are reported), over half the inspection interval. This is illustrated graphically in Fig. 4.3-3, where "a" is the crack size and "t" is the time elapsed from the previous inspection.

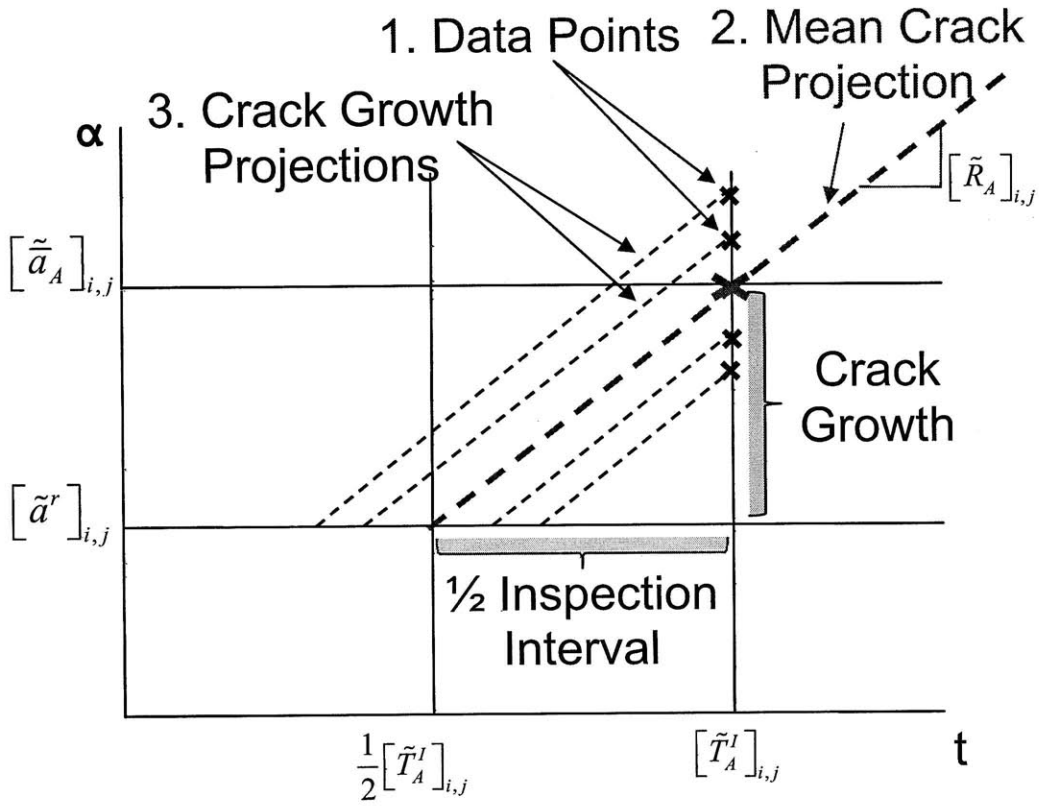


Fig. 4.3-3: Crack Growth Rate Approximation

The elements of matrix $\tilde{R}_A$ give the crack growth rates corresponding to each location, compartment and ship age. These values will be used extensively in the remaining analysis.

4.3.6 Crack Growth Rate vs. Age – "Bathtub Curve"

To answer the initial question of isolating the effect of design modifications and inspection frequency on the crack size vs. age relationship, we need a single value for each ship age. In other words, we need to determine an average crack growth rate $\overline{R}_A$ for each ship age irrespective of location. A quick preliminary result can be obtained by plotting the average crack growth rate of each ship against ship age. That is obtained as follows:

$$\overline{R}_S = \frac{\sum_i \sum_j \left[\tilde{R}_S\right]_{i,j} \left[\tilde{N}_S\right]_{i,j}}{\sum_i \sum_j \left[\tilde{N}_S\right]_{i,j}} \tag{4.3-18}$$

Plotting $\overline{R}_S$ against age "A" gives the result shown in Fig. 4.3-4, where each red dot corresponds to a data sample (one ship).

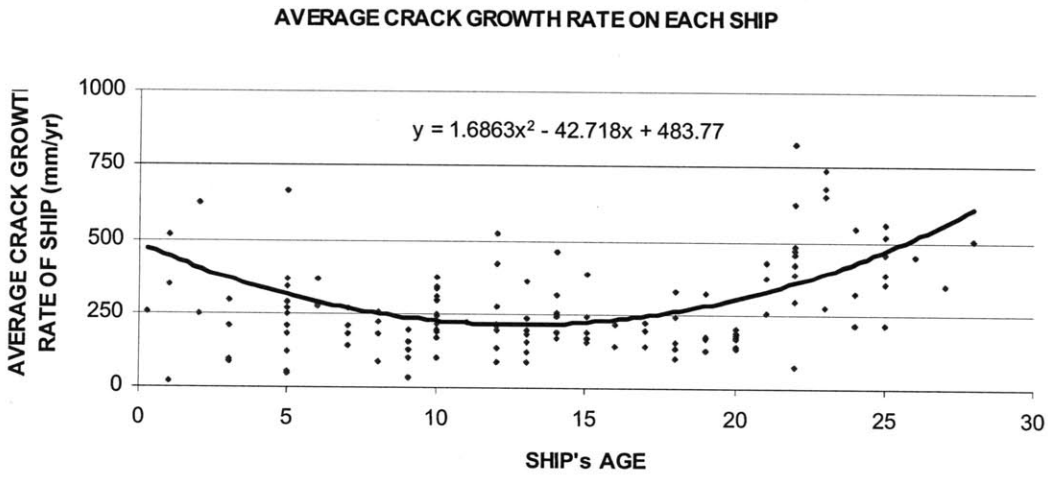


Fig. 4.3-4: Average Crack Growth Rate "$\overline{R}_S$" against Ship Age "A" for all Ships

This result gives us a rough idea but it is inaccurate as it ignores the number of cracks per ship. In other words, the average crack growth rate on a ship with 10 cracks has the same

weighting (one data point) as the average crack growth rate on a ship with 200 cracks. In order to correct for this and produce a more meaningful result, we can take a weighted average (by the number of cracks) of crack growth rates as follows:

$$\overline{R}_A = \frac{\sum_i \sum_j \left[\tilde{R}_A\right]_{i,j} * \left[\tilde{N}_A\right]_{i,j}}{\sum_i \sum_j \left[\tilde{N}_A\right]_{i,j}} \qquad (4.3\text{-}19)$$

By calculating $\overline{R}_A$ for each ship age, and by plotting it against age, we can isolate the effect of inspection frequency on the inspected crack sizes. This will allow us to draw some conclusions that help answer the above question. The result is shown in Fig. 4.3-5.

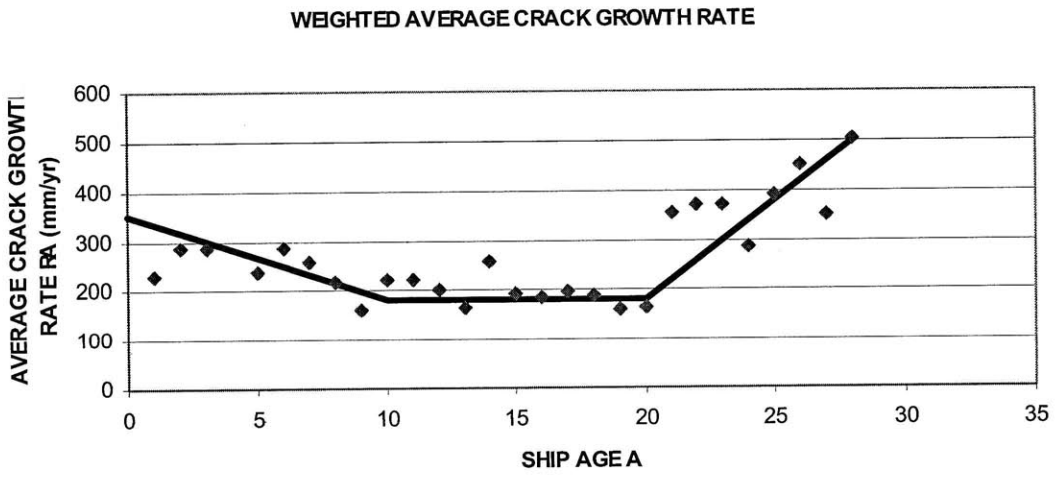


Fig 4.3-5: Plot of Average Crack Growth Rate "$\overline{R}_A$" against Ship Age "A"

The values of $\overline{R}_A$ corresponding to each age are indicated by the red dots. A simple modeling of the situation is to break it down into three linear regions as shown by the fit. These involve the first decade of a ship's life during which average growth rates decrease with time, the second decade during which they are constant, and the third decade during

which they increase again. This result actually resembles a "bathtub curve" which is common in many engineering applications but has not been identified before regarding cracks in ships.

A typical example where the bathtub curve is observed is in machinery or electronic components which show a high failure rate at a young age, then reach a steady as the initial design problems are sorted out, and then begin to fail again at an older age due to ageing related problems such as wear and tear. Bathtub curves also apply in people. Fig. 4.3-6 shows a bathtub curve in pilot accidents with respect to hours of experience, while Fig. 4.3-7 shows it in driver fatality rates with respect to driver's age.

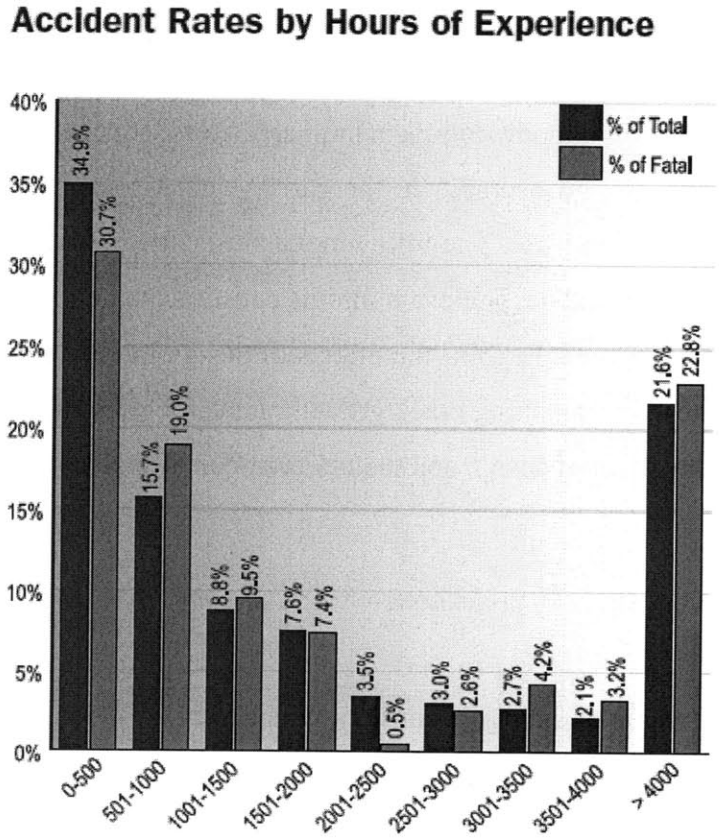


Fig. 4.3-6: Bathtub Curve in Pilot Accident Trends for 2005 [Nall Report 2006]

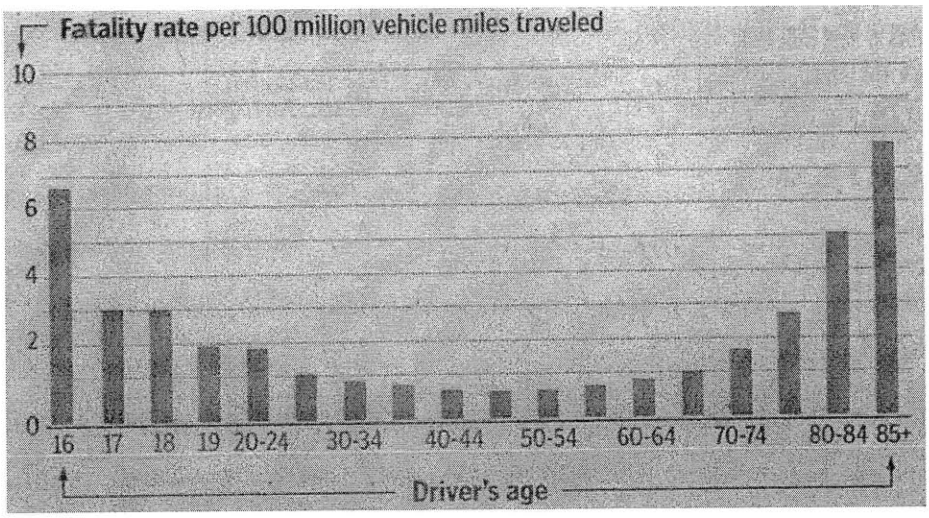


Fig. 4.5-7: Bathtub Curve in Driver fatality Rates based on 1996 figures from the National Bureau of Transportation; National Highway Traffic Safety Administration [Boston Sunday Globe 2004]

In our case, design modifications eliminate stress concentrations during repairs, causing crack growth rates to decrease in the early years. Corrosion causes crack growth rates to increase again in later life. The following analysis attempts to construct the Bathtub Curve describing the data, and decompose it into its constituent parts.

The Bathtub Curve results from the effects of design modifications and corrosion on the crack growth rates. The resulting crack growth rate can be resembled by a superposition of an initial value, the effect of design and the effect of corrosion:

$$R_{total} = R_{Original} + R_{CorrosionEffect} + R_{DesignEffect} \tag{4.3-20}$$

The original value is simply a constant equal to what the crack growth rate would have been in absence of the two other opposing effects. We can simply replace the first term by a constant:

$$\boxed{R_{Original} = a_O} \tag{4.3-21}$$

The effect of corrosion has been examined in great detail by many researchers in the past. Table 4.3-4 shows a sample of this work.

DIRECT MEASUREMENT BASED ON CORROSION		
Author	**No. of Ships/Type**	**Measurements**
[Wang et al 2007]	211 S-Hull Tankers	2195 sections
[Wang et al 2003a,b]	140 Tankers	110,082
[Paik et al 2003°,b]	>100 Tankers	33,820
[Harada et al 2001]	197 Tankers + 98 Bulk Carriers	>250,000
[Yamamoto et al 1998a]	50 Bulk Carriers	-
[Paik et al 1998a]	44 Bulk Carriers	-
[Paik et al 1997a]	40 Tankers	-
[TSFC 1992]	52 Tankers	-

Table 4.3-4: Corrosion Wastage Surveys

Based on passed research, the effect of corrosion can be represented as an exponential that sets in at an age of about 7.5 years. Therefore, we replace the second term as follows:

$$\boxed{R_{CorrosionEffect} = e^{a_C(AGE-7.5)}} \tag{4.3-22}$$

The effect of design modifications is slightly more complicated. In order to create the bathtub curve together with the other two terms, we know that it has to be of an exponential form so we can represent it as follows:

$$R_{DesignEffect} = a_D + b_D e^{c_D(AGE-d_D)} \tag{4.3-23}$$

We then have to apply some boundary conditions in order to solve for the constants and simplify the expression. First, we see that Eq. 4.3-23 is asymptotic with an asymptote value of a_D:

$$c_D < 0 : R_{DesignEffect} \xrightarrow{AGE \to \infty} a_D$$
$$c_D > 0 : R_{DesignEffect} \xrightarrow{AGE \to -\infty} a_D \qquad (4.3\text{-}24)$$

Based on the repairs of cracks in the database, and after verifying with surveyors and superintendents, we can conclude that the vast majority of design modifications during repairs are made between the age of 0 and 15 years. By assuming that the effect of design modifications is equal to zero for a new ship (no repairs yet) and that it reaches 99% of its final value at the age of 15 years, we get two boundary conditions that we can apply to Eq. 4.3-23. This gives us two additional equations:

$$BoundaryCondition\ 1 : R_{DesignEffect}(AGE = 0) = 0$$
$$\Rightarrow a_D = -b_D e^{-c_D d_D} \qquad (4.3\text{-}25)$$

$$BoundaryCondition\ 2 : R_{DesignEffect}(AGE = 15) = 0.99 a_D$$
$$\Rightarrow a_D = -100 b_D e^{c_D (15 - d_D)} \qquad (4.3\text{-}26)$$

By combining Eq. 4.3-25 and 4.3-26, we can solve for two of the constants. Rearranging Eq. 4.3-25 yields:

$$b_D = -a_D e^{c_D d_D} \qquad (4.3\text{-}27)$$

Substituting Eq. 4.3-27 into Eq. 4.3-26 and rearranging gives:

$$c_D = -\frac{\ln 100}{15} \qquad (4.3\text{-}28)$$

Combining Eq. 4.3-27 with Eq. 4.3-23 reduces its form to:

$$R_{DesignEffect} = a_D\left[1 - e^{c_D AGE}\right] \tag{4.3-29}$$

Substituting Eq. 4.3-28 into Eq. 4.3-29 gives the final form of the design effect in terms of only one constant:

$$\boxed{R_{DesignEffect} = a_D\left[1 - e^{-\frac{\ln 100}{15} AGE}\right]} \tag{4.3-30}$$

Having determined the form of the three components, we can substitute Eq. 4.3-21, 4.3-22 and 4.3-30 into 4.3-20 to give the form of the Bathtub Curve as follows:

$$\begin{aligned} R_{total} &= R_{Original} + R_{CorrosionEffect} + R_{DesignEffect} \\ &= a_O + e^{a_C(AGE-7.5)} + a_D\left[1 - e^{-\frac{\ln 100}{15} AGE}\right] \end{aligned} \tag{4.3-31}$$

This expression can be simplified by renaming the three constants as follows:

$$A = a_O + a_D \tag{4.3-32}$$

$$B = a_C \tag{4.3-33}$$

$$C = -a_D \tag{4.3-34}$$

This reduces the Bathtub Curve expression of Eq. 4.3-31 to:

$$\boxed{R_{total} = A + e^{B(AGE-7.5)} + Ce^{-\frac{\ln 100}{15} AGE}} \tag{4.3-35}$$

This is the final form of the Bathtub Curve. Non-Linear-Optimization was used to optimize the coefficients A, B and C of Eq. 4.3-32 in order to fit the data of Fig. 4.3-5. The resulting expression is given by:

$$R_{total} = 180.31 + e^{0.3021(AGE-7.5)} + 158.48e^{-\frac{\ln 100}{15}AGE} \tag{4.3-36}$$

Having determined constants A, B and C using non-linear optimization, we use Eq. 4.3-29, 4.3-30 and 4.3-31 to determine the coefficients a_O, a_C and a_D, and then back-substitute into Eq. 4.3-21, 4.3-22 and 4.3-30 to determine the individual contributions as follows:

$$R_{Original} = 338.79 mm / yr \tag{4.3-37}$$

$$R_{CorrosionEffect} = e^{0.3021(AGE-7.5)} \tag{4.3-38}$$

$$R_{DesignEffect} = -158.48\left[1 - e^{-\frac{\ln 100}{15}AGE}\right] \tag{4.3-39}$$

Finally, the Bathtub Curve (Eq. 4.3-36) and its individual contributions (Eq. 4.3-37, 4.3-38 and 4.3-39) can be plotted along with the data of Fig. 4.3-4 on the same graph. The result is presented in Fig. 4.3-8.

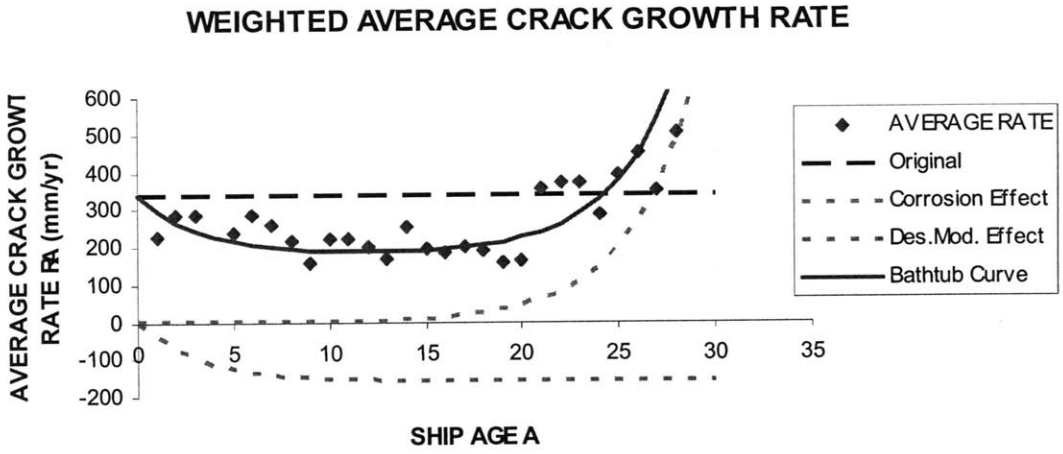


Fig. 4.3-8: Decomposed Bathtub Curve of $\overline{R}_A$ vs. A

This result clearly demonstrates how crack growth rates are gradually reduced by design modifications during repairs (the blue curve) and how corrosion (in orange) has the opposite effect as a ship gets older. This "Bathtub" shaped curve of average crack growth rates, combined with the increased frequency and rigor of inspections as a ship gets older, result in the observed pattern of mean and median crack sizes with respect to age depicted in Fig. 4.2-45 of Section 4.2.5.3.

This Bathtub Curve is also observed for individual locations but a significant number of cracks are required across a wide range of ages in order to demonstrate it. This is done by picking the elements of each matrix $\tilde{R}_A$ (for every age) that correspond to the chosen location "i" and compartment "j" $\left[\tilde{R}_A\right]_{i,j}$, and plotting them against age "A". The result for shell frame brackets, which was used in the previous analysis, is shown in Fig. 4.3-9.

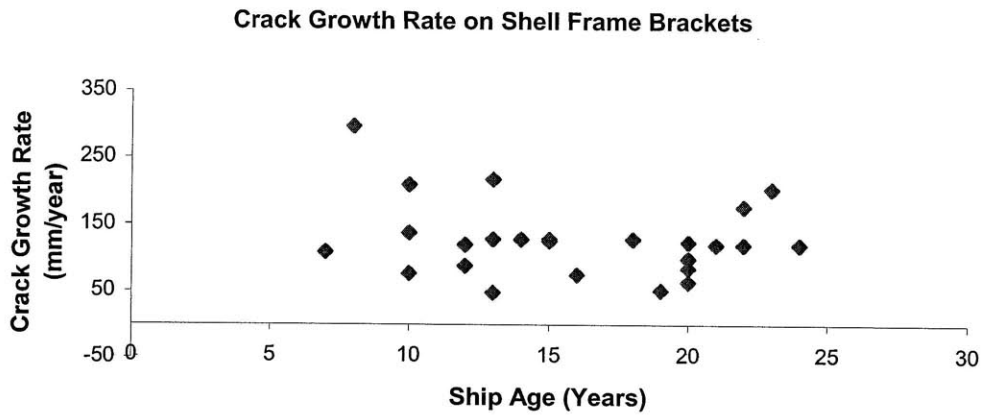


Fig 4.3-9: Bathtub Curve $\overline{R}_{Aij}$ vs. A for Shell Frame Brackets

Due to the absence of data in the early and late years of the ship's life, the Bathtub Curve is not very well defined. However, a pattern is still evident showing that crack growth rates in a given location vary significantly with age. That is why a separate crack growth rate matrix $\tilde{R}_A$ had to be constructed for each ship age. In the cases were enough data was available, Bathtub Curves were used to read off elements of the $\tilde{R}_A$ matrices in order to eliminate the effect of outliers.

4.3.7 Crack Growth Rates by Location

Having examined the crack growth rate vs. age relationship (Bathtub Curve), and having adjusting the entries of the crack growth rate matrices using the bathtub curves, we can proceed to compare the various locations and compartments in terms of crack growth rates.

The first result is the average crack growth rate along the ship. The average crack growth rate in each compartment "j" is determined as follows:

$$\overline{R}_j = \frac{\sum_i \left[\tilde{R}\right]_{i,j} \left[\tilde{N}\right]_{i,j}}{\sum_i \left[\tilde{N}\right]_{i,j}} \qquad (4.3\text{-}40)$$

Plotting $\overline{R}_j$ against "j" gives the average crack growth rate along the ship as shown in Fig. 4.3-10.

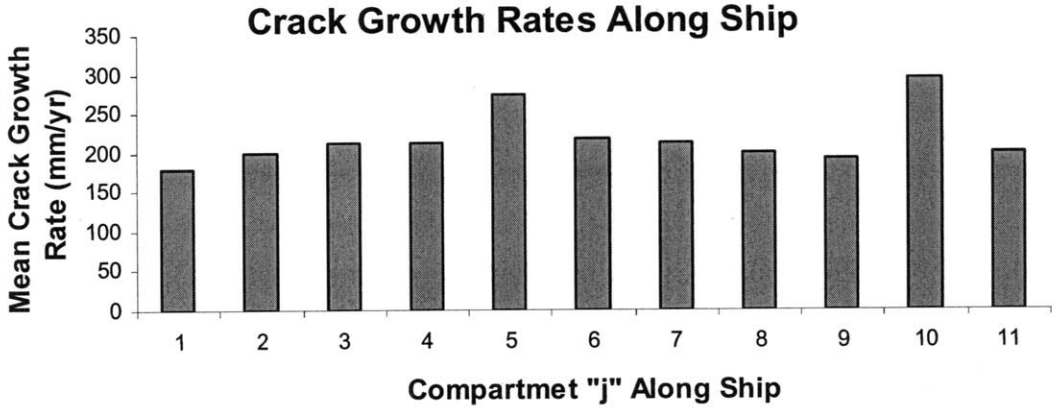


Fig. 4.3-10: Mean Crack Growth Rates per Compartment "j"

The crack growth rate seems to be significantly higher in the ballast hold (j=5) and in the first cargo hold (j=10). This may be due to wave slamming. The fore peak, j=11, is of a different geometry and, therefore, not comparable to j=10. The crack growth rate distribution, very closely resembles the distribution of average still water bending moments along the hull shown in .Fig 4.1-5 of Section 4.1.2.2.

Whereas in Chapter 4.2 we saw that the distribution of crack frequency was similar to the distribution of wave induced bending moments, here we see that the distribution of mean crack growth rates is similar to the average still water bending moments. This points to the fact that crack growth rates are governed primarily by the still water bending moments (low cycle, high amplitude stresses) while crack frequency or rack initiation is driven primarily by wave induced bending moments (high frequency, low amplitude stresses). This is consistent

with conclusions drawn by late research on "springing ships" [Drummen at al 2008, Jang et al 2007, Gu and Moan 2000, Dudson et al 2001]. Though most of these studies cover a wide range of ships, research has also lately focused specifically on the springing effects and fatigue implications in bulk carriers [Hirdaris et al 2009, Storhaug et al 2007, Malenica et al 2006, Vidic-Perunovic & Jensen 2005], showing that it is very significant.

The average crack growth rate along the ship can also be examined with respect to ship age. In other words, plots such as 4.3-8 can be produced for each ship age. The values to be plotted against compartment "j" for each ship age "A" are obtained from the data as follows.

$$\overline{R}_{A,j} = \frac{\sum_i \left[\tilde{R}_A\right]_{i,j}\left[\tilde{N}_A\right]_{i,j}}{\sum_i \left[\tilde{N}_A\right]_{i,j}} \tag{4.3-41}$$

Due to the limited number of ships, however, it is more appropriate to produce the plot for age groups (of five years) as opposed to one plot for each ship age. For example, to create a plot for ship ages 6 to 10 years, the mean crack growth rates in each compartment "j" are given by:

$$\overline{R}_{A=6:10,j} = \frac{\sum_{A=6}^{10}\sum_i \left[\tilde{R}_A\right]_{i,j}\left[\tilde{N}_A\right]_{i,j}}{\sum_{A=6}^{10}\sum_i \left[\tilde{N}_A\right]_{i,j}} \tag{4.3-42}$$

The plots for each age group are shown in Fig. 4.3-11 to 4.3-22. They show no significant changes in crack growth rate variations along the ship with respect to age.

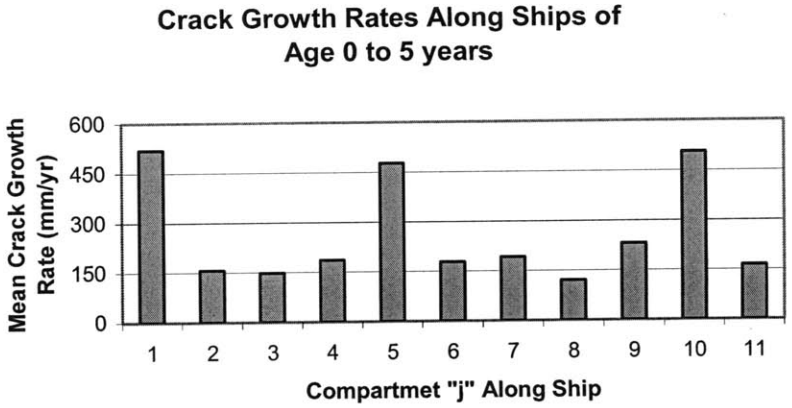


Fig. 4.3-11: Mean Crack Growth Rates by Compartment for Ages 0-5 years

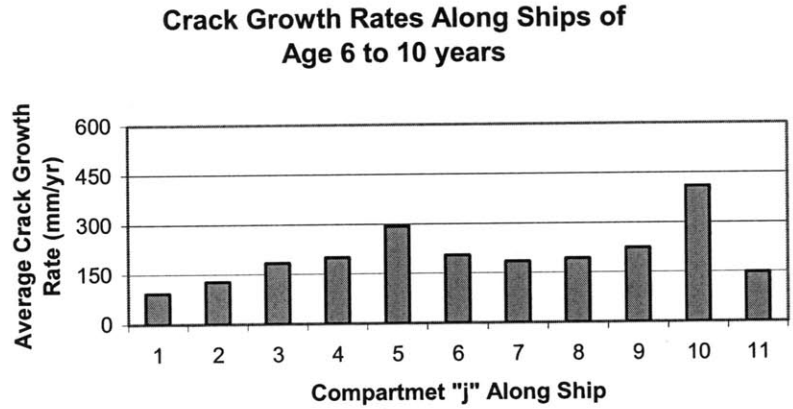


Fig. 4-3-12: Mean Crack Growth Rates by Compartment for Ages 6-10 years

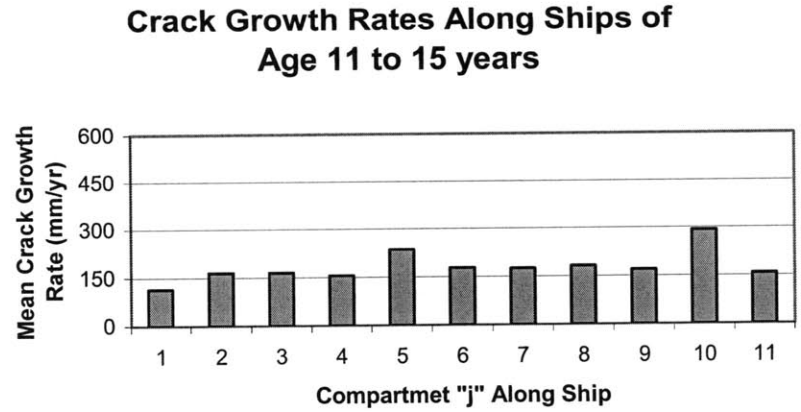


Fig. 4.3-13: Mean Crack Growth Rates by Compartment for Ages 11-15 years

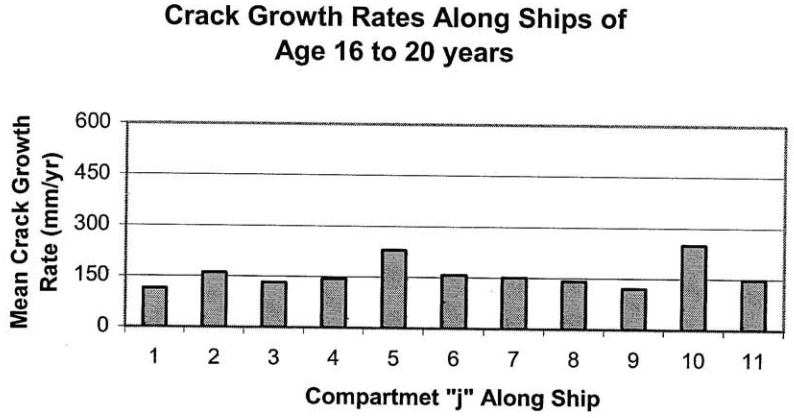


Fig. 4.3-14: Mean Crack Growth Rates by Compartment for Ages 16-20 years

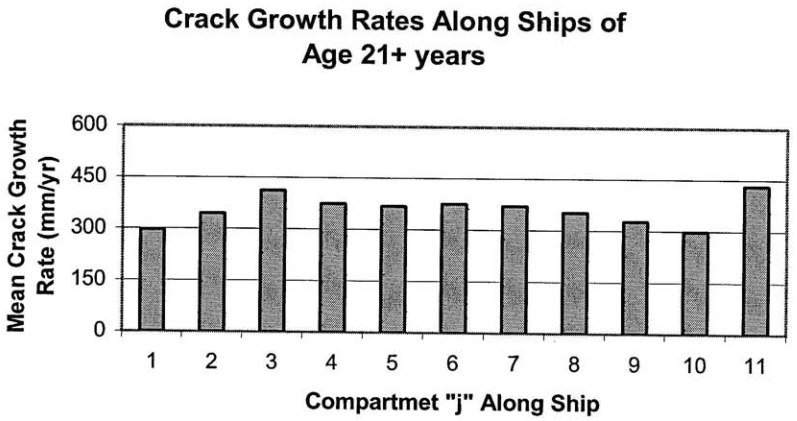


Fig. 4.3-15: Mean Crack Growth Rates by Compartment for Ages 21+ years

We can also examine mean crack growth rates by location across all compartments. In this case, we consider groups of locations 1 to 6 as per Section 4.2.4. For example, group 3 is the lower wing tank area which includes locations 3A (i=10) to 3D (i=13). The value of mean crack growth rate for this group is computed by:

Lower Wing Tanks:
$$\overline{R}_{i=10:13} = \frac{\sum_{i=10}^{13}\sum_{j}\left[\tilde{R}\right]_{i,j}\left[\tilde{N}\right]_{i,j}}{\sum_{i=10}^{13}\sum_{j}\left[\tilde{N}\right]_{i,j}} \qquad (4.3\text{-}43)$$

The mean crack growth rate was thereby computed for the 6 location groups and plotted in Fig 4.3-16.

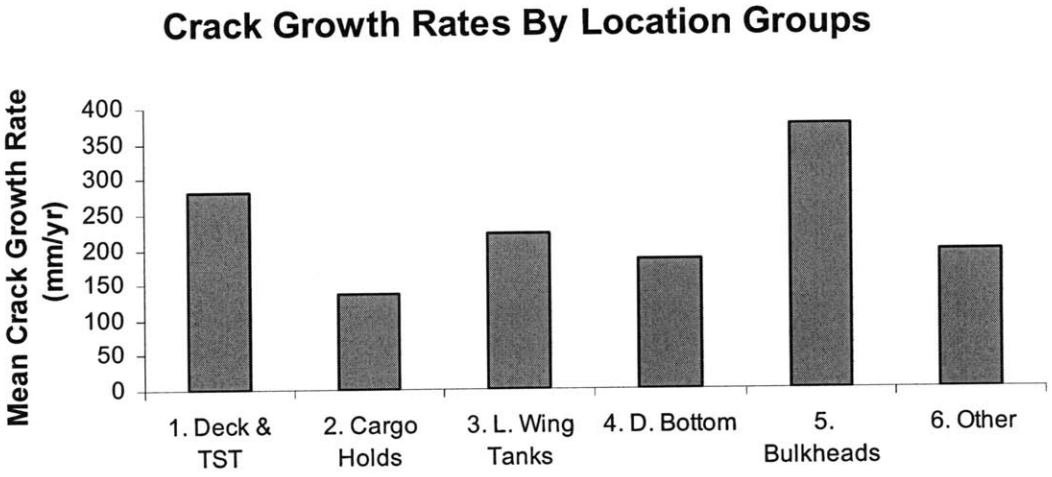


Fig. 4.3-16: Mean Crack Growth Rates per Location Group

The highest crack growth rates were found to be in the bulkheads with an average of 371mm/year. This analysis can be repeated for each age "A" in which case the values are obtained using the corresponding matrices for each age. For example, for lower wing tanks (i=10 to 13), it would be:

$$\overline{R}_{A,i=10:13} = \frac{\sum_{i=10}^{13}\sum_{j}\left[\tilde{R}_A\right]_{i,j}\left[\tilde{N}_A\right]_{i,j}}{\sum_{i=10}^{13}\sum_{j}\left[\tilde{N}_A\right]_{i,j}} \qquad (4.3\text{-}44)$$

Again, however, it is best to do it for age groups to ensure enough data points in each result. The corresponding value for ages 6 to 10 years would be obtained as shown in Eq. 4.3-45.

$$\overline{R}_{A=6:10,i=10:13} = \frac{\sum_{A=6}^{10}\sum_{i=10}^{13}\sum_{j}\left[\tilde{R}_A\right]_{i,j}\left[\tilde{N}_A\right]_{i,j}}{\sum_{A=6}^{10}\sum_{i=10}^{13}\sum_{j}\left[\tilde{N}_A\right]_{i,j}} \tag{4.3-45}$$

The plots of these results are shown in Fig 4.3-17 to 4.3-21.

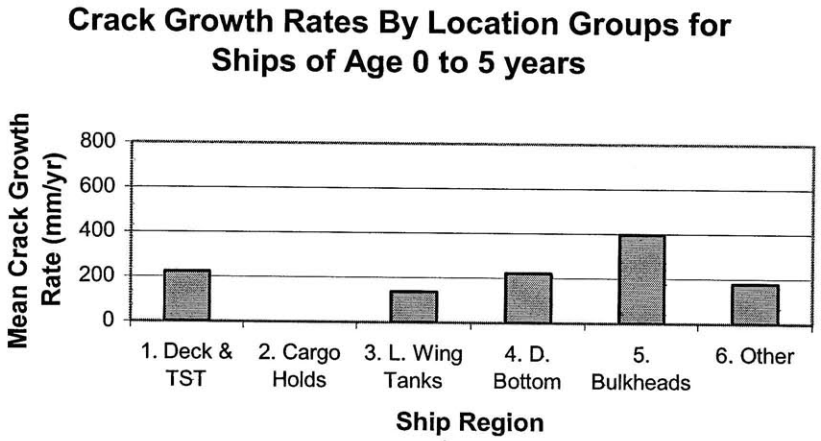


Fig. 4.3-17: Mean Crack Growth Rates by Location for Ages 0-5 years

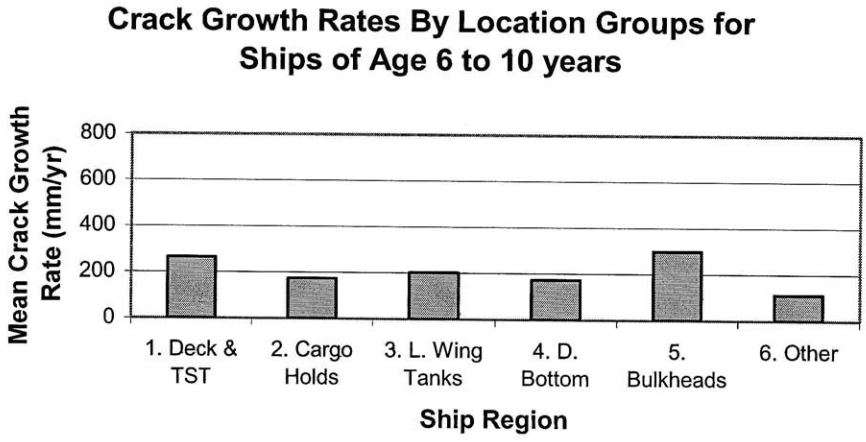


Fig. 4.3-18: Mean Crack Growth Rates by Location for Ages 6-10 years

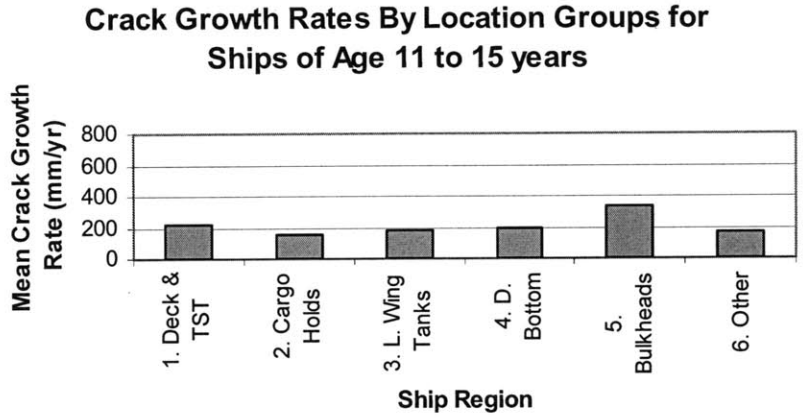


Fig. 4.3-19 Mean Crack Growth Rates by Location for Ages 11-15 years

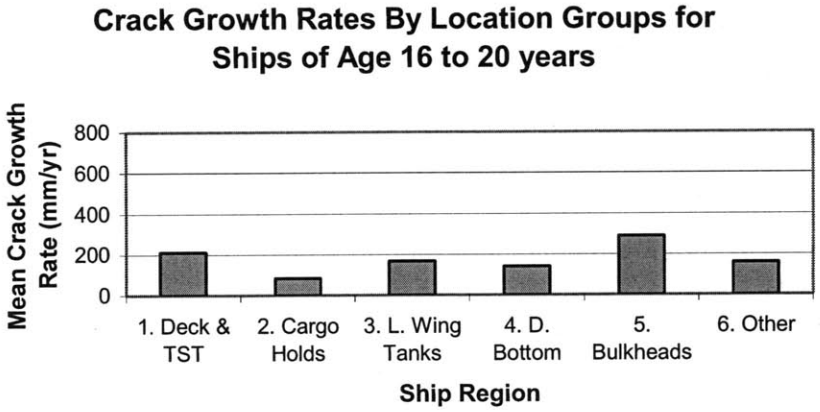


Fig. 4.3-20: Mean Crack Growth Rates by Location for Ages 16-20 years

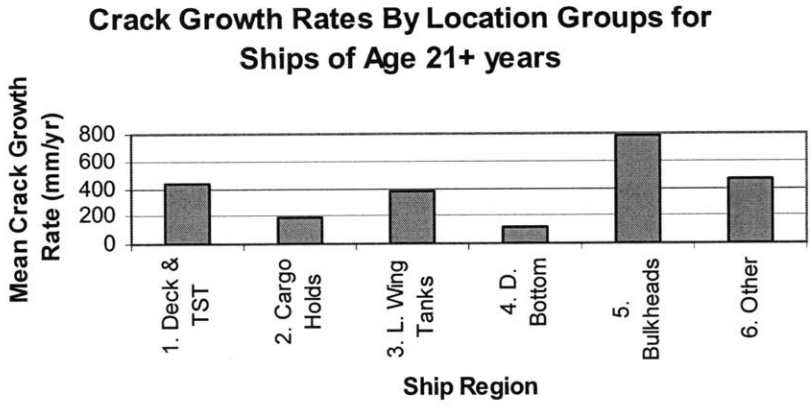


Fig. 4.3-21: Mean Crack Growth Rates by Location for Ages 21+ years

Along with the plots of crack growth rates by compartment, they can be used to estimate the size to which a crack of a given size will grow if left in service, depending on its location and the ship's age. The ranges observed were from 84mm/year, in cargo holds of ships aged 16 to 20, to 786 mm/year, in bulkheads of ships aged 21+ years.

The average crack growth rate across the whole database can also be obtained using Eq. 4.3-46

$$\overline{R} = \frac{\sum_i \sum_j \left[\tilde{R}\right]_{i,j} * \left[\tilde{N}\right]_{i,j}}{\sum_i \sum_j \left[\tilde{N}\right]_{i,j}} \qquad (4.3\text{-}46)$$

The average crack growth rate across the whole database was **233mm/year.** This is very consistent with the findings of [Antoniou 1977] around thirty years ago. By considering data from 29 tankers of ages 9 to 22 years old, which returned to the shipyard of Skaramangas consecutively for repairs, and by assuming that no cracks were left over after each repair, Prof Antoniou calculated an average crack growth rate of 250-300mm/year, but he estimates the value to be closer to 200mm/year.

4.4 Crack Safety

4.4.1 Background

Classification societies have a limited understanding of cracks. Therefore, they choose to adopt a conservative approach. In other words, they inspect frequently and rigorously, and they repair all cracks without exception to be on the safe side. Owners make their decisions on maintenance, repairing, buying, selling and scrapping after factoring in their perception of safety related to cracks, which is based solely on experience.

The fracture mechanics community has worked on the area but there are some difficulties in obtaining reliable results. The vast majority of the work has been analytical which requires many simplifying assumptions. Direct measurement based research is more reliable but it is very difficult to collect confidential data. Some of the most important work on safety implications of cracks in ships has been carried out in a joint project between PNU, ABS, and Chevron. Paris Law is used to predict fatigue crack growth and thereby the crack sizes throughout the hull [Paik et al 2003, Paik et al 2004]. The crack sizes are then used to compute the effective areas of plates contributing to the longitudinal strength of the hull girder as shown in Fig. 4.4-1.

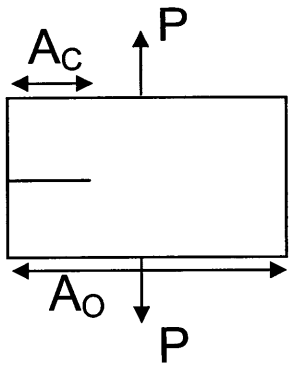


Fig. 4.4-1: Calculation of Effective Area Due to the Presence of a Crack

A longitudinal strength knockdown factor is then computed as follows:

$$R = \frac{Strength(new)}{Strength(old)} = \frac{\sigma_{ult} * (A_0 - A_c)}{\sigma_{ult} * A_0} = \frac{(A_0 - A_c)}{A_0} \qquad (4.4\text{-}1)$$

Similarly, longitudinal strength knockdown factors are computed to account for corrosion and other forms of damage before combining them all together to one knockdown factor.

There are several limitations of this approach, which we attempt to overcome in this project. First, no real data is used to examine crack growth rates. Instead, Paris Law was used which, as shown in Chapter 4.3, is extremely conservative in predicting crack sizes in capes.

Second, only the effective area of a crack plate is used, while the stress intensity at the crack tip is ignored. The strength of a cracked plate is usually significantly lower than that of a similar plate in which one of the dimensions is reduced by the length of the crack, particularly when the crack is loaded in Mode I (see Fig. 3.3-9 of Section 3.3). Furthermore, a lot of the danger is associated with the probability of fracture, which is determined by the stress intensity at the crack tip.

Thirdly, the focus is on the longitudinal strength of the ship hull while the danger of a leak is ignored. Most of the tragic losses of capesize bulk carriers begin by a leak which is followed by a domino effect and a rapid sinking. The possibility of a leak into the cargo hold that is loaded with heavy iron ore, is arguably the greatest danger when it comes to cracks in capes.

4.4.2 Method Overview

The purpose of this chapter is to develop a procedure to assess crack related safety as a function of ship age. First, a danger value is assigned to each crack depending on its location, size, growth rate, and inspection interval. Then a safety parameter is assigned on

each ship based on the cracks in its hull and their danger values. Finally, the safety parameter of each ship and its age are used to determine a safety function with respect to ship age.

4.4.3 Crack Danger Value

The danger value of each crack is associated with the likelihood of it reaching a critical size, and the consequences. Both properties are very hard to quantify, but we can assume they are a function of the current size of the crack, its growth rate, its location, and the frequency of inspection. Therefore, we start by saying:

$$D_c = f(\alpha_c, i, j, \left[\tilde{R}_A\right]_{i,j}, \left[\tilde{T}_A^I\right]_{i,j}) \qquad (4.4\text{-}2)$$

We can break down the danger value into two components. One component will be a constant "C_1" equal to the minimum danger value associated only with the location. In other words, this is the minimum danger value assigned to a crack in a specific location, irrespective to its size, growth rate and inspection interval.

The other component will be another constant "C_2" multiplied by a function that is associated with the possibility of the crack reaching a particular "critical length", and will include the remaining parameters.

The total danger value is the sum of these two components so for each crack, we have:

$$D_c = C_{1i,j} + C_{2i,j} f'(\alpha, i, j, \left[\tilde{R}_A\right]_{i,j}, \left[\tilde{T}_A^I\right]_{i,j}) \qquad (4.4\text{-}3)$$

The two constants "C_1" and "C_2" are the *Criticality Parameters,* which depend only on the location. "C_1" depends on how critical it is for a crack of any size to be present in that

location, while "C_2" depends on how dangerous it is for a crack in that location to reach a critical length.

Three 2-D matrices have to be created with inputs for every location "i" and compartment "j"; one for critical crack lengths "a^c" and two for criticality parameters "C_1" and "C_2". These three parameters are assumed not to vary with age, so only one matrix is created for each parameter to cover all ages.

Critical crack lengths "a^c" have to be defined for each location. Since brittle fracture is very unlikely, owing to the improvements in materials and crack-arrest design since WW2, and due to the lack of data regarding brittle fracture crack lengths, the value chosen for the critical length is not the critical crack length for fast fracture.

As in [Paik et al 2004], it is common to take the length of the component as the critical length. That is relevant because, the crack often starts at the one end of the component and results in leaking (from the sea or ballast tanks) when the crack reaches the other end. This definition of critical crack length is not to say that all ship components are designed using the "leak before break" concept. However, a great effort is made in design to ensure that this applies throughout the ship during normal operating conditions. If data becomes available on the brittle fracture lengths, and if these lengths happen to be smaller than the corresponding values currently used, for example in cold water applications, then the critical crack lengths can simply be adjusted. Alternatively, a more detailed model to incorporate both values can be used. An alternative model that allows for this, was also developed, and is discussed in Section 4.4.7.

Some adjustments have to be made for components that are very large, and in which fast fracture would occur before the crack reaches the end. In bulkheads, for example, the critical crack length is set to the length of each corrugation side. In cases where cracks are very dangerous, such as the side shell, the critical crack length is simply set to zero in order to maximize the danger value. After these adjustments are made, the 2-D Matrix $\tilde{a}^c$ is created using average cape dimensions. The matrix elements $\left[\tilde{a}^c\right]_{i,j}$ give the critical crack length of location "i" and compartment "j".

The criticality parameters for each location are determined based on the experience of surveyors of major classification societies and of superintendent engineers and naval

architects. In cases where opinions varied, average values are used. Judgment is also used based on past known accidents and on the description of cracks in the database. This was only done for locations "i" amidships before adjusting values for the other compartments "j".

We want the crack danger value to range between 0 and 1. The function multiplied by "C_2" will also be designed to range from 0 and 1. Therefore, the criticality parameters range from 0 to 0.5. Table 4.4-1 shows the critical crack lengths "a^c", and criticality parameters "C_1" and "C_2" for each location "i" amidships (j=5&6).

Maximum criticality values are set for locations where cracks are very dangerous, such as i=17 (3D in Fig. 4.4-2). Lowest values are assigned to cracks which do not pose a big threat, such as those in i=26, which are usually on pipes.

The usual direction of propagation is also considered. High values are used for i=4 and i=6, in which cracks usually grow transversely towards the shell. Low values are used in i=1, which usually corresponds to longitudinal cracks on the deck.

Another factor considered is that cracks in some locations, such as i = 14, 23 and 3 (1C in Fig. 4.4-2), are followed by a leak and become very visible. They are identified and repaired quickly by the crew, so the criticality values are adjusted downwards. Locations that are less frequently inspected by the crew, such as i=10, are adjusted upwards.

Finally, in some cases, one criticality parameter may be high and one low. An example is location i=7 (2A in Fig. 4.4-2). The presence of a crack there is not very dangerous, since it is very visible and does not propagate fast. If it reaches the side shell, however, it becomes very dangerous. A few of these examples are shown in Fig. 4.4-2.
Having the base values amidships, the next task is to adjust them to each compartment "j" along the ship. An array of adjustment factors for each compartment first has to be created. We start by assuming a shape similar to that of the wave induced bending moment. That is high amidships and gradually reducing towards the stern and bow.

One may argue that these results in double counting because the effect of the wave induced bending moment is already captured in the crack growth rates which are included in the function multiplied by "C_2". However, failure from a crack is likely to occur under a big rogue wave or under a storm. The resulting stress to which a crack will be subjected in such an incident is also directly proportional to the wave induced bending moment.

Base Criticality Values by Location Amidships				
"i"	Letter Code	$a^{c}_{i,j=5,6}$ (mm)	$C_{1\ I,j=5,6}$	$C_{2\ i,j=5,6}$
1	1A	1,500	0.2	0.2
2	1B	350	0.3	0.4
3	1C	350	0.1	0.1
4	1D	300	0.3	0.4
5	1E	200	0.3	0.2
6	1F	300	0.4	0.4
7	2A	1,700	0.2	0.4
8	2B	600	0.5	0.4
9	2C	1,700	0.3	0.4
10	3A	1,800	0.3	0.3
11	3B	400	0.4	0.5
12	3C	400	0.2	0.2
13	3D	800	0.5	0.5
14	4A	700	0.2	0.3
15	4B	800	0.2	0.3
16	4C	400	0.4	0.4
17	4D	800	0.5	0.5
18	5A	1,000	0.3	0.4
19	5B	1,000	0.3	0.4
20	5C	1,000	0.2	0.4
21	5D	1,000	0.4	0.5
22	5E	1,000	0.2	0.2
23	5F	100	0.4	0.5
24	6A	2,500	0.2	0.3
25	6B	2,000	0.2	0.3
26	6C	400	0.1	0.1

Table 4.4-1: Critical Crack lengths and Criticality Parameters for j = 5 and 6

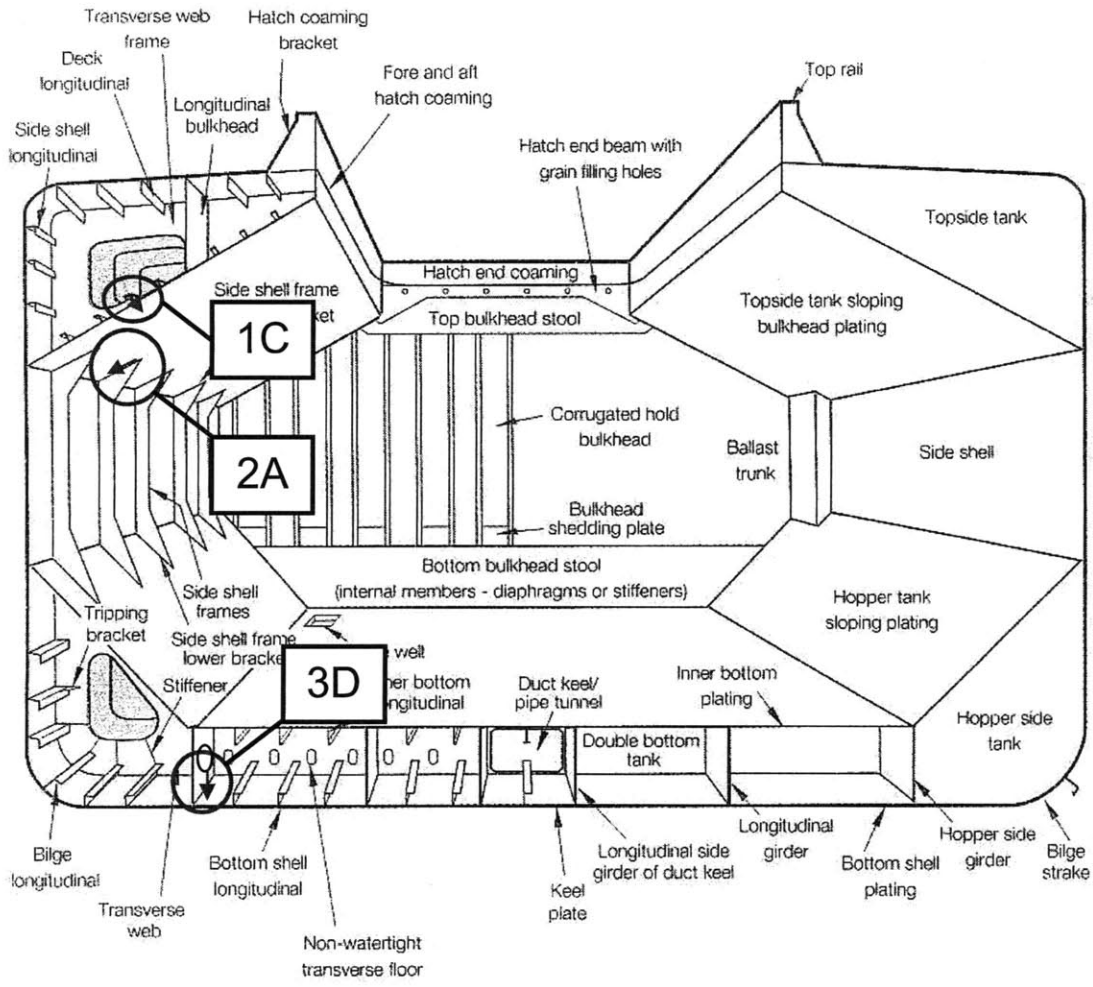


Fig. 4.4-2: Typical direction of crack propagation for some cracks

Therefore, we start with a multiplying factor that ranges linearly from 0.5 at the stern (j=1) and bow (j=11) to 1 amidships (j=5 and j=6). Some simple adjustments are then made to these values. Based on previous accidents and discontinuities in the hull (e.g. at the accommodation), the value at j=2 is set to 1, and the value at the bow (j=11) is adjusted up to 0.8. Since the adjustment factor is used for both criticality parameters, it automatically results in a scaling of the crack danger value relative to amidships. The resulting array $\tilde{F}$ of adjustment factors $\left[\tilde{F}\right]_j$ is:

$$\tilde{F}_j = \{0.5, 1.0, 0.7, 0.8, 1.0, 1.0, 0.9, 0.8, 0.7, 0.6, 0.8\} \qquad (4.4\text{-}4)$$

The arrays $C_{1i,j=5,6}$ and $C_{2i,j=5,6}$, from Table 4.4-1 are combined with array $\tilde{F}$ in Eq. 4.4-4, to produce 2-D Matrices $\tilde{C}_1$ and $\tilde{C}_2$ with elements $\left[\tilde{C}_1\right]_{i,j}$ and $\left[\tilde{C}_2\right]_{i,j}$ respectively, denoting the criticality parameters of locations "i" in compartments "j". These elements are given by:

$$\left[\tilde{C}_1\right]_{i,j} = C_{1_{i,j=5,6}}\left[\tilde{F}\right]_j \qquad (4.4\text{-}5)$$

$$\left[\tilde{C}_2\right]_{i,j} = C_{2_{i,j=5,6}}\left[\tilde{F}\right]_j \qquad (4.4\text{-}6)$$

In Section 4.3, we developed the matrices with elements $\left[\tilde{R}_A\right]_{i,j}$ and $\left[\tilde{T}_A^I\right]_{i,j}$. So far in this chapter, we have developed the matrices with elements $\left[\tilde{a}^c\right]_{i,j}$, $\left[\tilde{C}_1\right]_{i,j}$ and $\left[\tilde{C}_2\right]_{i,j}$. The next step is to develop the crack danger value given by Eq. 4.4-3 in terms of these parameters.

The function by which "C_2" is multiplied, has to be in terms of the current crack length a_c, $\left[\tilde{R}_A\right]_{i,j}$, $\left[\tilde{T}_A^I\right]_{i,j}$ and $\left[\tilde{a}^c\right]_{i,j}$. As mentioned earlier, this function is associated with the likelihood of a crack reaching the critical length $\left[\tilde{a}^c\right]_{i,j}$ before the next inspection, and it has to range between 0 and 1.

We start by defining a time to failure T_c^F which can be calculated for each crack. This is simply the time that the crack needs to grow from its current length to the critical length given its location and compartment. It is estimated as follows:

$$T_c^F = \frac{\left[\tilde{a}^c\right]_{i,j} - a_c}{\left[\tilde{R}_A\right]_{i,j}} \tag{4.4-7}$$

This value is then non-dimensionalized. By subtracting from this required time, the time that a crack has until the next inspection interval (if it is not repaired), we get a time margin. If this time margin is positive, it means that there will be a chance to repair the crack at the next inspection. If it is negative, it implies that the crack is expected to reach its critical length before the next inspection. A dimensionless time margin is then developed by dividing by the inspection interval:

$$T_c^* = \left(\frac{T_c^F - \left[\tilde{T}_A^I\right]_{i,j}}{\left[\tilde{T}_A^I\right]_{i,j}} \right) \tag{4.4-8}$$

This parameter captures the likelihood of a crack reaching its critical value if it is not repaired in the current inspection. It has the following two properties:

$T_c^*<0$: The crack will reach the critical length before the next inspection
$T_c^*=1$: The crack will reach the critical length two inspections from now

The crack danger function can now be determined in terms of only three parameters; the dimensionless time margin and the two criticality parameters. After examining a wide variety of options, the following model was constructed:

$$D_c = \left[\tilde{C}_1\right]_{i,j} + \left[\tilde{C}_2\right]_{i,j} MIN\left[1, e^{(\ln 0.1)T_c^*}\right] \tag{4.4-9}$$

The easiest way to understand this model is through a diagram. Fig. 4.4-3 shows a plot of the crack danger value D_c as a function of dimensionless time margin T_c^*. Note that for a given location, compartment and ship age, T_c^* is defined only by the current crack length.

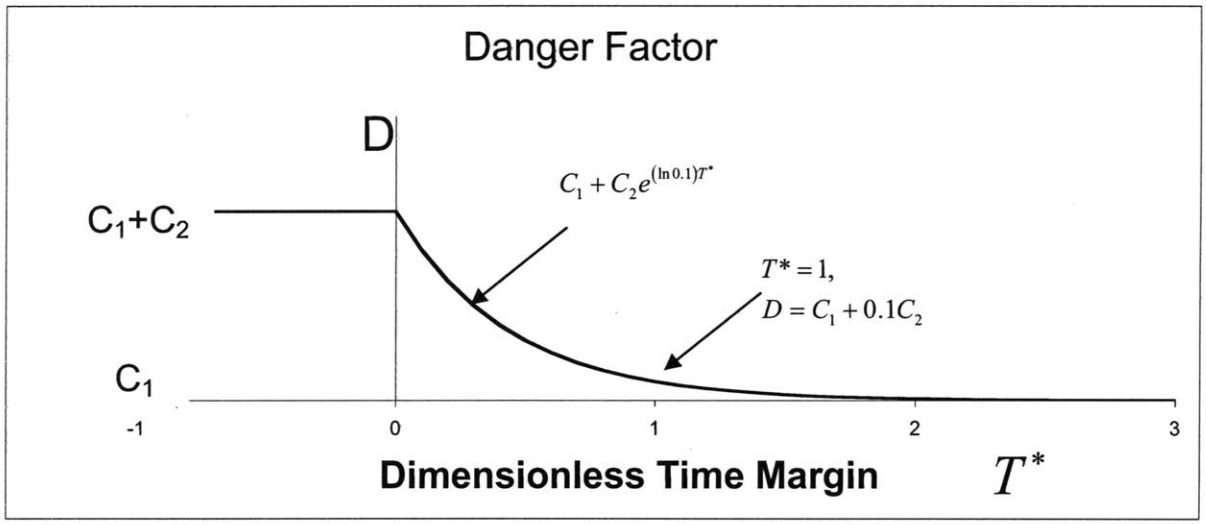


Fig. 4.4-3: D_c as a function of T*

For $T_c^* \leq 0$, the crack is expected to reach the critical length before the next inspection, so the crack danger factor takes the maximum value of $D_c = \left[\tilde{C}_1\right]_{i,j} + \left[\tilde{C}_2\right]_{i,j}$. As T_c^* decreases, the danger value decreases exponentially to its minimum value $D_c = \left[\tilde{C}_1\right]_{i,j}$.

When $T_c^* = 1$, we are at the point where even if the crack is missed in the next inspection, it will not grow to its critical length until the inspection after that. In other words, the crack will reach the critical length two inspection intervals from now. At that point, the crack danger factor is 10% along the way between the two extremes. It takes the value $D_c = \left[\tilde{C}_1\right]_{i,j} + 0.1\left[\tilde{C}_2\right]_{i,j}$.

4.4.4 Examination of Inspection Intervals

The maximum danger value of a crack in location "i" and compartment "j" is given by:

$$D_c = \left[\tilde{C}_1\right]_{i,j} + \left[\tilde{C}_2\right]_{i,j} \qquad (4.4\text{-}10)$$

From Eq. 4.4-9, we see that this happens when: $T_c^* \leq 0$

From Eq. 4.4-8 it follows that: $T_c^F \leq \left[\tilde{T}_A^I\right]_{i,j}$

Then from Eq. 4.4-7 we get: $$\left[\tilde{a}^c\right]_{i,j} - a_c \leq \left[\tilde{T}_A^I\right]_{i,j}\left[\tilde{R}_A\right]_{i,j} \qquad (4.4\text{-}11)$$

In other words, if the crack keeps growing from its current length a_c with growth rate $\left[\tilde{R}_A\right]_{i,j}$, it will reach the critical length $\left[\tilde{a}^c\right]_{i,j}$ within an inspection interval $\left[\tilde{T}_A^I\right]_{i,j}$ (before the next inspection).

There are locations for which the cracks take this maximum location irrespective of the size of the crack. One case is when the critical crack size is set to zero. This is done for the most dangerous locations such as the side shell. The other case can be determined by substituting $a_c = 0$ into Eq. 4.4-11. This gives:

$$\left[\tilde{T}_A^I\right]_{i,j} \geq \frac{\left[\tilde{a}^c\right]_{i,j}}{\left[\tilde{R}_A\right]_{i,j}} \qquad (4.4\text{-}12)$$

If this equation holds, it implies that a crack of any length is predicted to reach its critical length by the next inspection. In other words, classification societies might consider reducing the inspection interval $\left[\tilde{T}_A^I\right]_{i,j}$.

It is best, however, to consider dimensional time margins in order to get a feel of how conservative current inspection intervals are even if they are shorter than this value. So far

we have assumed that cracks start growing with rate $\left[\tilde{R}_A\right]_{i,j}$ from a size equal to the measurement resolution $\left[\tilde{a}^r\right]_{i,j}$. Therefore, the minimum time to failure in the absence of a visible crack can be evaluated. A 2-D Matrix $\tilde{T}^F_{0A}$ is thereby created for each age "A" with elements $\left[\tilde{T}^F_{0A}\right]_{i,j}$ calculated as follows:

$$\left[\tilde{T}^F_{0A}\right]_{i,j} = \frac{\left[\tilde{a}^c\right]_{i,j} - \left[\tilde{a}^r\right]_{i,j}}{\left[\tilde{R}_A\right]_{i,j}} \tag{4.4-13}$$

The resulting inspection interval time margin can then be evaluated for each location. A 2-D matrix $\tilde{T}^M_{0A}$ is created for each ship age "A" with elements $\left[\tilde{T}^M_{0A}\right]_{i,j}$ calculated as follows:

$$\left[\tilde{T}^M_{0A}\right]_{i,j} = \left[\tilde{T}^F_{0A}\right]_{i,j} - \left[\tilde{T}^I_A\right]_{i,j} = \frac{\left[\tilde{a}^c\right]_{i,j} - \left[\tilde{a}^r\right]_{i,j}}{\left[\tilde{R}_A\right]_{i,j}} - \left[\tilde{T}^I_A\right]_{i,j} \tag{4.4-14}$$

Note that current crack size does not appear anywhere in the equation. These values are irrespective of current cracks. They simply measure how conservative current inspection intervals are by comparing them to the time required for a barely unidentifiable crack to reach its critical length.

By calculating this inspection interval time margin for each location and each ship age, one can see when there is more room and when extra care during inspections is critical. Before plotting the results with respect to age, we compute average values across the six location groups (as opposed to each location "i") and across the whole ship. We also compute average values across ship ages and group them in intervals of 5 years. The results are presented in Fig. 4.4-4 and Fig. 4.4-5.

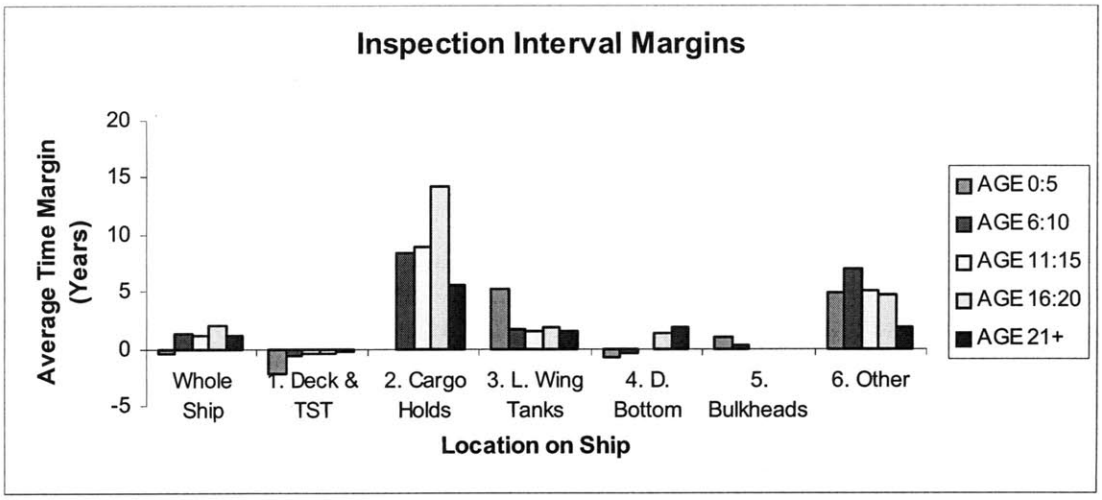


Fig. 4.4-4: Inspection Interval Time Margins for Each Age Group vs. Location

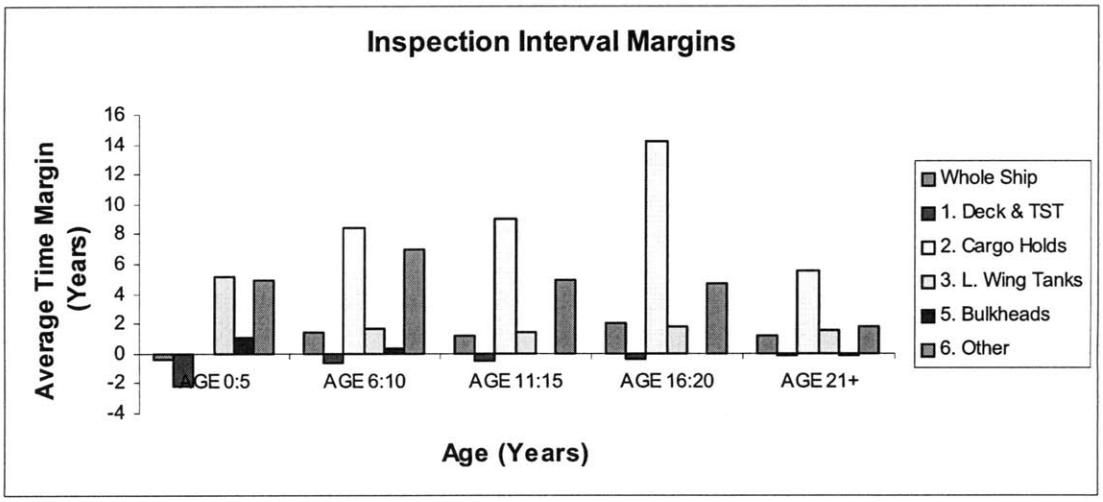


Fig. 4.4-5: Inspection Interval Time Margins for Location Group vs. Age

The points with negative average margins indicate that the inspection intervals should be reduced while the ones with high margins can afford less frequent inspections.

The results indicate that the inspection intervals of new ships should be slightly shorter. That would be expected because there is on dry dock until the age of 5 years, after which, ships are dry docked every 2.5 years. Furthermore, growth rates are relatively higher at young ages. It should be noted, however, that since the average number of cracks for young ships is much smaller, this result is not as threatening as it seems. The location which on average needs more frequent inspections is the deck and top side tanks.

4.4.5 Ship and Age Safety Parameter

Having defined the danger value for each crack using Eq. 4.4-9, we now have to assign a value to each ship based on all the cracks in its hull. Intuitively, the *ship safety parameter* S_s should depend on the number of cracks in the ship and on the Danger value D_c associated with these cracks. Furthermore, we want to design this parameter so that it ranges from 0 to 100.

Since we have a large database, it is reasonable to make this a "relative safety parameter" that it expresses safety relative to that of the rest of the ships. The following simple definition fits with the above requirements:

$$S_s = PercentRank\left\{\frac{1}{\sum_c D_c}\right\} \tag{4.4-15}$$

A value of $S_s = 85$ simply means that 85% of ships in sample have a lower value of $\frac{1}{\sum_c D_c}$, which is a measure of safety.

By choosing a percent rank we automatically satisfy the "relative" and the $0 \le S_s \le 100$ requirement. Furthermore, we ensure that the safety value does not go to infinity in the extreme event that there are no cracks.

By summing over the danger values in the hull, we ensure that it depends directly on the number and danger values of all the cracks in the hull. Finally, the reciprocal of the sum is taken to ensure that a high value means safer than a lower value. Alternatively, one minus the sum could be used. This was also examined and the results are provided later on for comparison.

Having defined a ship safety parameter S_s for each ship, the final step is to compute an average safety parameter S_A for each ship age A. That is simply done by computing the average for each ship age:

$$S_A = \frac{\sum_{S \in A} S_S}{\sum_{S \in A} 1} \tag{4.4-16}$$

The values of S_A are then plotted against "A" to examine how the mean safety varies with ship age. The result is presented in Fig. 4.4-6.

Fig. 4.4-6: Average Ship Safety as a function of Ship Age

It turns out that this function can be well represented by a third order polynomial. The data follows a clear trend with little scatter. Safety remains relatively level for the first few years until the age of about 4 years. It then gradually decreases to reach a minimum at the age of about 20 years before increasing again.

Up to the age of 20 years, the result is intuitive. Part of the reason accounting for the increase after that point is the more frequent and rigorous inspections which step up at that point, both from classification societies and from port state authorities. When a ship is over 20 years old it is usually scrutinized at every chance.

Another reason is that many low quality vessels are scrapped relatively soon. This leaves only the best designed, built and maintained vessels towards right of the graph. Therefore, the result is biased in this sense. Consequently, Fig. 4.4-6 does not necessarily show how the safety of a ship built today, will vary throughout its life. It simply shows the average safety level of existing vessels of each ship age.

A recent study of total losses between 1997 and 2006, by the International Union of Marine Insurance IUMI, found that losses, as a percentage of the existing fleet, were found to decrease with age for ships aged 25 years or older [Wang et al 2009]. Given that detentions are more frequent for older ships, [Wang et al 2009] explains this outcome by the fact that bad quality ships have been scrapped.

Scrapping bad quality ships probably has an effect, explaining part of the outcome. However, one should keep in mind that scrapping is mainly governed by the level of the market. For example, only 4 capes were scrapped in the last market boom, between Nov 2003 and Sept 2008 [Clarksons 2009a]. Surely, there was a mix of quality in the fleet throughout these years, but given the high market, ships were kept in operation. The four ships were actually scrapped between July 2005 and May 2006, precisely at the lowest part of the market during these 5 years.

Considering the last 50 years, market cycles have lasted an average of 8 years [Stopford 2009]. Given that a low market is "required" for scrapping, the removal of low quality ships does not perfectly explain the phenomenon depicted in Fig. 4.4-6 or the results of the IUMI study. Other factors include the design improvements during repairs and the more frequent and rigorous inspections, which also explain the more frequent detentions in older ships.

4.4.6 Alternative definition check

As mentioned earlier, a slight modification to the definition of the ship safety parameter would be examined. That is:

$$S_s = 1 - PercentRank\left\{\sum_i D_i\right\} \tag{4.4-17}$$

The results using that procedure are shown in Fig. 4.4-7.

Fig. 4.4-7: S_A vs. Age using the Alternative Definition of S_s

This is essentially the same result as that in Fig. 4.4-6. Therefore, the result is not sensitive to our choice in how we define the ship safety parameter.

4.4.7 Alternative ship Safety Model

Several methods were considered before designing the above model. One example is the following:

$$LDG_{Si,j} = \sum_{c \in i,j} \left\{ L_{i,j} + \left[\tilde{T}_A^I \right]_{i,j} \left[\tilde{R}_A \right]_{i,j} \left[\frac{B}{ss_{i,j}} + \frac{C}{sac_{i,j}} + \frac{D}{sce_{i,j}} \right] \right\} \qquad (4.4\text{-}18)$$

$$S'_S = PercentRank \left\{ \frac{1}{\sum_j \sum_i LDG_{Si,j}} \right\} \qquad (4.4\text{-}19)$$

Where:

$LDG_{Si,j}$: Location Danger

$L_{i,j}$: Alternative Model Location Factor (similar to the criticality parameters)

$ss_{i,j}$: Distance from crack tip to the side shell

$sac_{i,j}$: Distance required to reach critical length for fast fracture

$sce_{i,j}$: Distance from crack tip to the end of the component

B: Alternative Model dimensionless parameter

C: Alternative Model dimensionless parameter

D: Alternative Model dimensionless parameter

S' : Alternative Model Ship safety Parameter

This model essentially, begins by assigning a dimensionless danger value to each location and compartment depending on the number of cracks and a more detailed calculation of their danger contributions. The ship danger value is then calculated by summing these location dangers across the locations and compartments of each ship. The rest of the procedure is essentially the same as the previous model. The percent rank again has to

be used to ensure that the safety value does not tend to infinity in the extreme even that there are 0 cracks. The main problem with this model is that it requires values of $ss_{i,j}$, $sac_{i,j}$ and $sce_{i,j}$.

4.4.8 Danger Composition by Location vs. Age

Using the ship safety model defined by Eq. 4.4-9, 4.4-15 and 4.4-16, we can examine how the danger value is distributed on average throughout the hull for each ship age. This is valuable information when it comes to deciding which areas to inspect in time constrained inspections.

From Eq. 4.4-20 we have:

$$D_c = \left[\tilde{C}_1\right]_{i,j} + \left[\tilde{C}_2\right]_{i,j} MIN\left[1, e^{(\ln 0.1)T_c^*}\right]$$

The contribution of total danger accounted for by a location "i" is given by:

$$D_{A,i} = \frac{\sum_j D_{c\in A,i,j}}{\sum_i \sum_j D_{c\in A,i,j}} \qquad (4.4\text{-}20)$$

The danger contribution for groups can be determined as shown in the following example. For lower location group 3 (Lower Wing Ballast Tanks) which includes locations "i" from 10 to 13, the danger contribution is calculated by:

$$D_{A,i=10:13} = \frac{\sum_{i=10}^{13}\sum_{j} D_{c\in A,i,j}}{\sum_{i}\sum_{j} D_{c\in A,i,j}} \qquad (4.4\text{-}21)$$

This is more meaningful not only in terms of presenting the data but also because a surveyor makes a decision of whether or not to inspect a location group, such as the lower wing ballast tanks as opposed to deciding on each specific location.

After doing this for all location groups, we can plot them against age "A" to allow for comparisons. The result is shown in Fig. 4.4-8.

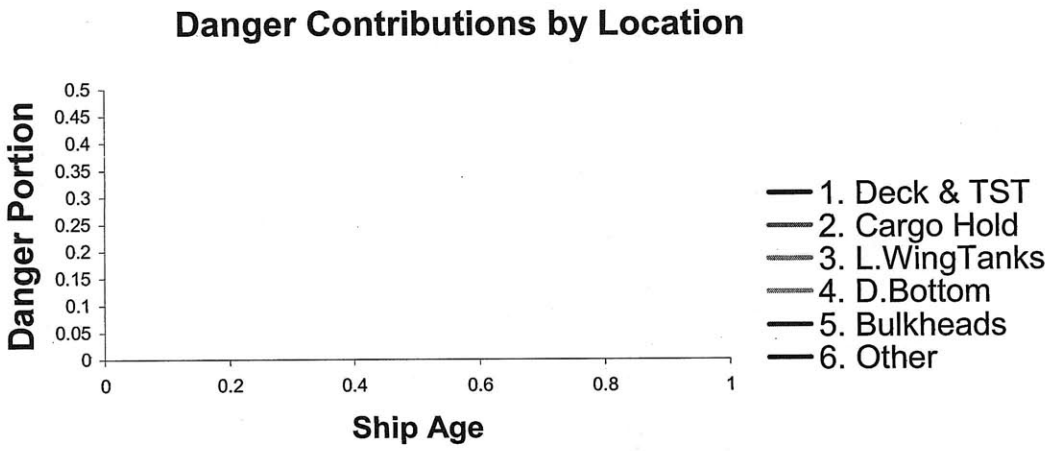


Fig. 4.4-8: Location Danger Contributions vs. Ship Age

We see that the highest danger contribution is accounted for by the deck and top side ballast tanks (location group 1). The danger contribution accounted for by this location is almost half for new ships and decreases steadily to about a third for older ships. The cargo hold region on the other hand is relatively safe in new ships and accounts for an increasing portion of the total danger as the ship gets older.

We can also examine the danger contribution of each compartment "j" along the ship length. For an average across all ship ages, the calculation is as follows:

$$D_j = \frac{\sum_j D_{c\in i,j}}{\sum_i \sum_j D_{c\in i,j}} \tag{4.4-22}$$

A plot of this against ship compartment "j" is shown in Fig. 4.4-9.

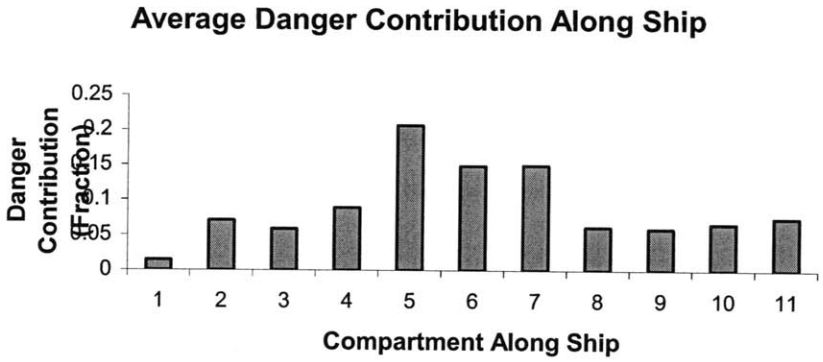


Fig. 4.4-9: Average Compartment Danger Contributions

The ballast tank compartment (j=5) accounts for more danger than all others on average. The mid ship region including j=5 to 7 contributes about 50% to the total danger value.

Variations with respect to age can also be examined by repeating the same plot for ships within each age group. For age between 6 and 10 for example, the calculation would be as follows:

$$D_{A=6:10,j} = \frac{\sum_{A=6}^{10} \sum_j D_{c\in A,i,j}}{\sum_{A=6}^{10} \sum_i \sum_j D_{c\in A,i,j}} \tag{4.4-23}$$

The results for each age group are presented in Fig. 4.4-10 to 4.4-14.

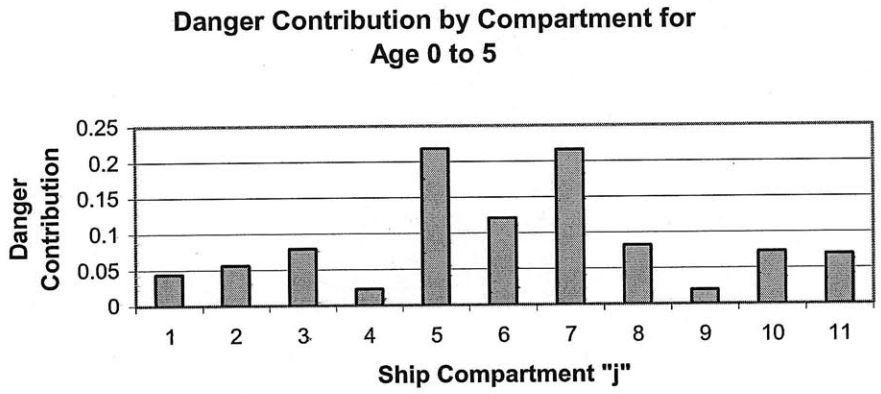


Fig. 4.4-10: Average Compartment Danger Contributions for Ship Age 0 to 5 Years

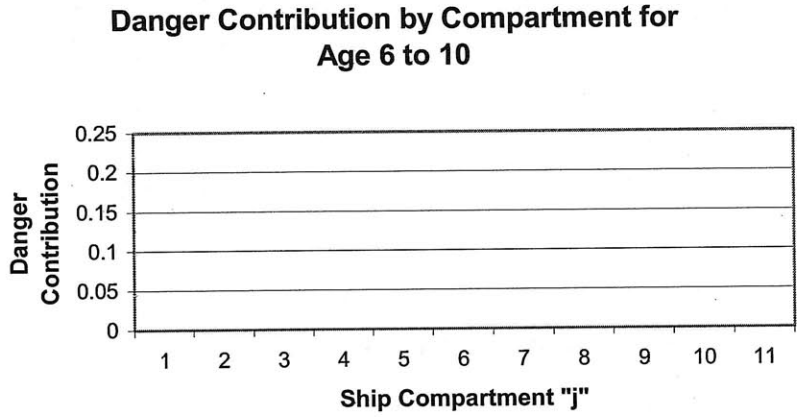


Fig. 4.4-11: Average Compartment Danger Contributions for Ship Age 6 to 10 Years

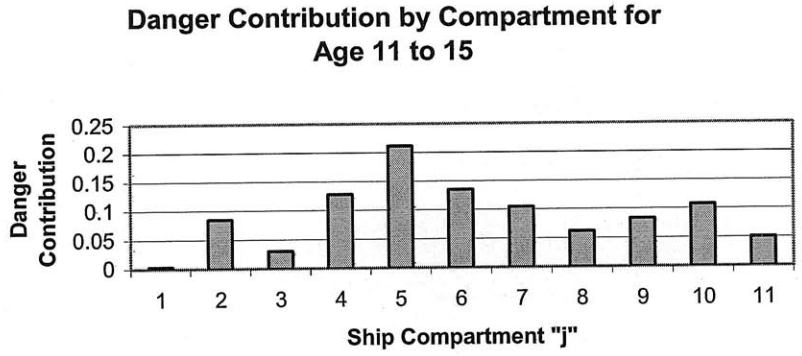


Fig. 4.4-12: Average Compartment Danger Contributions for Ship Age 11 to 15 Years

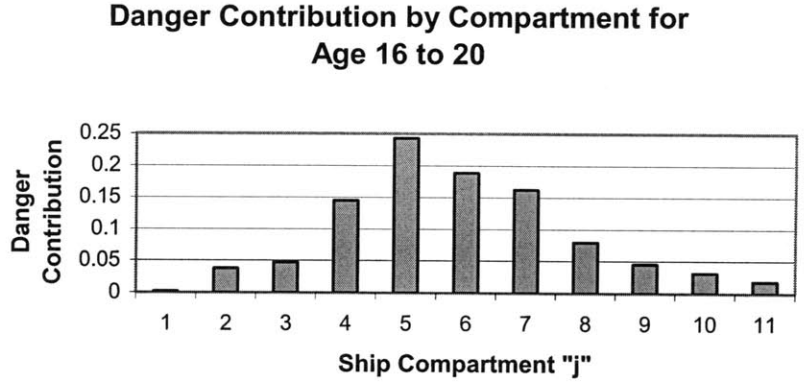


Fig. 4.4-13: Average Compartment Danger Contributions for Ship Age 16 to 20 Years

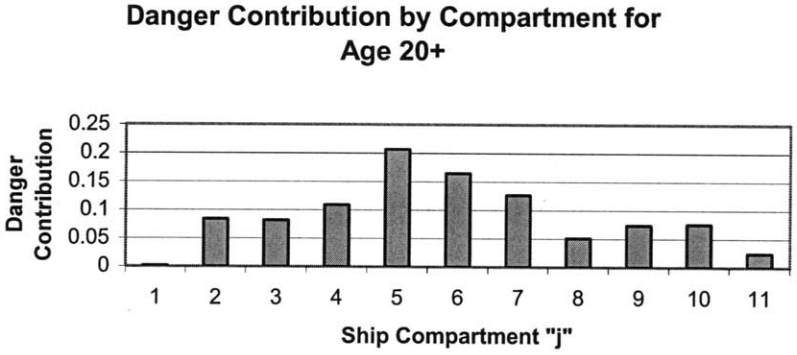


Fig. 4.4-14: Average Compartment Danger Contributions for Ship Age 21+ Years

No significant variations are observed with respect to age. Most of the danger is associated with the compartments at the middle of the ship irrespective of age. One exception is the fore peak for ages 6 to 10, though this could be because of limited data. One factor contributing to this result is the scaling of the criticality parameters across compartments using the array $\tilde{F}$.

Under classification rules, surveyors are often required to inspect some specific compartments and are required to inspect a further one or two more of their choice. These results can be factored into that decision depending on the ship's age.

4.5 Reliability Assessment

4.5.1 Introduction

Chapter 3.11, describes the calculation of a danger value for each ship D_s based on the distribution of cracks in its hull right before a repair. This chapter will describe the procedure for estimating the expected probability of failure for a ship at any point in time based on the D_s value of the ships in the database plus some additional data. Failure in this context refers to sinking of a ship or the need for an emergency (unscheduled) repairs due to the presence of cracks in the hull.

4.5.2 Background on Risk Assessment using Duration Models

4.5.2.1 Basics of Reliability Analysis

The duration variable is the time to failure and can be described by its probability density function f(t) and cumulative distribution function F(t) which are related as follows:

$$F(t) = \int_0^t f(\tau) d\tau \qquad (4.5\text{-}1)$$

Three additional functions are introduced in duration analysis:

1. Survivor Function S(t): Probability that failure will occur after time t

2. Hazard Function λ(t): Probability that failure will occur very shortly after time t given that failure has not yet occurred at time t
3. Expected Residual Lifetime Function r(t): Expected remaining time to failure assuming failure has not yet occurred at time t

The survivor function is defined as follows: $S(t) = P(T_f \geq t) = 1 - F(t)$ (4.5-2)

Combining Eq. (4.5-1) and (4.5-2) yields: $\frac{\partial S(t)}{\partial t} = -f(t)$ (4.5-3)

The hazard function is defined as: $\lambda(t) = \lim_{dt \to 0} \frac{1}{dt} P(T_f \leq t + dt \mid T_f \geq t)$ (4.5-4)

By the definition of conditional probability it follows that:

$$\lambda(t) = \lim_{dt \to 0} \frac{1}{dt} \frac{P(T_f \leq t + dt)}{P(T_f \geq t)} = \lim_{dt \to 0} \frac{1}{dt} \frac{S(t) - S(t + dt)}{S(t)} = -\frac{1}{S(t)} \frac{dS(t)}{dt} \quad (4.5\text{-}5)$$

Combining (4.5-3) and (4.5-5) yields the identity: $\lambda(t) = \frac{f(t)}{S(t)}$ (4.5-6)

Following from (4.5-5): $\lambda(t) = -\frac{1}{S(t)} \frac{dS(t)}{dt} = -\frac{d}{dt} \ln S(t)$ (4.5-7)

Integrating (4.5-7) and solving for the survivor function we get:

$$\int_0^t \lambda(\tau) d\tau = -\int_0^t d \ln S(\tau) = -\ln\left(\frac{S(t)}{S(0)}\right)$$

$$S(t) = S(0) e^{-\int_0^t \lambda(\tau) d\tau} \quad (4.5\text{-}8)$$

Finally, setting S(0)=1 yields: $$S(t) = e^{-\int_0^t \lambda(\tau)d\tau} \quad (4.5\text{-}9)$$

4.5.2.2 Duration Dependence and Duration Models

An important property is the positive or negative duration dependence which is determined by the form of the hazard function.. This describes the relationship between the instantaneous probability of failure and the elapsed time.

A positive duration dependence means that the hazard function increases with time meaning that the older a component is, the more likely it is to fail. An example falling under this category would be cars and other machines that break down due to ageing. A negative duration on the other hand is described by a decreasing hazard function implying that reliability increases with age which is very common for electronic equipment. Another possibility is the absence of duration dependence meaning that the probability of failure is independent of elapsed time.

One of the simplest duration models is the exponential distribution model which has no duration dependence: $\lambda(t) = \lambda$, $S(t) = e^{-\lambda t}$ and $r(t) = \frac{1}{\lambda}$. Other examples include the Gamma distribution, the Weibull distribution, the bathtub curve distribution and the Log-Normal Distribution [Gourieroux & Jasiax 2007].

The analysis of cracks in capes showed that average crack growth rates slow down during the early years due to design modifications which eliminate stress concentrations, and then accelerate after a certain age due to the effect of corrosion. Absent of repairs and based solely on crack growth rates, the bathtub curve duration model may have been appropriate as it would account for a decreasing hazard function during the early life and an increasing hazard function during the later stages.

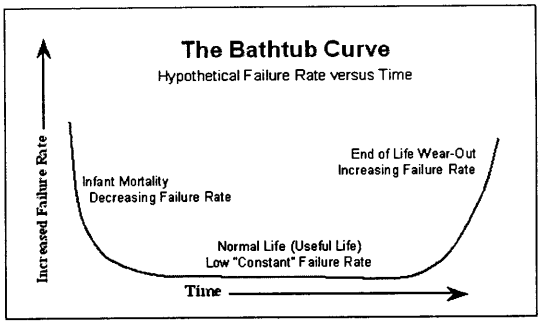


Fig. 4.5-1: Bathtub Reliability Curve [Wilkins, 2002]

However, if we exclude the repairs, the hazard function at any point in time should theoretically depend on the frequency, size and criticality of the cracks in the hull and should, therefore, always be increasing. Consequently, the Weibull duration model is more appropriate because it is a flexible life distribution model, allowing for the slope of the hazard function to be controlled through its parameters. The Weibull CDF is:

$$F(t) = 1 - e^{-at^b} \tag{4.5-10}$$

4.5.3 Developing a New Customized "Ship Reliability Duration Model"

4.5.3.1 Basis

Scheduled repairs throughout the ship's life eliminate the great majority of cracks in the inspected areas and represent big, sudden one-time decreases in the hazard function. The duration at any point in time between any two repairs should be positive implying an increasing hazard function which reaches a peak value just before the next inspection. This can be simulated by a series of Weibull duration models. Starting from the Weibull CDF. given by 4.5-10, we can derive the survivor and hazard functions

C.D.F. (Eq. 4.5-10): $$F(t) = 1 - e^{-at^b}$$

=> Survivor Function (Eq. 4.5-2): $$S(t) = 1 - F(t) = e^{-at^b} \quad (4.5\text{-}11)$$

=> PDF. (Eq. 4.5-3): $$f(t) = -\frac{\partial S(t)}{\partial t} = abt^{b-1}e^{-at^b} \quad (4.5\text{-}12)$$

=> Hazard Function (Eq. 4.5-6): $$\lambda(t) = \frac{f(t)}{S(t)} = abt^{b-1} \quad (4.5\text{-}13)$$

We can also use Eq. (4.5-8) to verify as follows:

$$S(t) = e^{-\int_0^t \lambda(\tau)d\tau} = e^{-\int_0^t ab\tau^{b-1}d\tau} = e^{-at^b} = 1 - F(t)$$

4.5.3.2 Modifying and Connecting the Hazard Functions

Each of the 10 repair intervals considered throughout a ship's life can be modeled by a separate distribution model. An example of a repair interval is from the intermediate inspection between the 2nd and 3rd special survey (scheduled at 12.5 years of age) until the third special survey (scheduled at 15 years of age). Then, by joining the hazard functions we get a shape that will look like Fig. 4.5-2.

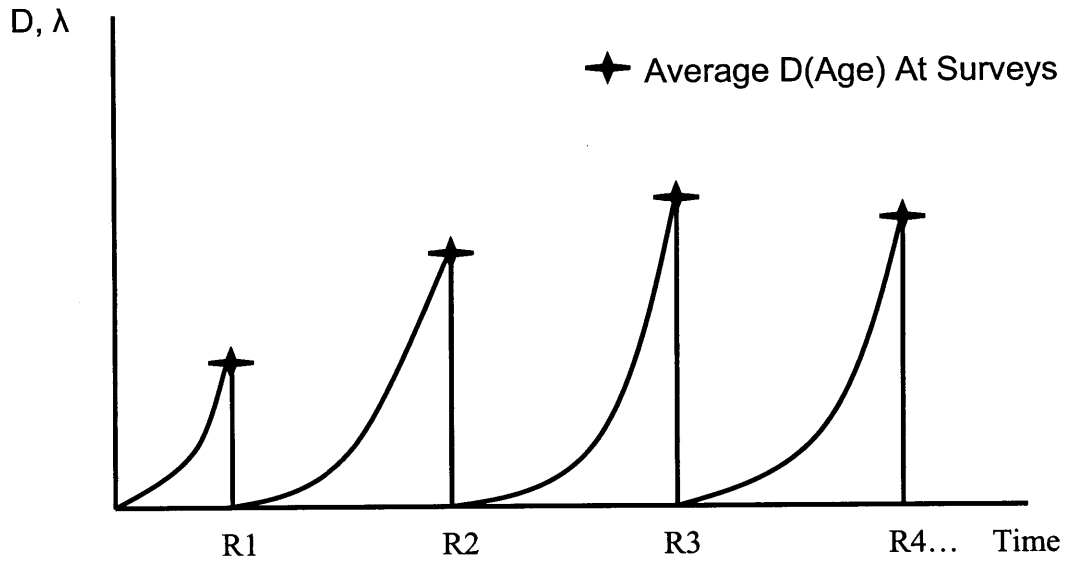


Fig. 4.5-2: Proposed Discontinuous Hazard Function For Ship's life

The hazard function reaches a peak value at the end of the repair interval and then drops at the repair. However, it is not realistic to assume it drops to 0. This is because not all areas are inspected during all repairs, and because not all cracks are found in the inspected areas. That is particularly true for cracks that are smaller than the minimum identifiable crack length as defined earlier depending on the ship's age and the location on the ship. With the exception of the first repair interval, therefore, the hazard function should start at a value greater than zero. We can call that value "c" and modify the hazard function of each repair interval "R" as follows:

$$\lambda_R(t_R) = c_R + a_R b_R t_R^{\,b_R - 1} \tag{4.5-14}$$

"t_R" is the time vector t, measured in months, for the corresponding repair interval "R" and starts at zero at the beginning of the repair interval. The survivor function for that repair interval is equal to 1 at $t_R = 0$. Therefore, we can use S(0) = 0 in Eq. (4.5-8) to get:

$$S_R(t_R) = S(0)e^{-\int_0^{t_R} \lambda(\tau)_R\, d\tau} = e^{-\int_0^{t_R} (c+ab\tau^{b-1})_R\, d\tau} = e^{-\left[ct+at^b\right]_R} \tag{4.5-15}$$

4.5.3.3 Determining the value of "a_R"

Let's define the cumulative probability of failure at the end of the repair interval "R" (ignoring previous repair intervals) as $P(fail)_R$. Assuming that this value is known, we can eliminate the constant "a_R" in Eq. 4.5-15. Using the survivor function at the end of the repair interval ($t_R = T_R$) from Eq. 4.5-15,

$$S_R(T_R) = e^{-\left[cT + aT^b\right]_R} = 1 - P(fail)_R \tag{4.5-16}$$

Solving for a_R:

$$a_R = -\frac{c_R T_R + \ln\left[1 - P(fail)_R\right]}{T_R^{\,b_R}} \tag{4.5-17}$$

The hazard function reduces to:

$$\lambda_R(t_R) = c_R + a_R b_R t_R^{b_R - 1} = c_R - \frac{c_R T_R + \ln\left[1 - P(fail)_R\right]}{T_R^{\,b_R}} b_R t_R^{\,b_R - 1} \tag{4.5-18}$$

4.5.3.4 Determining the value of "c_R"

The value of "c_R" is the initial value of the hazard function for the repair interval "R". It can reasonably be assumed that "c_R" is a fraction of the peak hazard value of the previous interval (just before the repair). This will be discussed later in more detail. If we denote that fraction as "f_R" we have:

$$c_R = f_R * \lambda_{R-1}(T_{R-1}) \tag{4.5-19}$$

Where "R" is the current repair interval and T_{R-1} is the time at the end of the previous repair interval. By combining with Eq. 4.5-18 we get:

$$
\begin{aligned}
c_R &= f_R * \lambda_{R-1}(T_{R-1}) \\
&= f_R \left\{ c - \frac{cT + \ln[1 - P(fail)]}{T^b} b T^{b-1} \right\}_{R-1} \\
&= f_R \left\{ c - \frac{cT + \ln[1 - P(fail)]}{T} b \right\}_{R-1} \\
&= f_R \left\{ \frac{cT(1-b) - b\ln[1 - P(fail)]}{T} \right\}_{R-1}
\end{aligned}
\tag{4.5-20}
$$

By combining Eq. 4.5-18 and 4.5-20, we get a new expression for the hazard function:

$$
\begin{aligned}
\lambda_R(t) &= f_R \left\{ \frac{cT(1-b) - b\ln[1 - P(fail)]}{T} \right\}_{R-1} - \frac{T_R f_R \left\{ \frac{cT(1-b) - b\ln[1 - P(fail)]}{T} \right\}_{R-1} + \ln[1 - P(fail)_R]}{T_R^{b_R}} b_R t_R^{b_R - 1} \\
&= c_R - A_R t_R^{b_R - 1}
\end{aligned}
\tag{4.5-21}
$$

4.5.3.5 Determining the value of "b_R"

The preferred way of determining the value of "b" is based on the cumulative probability of failure half way between the repair interval (at t = T/2). This will be discussed in more detail later. The cumulative probability of failure half way between the repair interval can be expressed as a fraction "r" of the cumulative probability of failure at the end of the repair interval:

$$P(fail)_R(T_R/2) = r_R P(fail)_R(T_R) = r_R P(fail)_R \tag{4.5-22}$$

Using Eq. 4.5-16 we also have:

$$P(fail)_R(T_R/2) = 1 - S_R(T_R/2) = 1 - e^{-\left[c\left(\frac{T}{2}\right)+a\left(\frac{T}{2}\right)^b\right]_R} \tag{4.5-23}$$

By combining Eq.4.5-22 and 4.5-23, we get:

$$c_R\left(\frac{T_R}{2}\right) + a_R\left(\frac{T_R}{2}\right)^{b_R} = -\ln\left[1 - r_R P(fail)_R\right] \tag{4.5-24}$$

Solving Eq. 4.5-24 for "b_R" and replacing "a_R" using Eq. 4.5-17:

$$b_R = \frac{\ln\left\{c_R T_R + \ln\left[1 - P(fail)_R\right]\right\} - \ln\left\{c_R\left(\frac{T_R}{2}\right) + \ln\left[1 - r_R P(fail)_R\right]\right\}}{\ln 2} \tag{4.5-25}$$

4.5.3.6 The Hazard Function

By substituting Eq. (14.5-25) into Eq. (4.5-21), we get the final expression of the hazard function for each repair interval "R":

$$\lambda_R(t) = c_R - A_R t^{b_R - 1} \tag{4.5-26}$$

where:

$$c_R = f_R \left\{ \frac{cT(1-b) - b\ln\left[1 - P(fail)\right]}{T} \right\}_{R-1} \tag{4.5-27}$$

$$b_R = \frac{\ln\left\{ \dfrac{c_R T_R + \ln\left[1 - P\left(fail\right)_R\right]}{c_R\left(\dfrac{T_R}{2}\right) + \ln\left[1 - r_R P\left(fail\right)_R\right]} \right\}}{\ln 2} \tag{4.5-28}$$

$$A_R = \frac{T_R c_R + \ln\left[1 - P(fail)_R\right]}{T_R^{\,b_R}} b_R \tag{4.5-29}$$

In the first interval, the value of f is equal to zero. Therefore, we have a simple Weibull distribution model in which:

$$S(T) = e^{-aT^b} = 1 - P(fail) \tag{4.5-30}$$

Solving for a: $a = -\dfrac{\ln\left[1 - P(fail)\right]}{T^b}$ (4.5-31)

The hazard function reduces to: $\lambda(t) = abt^{b-1} = -\dfrac{\ln\left[1 - P(fail)\right]}{T^b} bt^{b-1}$

where: $b = \dfrac{\ln\left\{ \dfrac{cT + \ln\left[1 - P\left(fail\right)\right]}{c\left(\dfrac{T}{2}\right) + \ln\left[1 - rP\left(fail\right)\right]} \right\}}{\ln 2}$ (4.5-32)

This can also be obtained by setting $f_R = 0$ in Eq. (4.5-29)

The only unknown parameters (for each repair interval) needed to construct the hazard function using Eq. (4.5-29) are:

1. The length of the repair interval: T_R
2. The CPF at the end of the interval: $P(fail)_R$
3. The percentage drop of the hazard function during the previous repair: f_R
4. b_R or the CPF half way through the repair interval as a fraction of P(fail): r_R

Section 4.5.4, which follows, will explain how the data is used to determine these parameters. We can then proceed to construct the hazard function for the whole ship life by joining all the repair intervals. This is given by a plot of $\lambda(t)$, which is calculated using Eq. 4.5-26 where t is in months and is continuous for the ship's life.

4.5.4 Using the data to Calibrate the Model

4.5.4.1 Length of the repair interval: T_R

"t" is the time vector in months for the whole life of the ship, "t_R" is the time vector within the repair interval R and "T_R" is the total time of the repair interval (e.g. 30 months). The first repair interval is 5 years and the remaining 9 are 2.5 years each. These are not always exact since there is a time window in which a repair can be carried out but the scheduled values above are used.

4.5.4.2 Cumulative probability of failure $P(fail)_R$

$P(fail)_R$ is the cumulative probability of failure at the end of the repair interval R. The data needed to approximate it consists of two parts:

1. The average danger factor at each scheduled repair D_R – from previous chapter
2. Probability of failure between two scheduled inspections P(fail) – obtained from a survey of 50 ships and their records

4.5.4.3 Average Danger factor D_R

For each ship, we know D_S, the age and the type of survey. Not all ships undergo the repairs at the exact scheduled age e.g. 7.5 years. Therefore, some grouping needs to be made and the typical age is assigned to all these ships. After this grouping, all ships are of an age that is a multiple of 2.5 (the scheduled repair interval). Having done that, an average danger value is determined for each repair (each age) and that is denoted D_R. This is the average danger value at the end of the repair interval, just before the repair.

The aim is to determine the parameters for each interval that will define the shape of the hazard function and its initial and peak value. It may be assumed that the hazard rate is proportional to the danger value D_R, but there needs to be a calibration to convert D_R into a probability of failure. In addition, an assumption has to be made in order to use the peak value to determine the probability of failure throughout the interval.

4.5.4.4 Measured Probability of Failure $P_M(Fail)_R$

Using the records of several ships over a certain amount of time, the number of ship years can be counted for each age as well as the number of failures for each ship age. Hence,

for each repair interval, we have a number of ship years of records and the number of identified failures yielding a measured probability of failure P(fail) for that repair interval:

$$P_M(fail)_R = \frac{\sum_R Failures}{\sum_R Shipyears} \tag{4.5-33}$$

4.5.4.5 Calculated Cumulative Probability of Failure $P_C(fail)_R$

A plot of D_R and P(Fail) vs. age should be similar showing that the cumulative probability of failure at the end of a repair interval was measured to be high during the repair intervals after which the calculated danger value D_R was high. By plotting D_R against P_M(Fail) and conducting a linear regression, a relationship can be deduced of the form:

$$P_M(fail)_R = dD_R + e \tag{4.5-34}$$

After determining the constants c and d, a new "calculated" probability of failure can be calculated for each repair interval by substituting the corresponding value of D_R in:

$$P_C(fail)_R = dD_R + e \tag{4.5-35}$$

The main purpose of doing this is to utilize the extensive data available in D_R to compensate for the limited amount of data available for measuring $P_M(fail)_R$ accurately for all 10 repair intervals.

4.5.4.6 Cumulative Probability of Failure $P(fail)_R$

The probability of failure ultimately used is a combination of $P_M(Fail)_R$ and $P_C(fail)_R$ for each repair interval. A weighting function w_1 (between 0 and 1) is used to give this estimate of the probability of failure within an inspection interval.

$$P(fail)_R = w_1 P_M(fail)_R + (1 - w_1) P_C(fail)_R \tag{4.5-36}$$

4.5.4.7 Initial Value of the Hazard Function c_R (or f_R)

c_R is the initial value of the hazard function at each interval "R". Only in the first interval, this takes a value of zero. The sources accounting for c_R are:

1. Not all ship areas are inspected during the repair
2. Not all cracks are found and repaired in the inspected areas

Focusing on the first source, the areas typically inspected during repairs at each ship age are known. In the safety analysis, the "danger" contribution of each area was also determined as a function of ship age. Therefore, we can obtain a value of the fraction of danger accounted by the areas which are not inspected in a given repair. In reality, we don't know the danger contribution of non-inspected areas at that specific age since typically no cracks will be reported in these locations and ages. However, we can approximate it by interpolating between ages, or by reading off the regression plots of area-danger contributions vs. age. Since we are assuming that the hazard function is related to the danger value, we can use this number as an estimate of the remaining hazard due to un-inspected areas (as a fraction of the value before the repair). This can be denoted that as f_{RU}.

$$f_{RU} = \frac{\sum_{j=UnInspAreas} D_{Rj}}{\sum_{j=AllAreas} D_{Rj}} \tag{4.5-37}$$

For example, say that the hazard function peaks at 1% at the end of the second repair interval, and that the areas which are typically not inspected at that ship age (7.5 years) account for approximately 5% of the total danger value. In that case, $f_{RU} = 0.05$ and the hazard function should drop by 0.95% at the end of the first interval (as opposed to dropping by 1% to a value of zero).

In order to account for the second source of "c_R", it is reasonable to assume that the number of cracks that go un-repaired in an inspected area are proportional to the number of cracks that are repaired. This would apply both to cracks which are of an identifiable size but go unnoticed and also to smaller cracks. Therefore, we can assume again that the remaining danger value and, consequently, the remaining hazard value is proportional to the peak value of the previous interval (just before the repair). We can call this constant of proportionality f_{RI} meaning that it is the remaining fraction of hazard in the interval "R" due to inspected areas. Its value will depend on many factors such as the type of survey, the number of surveyors, their experience, the available time, the condition and cleanliness of the ship etc. The only way to get a reasonable estimate of this is by consulting experienced surveyors and superintendents.

As we see, both sources of c_R can be expressed as a fraction of the peak hazard value of the previous interval. By combining the two fractions, therefore, we get a value that can be used to determine c_R using Eq. (4.5-19).

$$c_R = \left(f_{RU} + f_{RI}\right) * \lambda_{R-1}(T_{R-1}) = \left(\frac{\sum_{j=UnInspAreas} D_{Rj}}{\sum_{j=AllAreas} D_{Rj}} + f_{RI} \right) * \lambda_{R-1}(T_{R-1}) \tag{4.5-38}$$

4.5.4.8 "Shape Parameter" of the Hazard Function b_R (or r_R)

After all other parameters are determined, the value of b is the one which defines the shape or curvature of the hazard function. One way of determining the shape of the hazard function is to assume it has the same shape as the Danger value of an average ship of the corresponding age. Since the crack growth rate has been deduced for each crack, the danger value of a ship can be projected backwards by projecting all the cracks backwards to their earlier size and re-evaluating D at various intervals. By doing this for several ships of the same age, a set of points can be obtained. T can be divided into 5 intervals and D be evaluated at t = 0, T/5, 2T/5, 3T/5, 4T/5 and T. If T is 2.5 years which is typical, that gives a value of D for t = 0, 0.5, 1, 1.5, 2 and 2.5years. A curve can then be fit though these points of the form:

$$D_R(t_R) = c_R + a_R b_R t_R^{b_R - 1} \qquad (4.5\text{-}39)$$

The parameters "c_R" and "a_R" can be determined by forcing the curve to meet the measured danger values D at t=0 and t=T or simply by using the already calculated values from the hazard function for the corresponding repair interval. The value of "b" can then be determined using the least squares method to give the best fit through the remaining points. This has to be done for each of the 10 repair intervals in order to obtain the value of "b_R" which defines the shape.

The above method is based only on the danger values so it should be modified to also include the data of emergency repairs. In Eq. (4.5-25) "b_R" is expressed in terms of "r_R". The next step is to use the danger value and the data on emergency repairs to determine "r_R".

By considering the time of all failures relative to the previous survey, we can determine how many occurred during the first half of the repair interval as a fraction of the total. If there was a significant amount of repairs for each repair interval, this could be carried out for each repair interval. Since the number of failures is limited, we can only get a meaningful value for the total (i.e. only one value for all repair intervals). Denote that value as r_M:

$$r_{M=}\frac{\sum_{R}\sum_{t_R=0}^{t_R=T_R/2} Failures}{\sum_{R}\sum_{t_R=0}^{t_R=T_R} Failures} \tag{4.5-40}$$

We can then get another estimate using by evaluating the danger value D at t = T/2 and at t = T. This again is done by projecting the cracks backwards using the growth rates corresponding to their location and the ship's age. Denote this value as r_{DR}:

$$r_{DR=}\left(\frac{D_{t=T/2}}{D_{t=T}}\right)_R=\frac{D_{t_R=\frac{T_R}{2}}}{D_R} \tag{4.5-41}$$

Finally, we can use a weighting function w_2 to combine r_M and r_{DR} and get an estimate of "r_R" for each repair interval:

$$r_{R=}w_2 r_M+(1-w_2)r_{DR} \tag{4.5-42}$$

This value can then be substituted back to Eq. 4.5-28 to get the value of "b_R" for each repair interval R.

$$b_R=\frac{\ln\left\{c_R T_R+\ln\left[1-P(fail)_R\right]\right\}-\ln\left\{c_R\left(\frac{T_R}{2}\right)+\ln\left[1-\left(w_2 r_{DR}+\langle 1-w_2\rangle r_m\right)P(fail)_R\right]\right\}}{\ln 2} \tag{4.5-43}$$

4.5.5 The Final Ship Reliability Model

Combining everything, the final model can be summarized as follows. In terms of parameters that are directly obtained from the data, the hazard function for each repair interval "R" is given by:

$$\lambda_R(t) = c_R - A_R t^{b_R - 1} \tag{4.5-44}$$

where:

$$c_0 = 0$$

$$c_{R\neq 0} = \frac{1}{T_{R-1}}\left[\frac{\sum_{j=UnInspAreas} D_{Rj}}{\sum_{j=AllAreas} D_{Rj}} + f_{RI}\right]\left\{c_{R-1}T_{R-1}(1-b_{R-1}) - b_{R-1}\ln\left[1-\left(w_1\frac{\sum_{R-1} Failures}{\sum_{R-1} Shipyears} + (1-w_1)(dD_{R-1}+e)\right)\right]\right\}$$

$$b_R = \left[\frac{1}{\ln 2}\right]\ln\left\{\frac{c_R T_R + \ln\left[1-\left(w_1\frac{\sum_{R} Failures}{\sum_{R} Shipyears} + (1-w_1)(dD_R+e)\right)\right]}{c_R\left(\frac{T_R}{2}\right) + \ln\left[1-\left[w_2\frac{\sum_{R}\sum_{t=0}^{t=T/2} Failures}{\sum_{R}\sum_{t=0}^{t=T} Failures} + (1-w_2)\frac{D_{t_R=T_R/2}}{D_R}\right]\left(w_1\frac{\sum_{R} Failures}{\sum_{R} Shipyears} + (1-w_1)(dD_R+e)\right)\right]}\right\}$$

$$A_R = \frac{b_R}{T_R^{b_R}}\left\langle \frac{T_R}{T_{R-1}}\left(\frac{\sum_{j=UnInspAreas} D_{Rj}}{\sum_{j=AllAreas} D_{Rj}} + f_{RI}\right)\left\{c_{R-1}T_{R-1}(1-b_{R-1}) - b_{R-1}\ln\left[1-\left(w_1\frac{\sum_{R-1} Failures}{\sum_{R-1} Shipyears} + (1-w_1)(dD_{R-1}+e)\right)\right]\right\} + \ln\left[1-\left(w_1\frac{\sum_{R} Failures}{\sum_{R} Shipyears} + (1-w_1)(dD_R+e)\right)\right]\right\rangle \tag{4.5-45}$$

By connecting the hazard function of all the repair intervals R, we obtain the hazard function for the whole life of the ship.

4.5.6 Validating the Model

A more direct approach in calibrating the model would be to match the area under the curve (Cumulative Hazard Function) to the measured cumulative probability of failure for each interval and to match the peak hazard function of each interval with the Danger value at the end of the interval. That would give us two equations, enough to get constants "a" and "b" for each interval.

Using Eq. 4.5-16 and 4.5-33 we have:

$$S_R(T_R) = e^{-\left[cT+aT^b\right]_R} = 1 - P_M(fail)_R = 1 - \frac{\sum_R Failures}{\sum_R Shipyears} \tag{4.5-46}$$

Then matching the ratio of peak hazard functions to the ratio of danger values at end of intervals, we obtain:

$$\lambda_R(T_R) = \frac{D_R}{D_{R-1}}\lambda_{R-1} \tag{4.5-47}$$

Combining with 4.5-14 we get:

$$\lambda_R(T_R) = c_R + a_R b_R T_R^{\,b_R-1} = \frac{D_R}{D_{R-1}}\lambda_{R-1} \tag{4.5-48}$$

So by applying Eq. 4.5-46 and 4.5-48 and by estimating "c" using the method described above, the model parameters for each repair interval could be obtained. This is attractive because it is simpler and because we do not need to worry about the cumulative probability of failure half way through the repair interval. However, the problem is in calculating the values of the first interval. Since we have no data before that to relate to, we would have to guess an arbitrary peak hazard function of the first interval. That is why this method was not chosen. However, we can verify our results against this logic. This is simply done by checking if the predicted peak hazard functions follow the trend of danger values at the end of corresponding intervals.

4.5.7 Results

Table 4.5-1 and Fig. 4.5-3 provide a summary of the data on ship emergency repairs. 36 failures in 740 ship-years imply a failure every 20.6 years on average which is relatively high. These consisted of 34 emergency repairs and two sinkings.

FAILURE DATA SAMPLE	
Ships	82
Ship-Years	740
Failures	36
Ship-Years per Failure	20.6

Table 4.5-1: Failure Data Summary

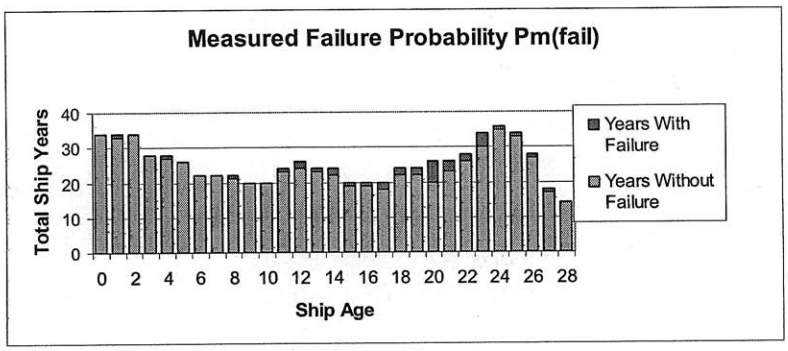


Fig. 4.5-3: Graphical Representation of Emergency Repair Data

Fig. 4.5-4 shows a plot of the measured probability of failure within each interval (in red) along with the danger value at the end of the repair interval (in blue).

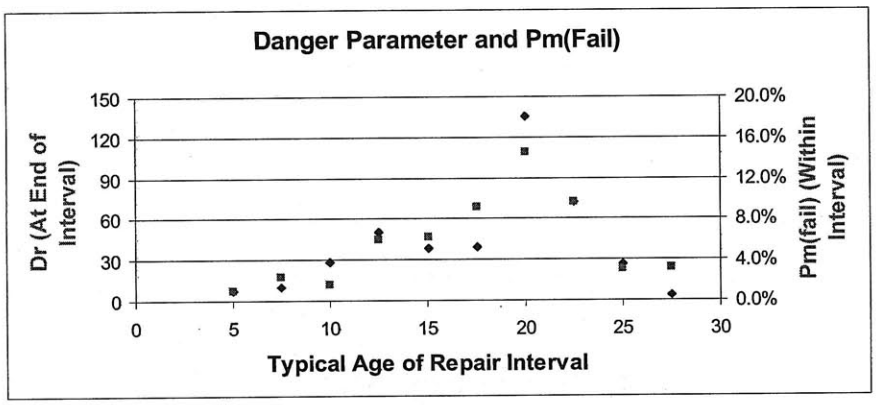


Fig. 4.5-4: Danger Parameter and Measured Probability of Failure for Each Interval

Although the scale on the two y-axes is different, this plot shows that there is a very similar trend in the two variables as one would expect. This confirms that the probability of failure is closely related to the presence and danger of cracks.

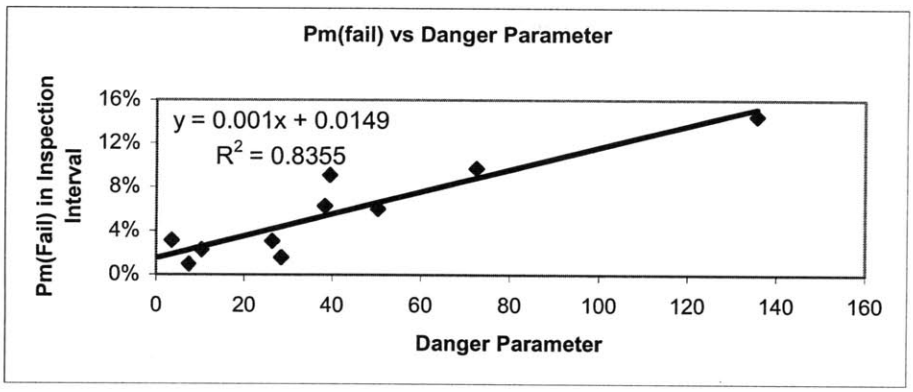


Fig. 4.5-5: Linear Regression of Measured Probability of Failure and Danger Value

The positive y-intercept of the graph shows that there is a small but non-zero probability of failure even without cracks which is logical. The R^2 value of 0.84 is high enough showing that it is reasonable to combine the two sets of data. Based on these results, weighting functions of 0.5 were used for w_1 and w_2. Tables 4.5-2 and 4.5-3 show the numerical results of the analysis using the above data that went into calibrating the model.

Repair	Age	ShipYears	%(data)	Failures	P_M(Fail)	D	%Ships	Pc(fail)	P(fail)
R1 (SS1)	0 – 6	206	28%	2	0.97%	7.44	19%	2.23%	**1.60%**
R2 (DD)	7 – 8	44	6%	1	2.27%	10.44	7%	2.53%	**2.40%**
R3 (SS2)	9 – 11	64	9%	1	1.56%	28.41	15%	4.33%	**2.95%**
R4 (DD)	12 - 13	50	7%	3	6.00%	50.26	11%	6.52%	**6.26%**
R5 (SS3)	14 - 16	64	9%	4	6.25%	38.26	11%	5.32%	**5.78%**
R6 (DD)	17 - 18	44	6%	4	9.09%	39.37	6%	5.43%	**7.26%**
R7 (SS4)	19 - 21	76	10%	11	14.47%	135.6	13%	15.05%	**14.76%**
R8 (DD)	22 - 23	62	8%	6	9.68%	72.47	10%	8.74%	**9.21%**
R9 (SS5)	24 - 26	98	13%	3	3.06%	26.39	7%	4.13%	**3.60%**
R10(DD)	27 - 28	32	4%	1	3.13%	3.47	1%	1.84%	**2.48%**

Table 4.5-2 Data Parameters and Calculation of P(fail)

	T	P(fail)	S(T)	λ(T)	r	F	C	b	A
R1	60	1.60%	98.40%	0.05%	0.26	20%	0.00%	1.95	-1.07×10^{-5}
R2	30	2.40%	97.60%	0.18%	0.24	32%	0.02%	2.56	-8.09×10^{-6}
R3	30	2.95%	97.05%	0.25%	0.23	16%	0.03%	4.5	-1.64×10^{-6}
R4	30	6.26%	93.74%	0.62%	0.22	29%	0.07%	3.83	-3.62×10^{-7}
R5	30	5.78%	94.22%	0.46%	0.27	12%	0.07%	4.5	-2.84×10^{-6}
R6	30	7.26%	92.74%	0.67%	0.20	11%	0.05%	3.10	-4.88×10^{-6}
R7	30	14.76%	85.24%	1.70%	0.15	10%	0.07%	3.50	-3.27×10^{-6}
R8	30	9.21%	90.79%	0.91%	0.27	9%	0.15%	4.49	-5.38×10^{-8}
R9	30	3.60%	96.40%	0.26%	0.33	8%	0.07%	3.89	-1.02×10^{-7}
R10	30	2.48%	97.52%	0.18%	0.26	7%	0.02%	2.40	-1.32×10^{-5}

Table 4.5-3 Model Parameters

Only 9 out of the 36 failures occurred during the first half of their corresponding repair interval which gives an r_M of 25%. This was combined with the results based on crack growth rates and danger values (r_{DR}) for each interval to give the values of R above. The average value of r_{DR} across all intervals was 23.5% which is close enough to 25%.

The only repairs in which not all areas are inspected are the first and second intermediate surveys meaning that only repairs R2 and R4 have a non-zero f_{RU}. As a ship gets older, more surveyors are practically involved in the inspection and they inspect more carefully as a ship gets older. They are also less stringent during the first two intermediate surveys. After the age of 15, intermediate and special surveys are identical with the exception of thickness gauge measurement requirements (irrelevant for our purposes). Based on these considerations and on consultations with experienced surveyors and superintendents f_{RI} values were determined as follows. The initial value of f_{RI} is 20% (for R1) and it decreases by 2% per survey until the age of 15 (R5) and then by 1% per survey until it reaches 7% for R10. After doing that, the value of the first two intermediate surveys (R2 and R4) was set to the maximum value of 20%. Finally, f_{RU} and f_{RI} were added to give the value of f.

The values of c, b and A were calculated based on the final ship reliability model (Eq. 4.5-41) and then the individual hazard functions were constructed to give the final result shown in Fig. 4.5-6. This is the hazard function for the ship's life.

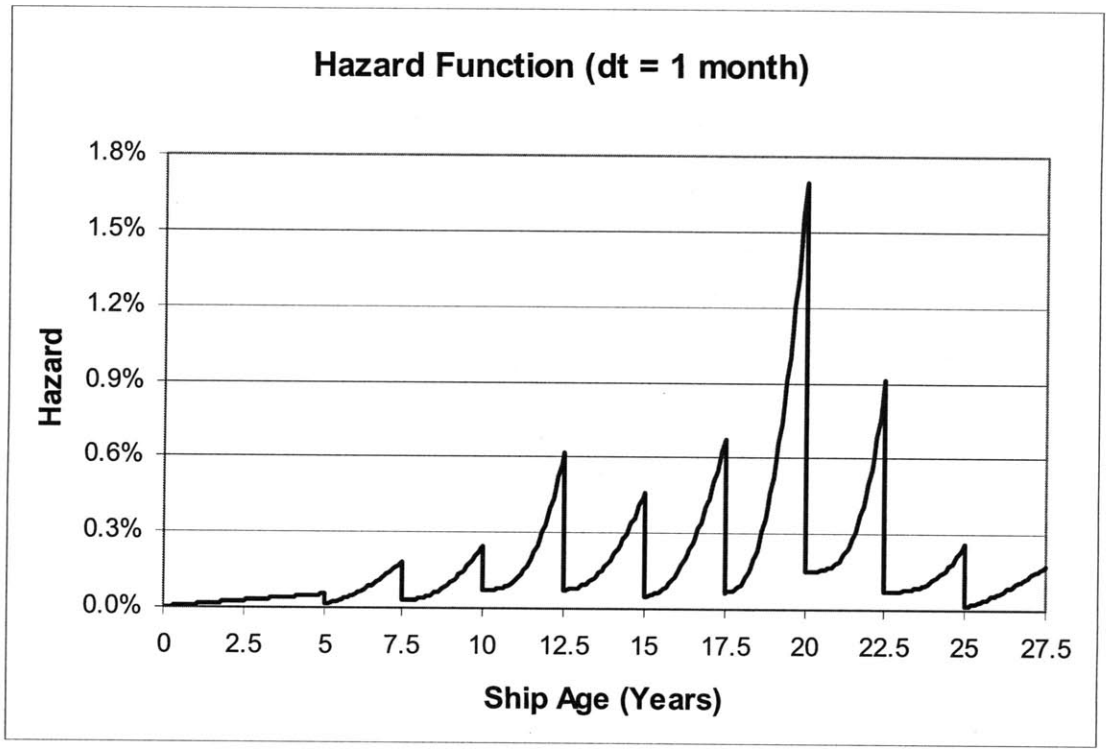


Fig. 4.5-6: Hazard Function throughout the ship's life

This shows the probability of an emergency repair for each month of a ship's life. The shape of the hazard function is reasonable and similar to what was expected based on the previous analysis. The tabulated results of this graph will be used in the financial analysis that follows.

[Bai 2006] modeled the probability of failure of a double hull tanker with respect to age, based on reliability assessment that considers the effect of corrosion, fatigue and the impact of repairs. The results are shown in Fig. 4.5-7.

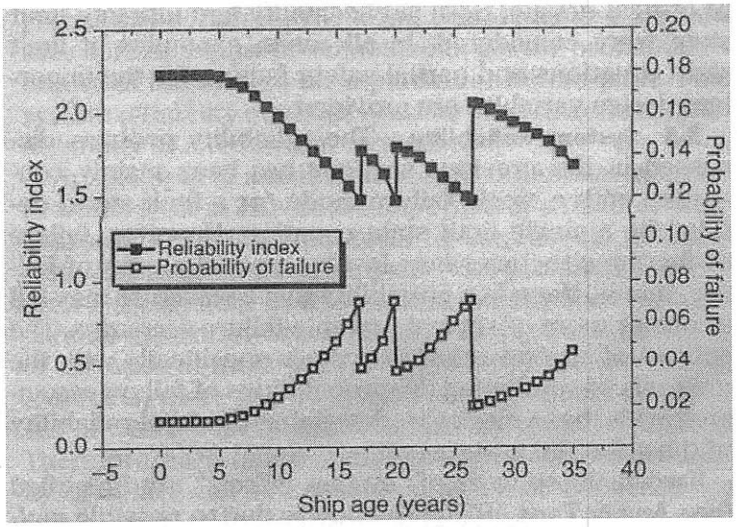


Fig. 4.5-7: Resulting Time-Dependent Reliability Index of a Double Hull Tanker Considering the Repair Scheme, Corrosion and Fatigue Cracks [Bai 2006]

The results are surprisingly similar to ours, bearing in mind that a completely different approach was used, and a different type of vessel is considered. The results of [Bai 2006] are theoretical predictions whereas our approach was data driven. The probability of failure in [Bai 2006] is annual and therefore, it is of the same order of magnitude. The trend of gradually increasing probability of failure, followed by sudden decreases to a finite value during repairs is also the same. For some reason, only three repairs are evident in the results of [Bai 2006], while two of them have a relatively small impact. Our results also agree on the fact that probability of failure is relatively low after the age of 25.

Similar analyses were also carried out by [Barltrop et al. 1992] and [Wang et al 2003b], who predict periodic peaks in the annual probability of failure due to fracture and in the hull girder strength reliability index respectively. These peaks correspond to the timing of repairs. Their results are shown in Fig. 4.5-8 and 4.5-9.

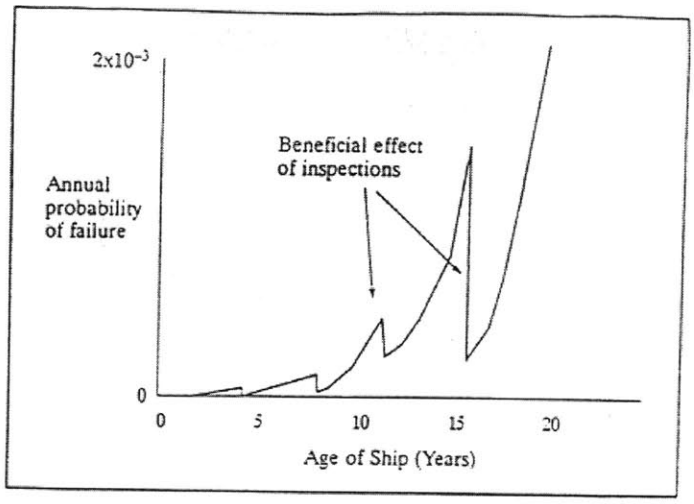


Fig. 4.5-8: Probability of failure due to fracture with time [Barltrop et al. 1992]

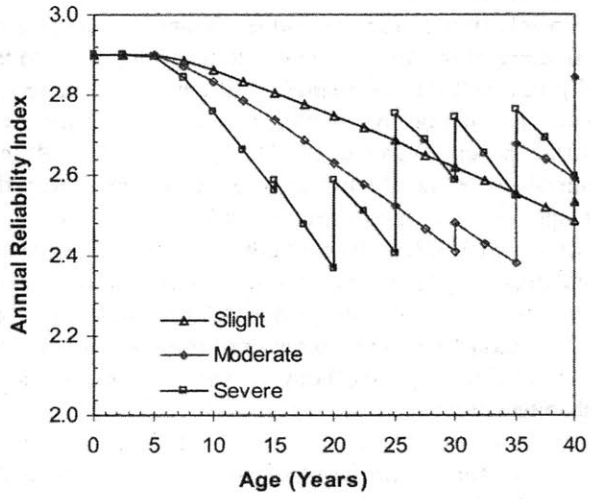


Fig. 4.5-9: Annual Reliability Index of the Hull Girder Strength of an Oil Tanker for Different Corrosion Levels [Wang et al 2003b]

Both our results and those of [Bai 2006], shown in Fig. 4.5-7, predict an annual probability of failure that is an order of magnitude higher than that predicted by [Barltrop et al. 1992]. The results of [Barltrop et al. 1992] do not extend beyond the age of 25 years, but they show the same trend as ours until that age.

Fig. 4.5-8 provides a plot of the danger value at the end of the interval and the peak hazard function (also at the end of each interval). The purpose of this graph is to validate the model as discussed under Section 4.5.6.

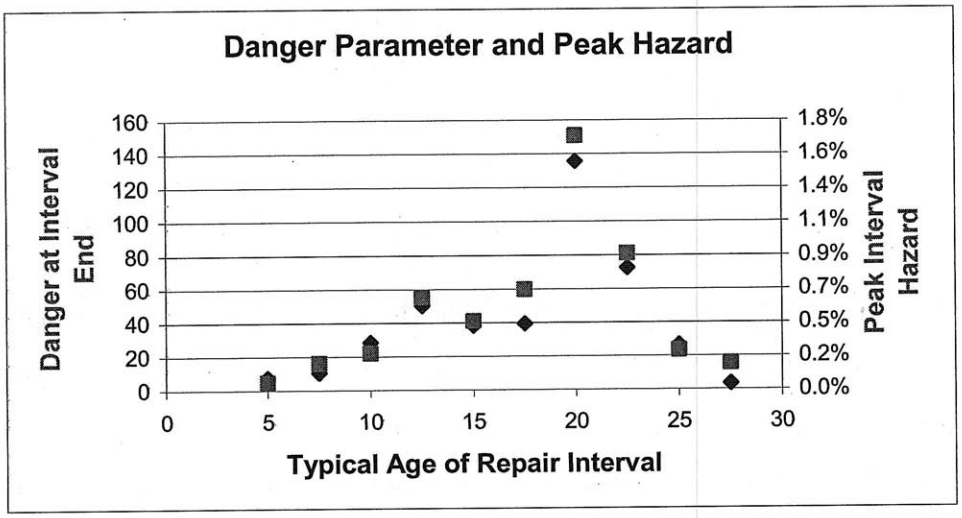


Fig. 4.5-10: Model Result Validation Plot

The scales of the axes are different but it is clear that the predicted peak hazard functions follow an almost exact pattern as the danger values at the end of the corresponding intervals obtained by analyzing the cracks in the hull.

The cumulative hazard function in Fig. 4.5-11 shows the probability of having undergone an emergency repair until the corresponding time.

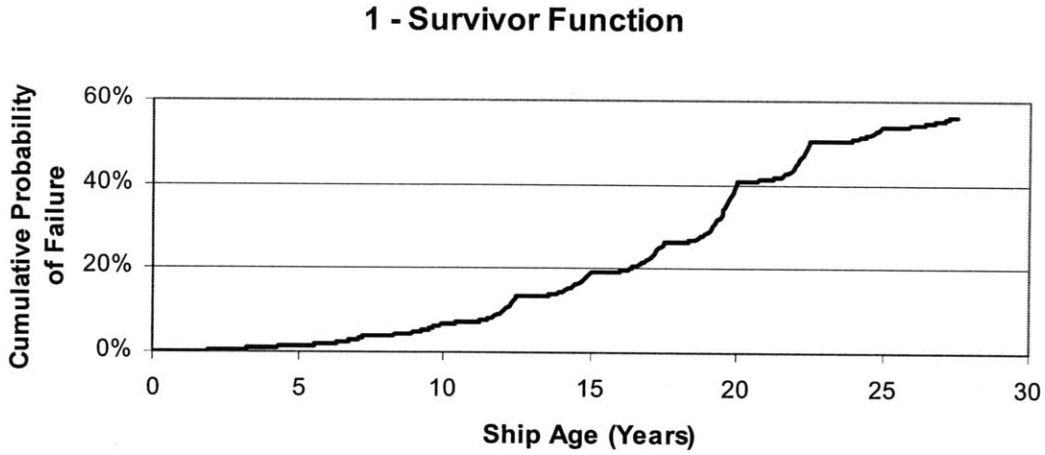


Fig. 4.5-11: Cumulative Hazard Function for ship's Life

The end value of the cumulative probability is 56.3%. This is the probability that a ship will undergo an emergency repair at some point in its lifetime.

4.6 Expected Failure Costs

4.6.1 The Various Cases and Relevant Costs

A failure as defined above has financial implications in terms of repair costs, loss of hire (loss of earning time), the possibility of a total loss, and other costs including possible delay claims. Whether an emergency repair or a total loss due to the emergence of cracks without an accident, the failure is classified under "damages under natural causes" that are not covered by the insurance. Therefore, the shipowner bears the whole cost and is not compensated for any part of it unless he/she can prove a different cause.

The costs are very different when talking about a total loss or an emergency repair. Based on the database of failures, we can assume that one out of every eighteen failures is a sinking (i.e. a "late" emergency repair). Costs can also vary dramatically between emergency repairs. In some cases, for example, it is unsafe for the ship to sail to the shipyard. It may also need to unload at sea in order to undergo the repair which takes several months. Furthermore, the repair costs are multiple times higher if you have to bring the yard equipment and workers to carry out the repair at the ship's location. Based on the repairs of the database, approximately a quarter of the emergency repairs are of this type.

Since we have an estimated probability of a failure being one of these three types, we can proceed to estimate the relevant costs of each type and calculate a weighted average. The estimates of costs that follow are based on the costs incurred during the failures in the database.

Markets are extremely volatile meaning that ship values and daily earnings change significantly on a daily basis. The purpose of this analysis is not to calculate the financial implication on a ship's value as of today but rather to get a long term estimate of the financial implication on a ship's value as a function of the ship's age. As such, historical values are used in the analysis and the financial data required has been sourced from [Clarksons 2009a].

4.6.2 Repair Costs

Repair costs include bunker costs, disbursements, port dues, pilot fees and shipyard costs. Bunker costs are calculated by assuming an average of fifteen days travel time (to and from the repair yard), an average consumption of 45t/day and bunker prices of $400/t which is close to the current price and three year average. This amounts to $270,000 of bunker costs. Yard repair costs are much higher than those of scheduled repairs because emergency repairs are usually not carried out in China (depending on where the ship is). Some adjustments had to be made to convert the cost of emergency repairs that were carried out a long time ago to present terms using today's prices and dollar values.

	Ordinary Repair	Extreme Repair	Weighted Average
Probability	75%	25%	100%
Yard & other	$600,000	$3,500,000	$1,325,000
Bunkers	$270,000	$270,000	$270,000
Total Repair Cost	$870,000	$3,770,000	**$1,595,000**

Table 4.6-4 Weighted Average Repair Costs of Emergency Repairs

The weighted average cost of an emergency repair is $1.6M. This will be multiplied by the hazard function to calculate the expected emergency repair cost per month throughout the ship's life.

4.6.3 Loss of Hire

The expected lost revenues per month throughout the ship's life due to emergency repairs are calculated as follows. Multiplying the hazard function by 34/36 (to exclude sinking) and then by the expected off-hire days of an emergency repair yields the expected

loss of revenue earning days per month. Then multiplying by the expected daily rate gives us the expected lost revenues.

The expected off-hire days are deduced using a weighted average of the two types of emergency repairs. Including the fifteen days of travel time, off-hire time amounts to sixty days for the usual type and one hundred and eighty days for the extreme type. The weighted average is, therefore, ninety days.

For this part of the analysis which aims to give an estimate of the financial implications of expected failures at any given time, we must refrain from using current market rates. Daily rates are extremely volatile as shown in Fig. 4.6-1 which refers to a ship built in 1990. Despite the ship getting older, market volatility is so high that it was earning about ten times as much as an eighteen year old ship than when it was new.

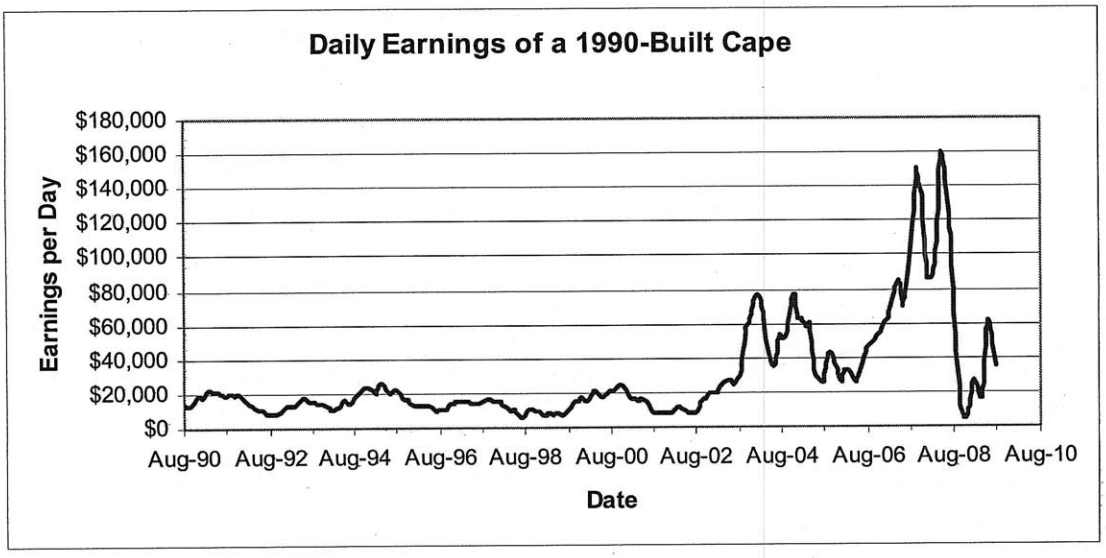


Fig. 4.6-1: Average Earnings of a Cape Built in 1990

Therefore, we use the ten year average daily earnings of a new capesize vessel. As of September 2009, that value is approximately $44,500/day.

However, we still need to account for a discount in earnings due to ship age. To do that, we consider the earnings ratio of the 1990 built ship to a 1999/2000 built ship. This is shown in Fig. 4.6-2.

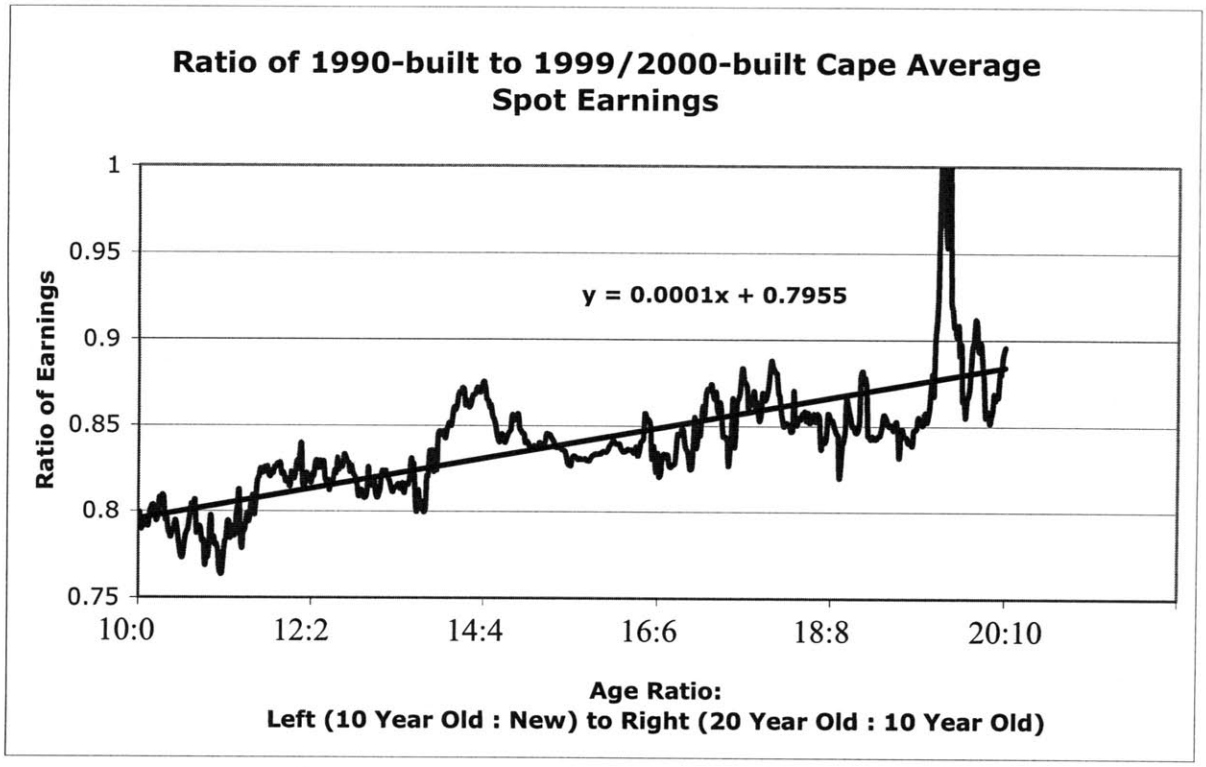


Fig. 4.6-2: Earnings Ratio of 1990 to 1999/2000 built Cape

On the far left of the graph, the 1990 built ship is about ten years old whereas the 1999/2000 built ship is new, so this corresponds to the earnings ratio of a 10-year old to a new vessel. On the far right, both ships have aged by ten years so this corresponds to the earnings ratio of a 20-year old to a 10-year old. Noting the scale of the y-axis and the volatility of the market, the linear regression fit is a fairly good representation of the results. Therefore, we can use it to determine the earnings discount due to age as follows:

Age Ratio	Earnings Ratio
10 to New (Regression Line - Left)	**0.796**
20 to 10 (Regression Line - Right)	0.880
20 to New (Implied = 0.796*0.880)	**0.700**
30 to New (Estimate)	**0.600**

Table 4.6-5 Estimated Age Discount for Daily Earnings

Using the above figures and interpolating between the values, we can deduce the appropriate discount from the new ship earnings, for each month of the ship's life. By applying the ten-year average value for daily freight rate of a new ship of $45,500 we can find the corresponding earnings throughout the ship's life.

4.6.4 Sink Cost

This only includes the value of the ship assuming total loss. Again, due to the volatility of the market, to get a long term estimate we focus on 10-year average values. The relevant values are summarized in Table 4.6-6

Quantity	10-year Average Value
New Ship Value	$67.6M
20 Years Old Ship Value	$23.9M
Scrap Price Per Ton (India)	289.65 $/ltd

Table 4.6-6 10-Year Average Values

Using the ten year average values and assuming linear depreciation, the new and twenty year old values imply a depreciation of $2.185M per year. Assuming a lightship of 22,000t for the average cape, we get a ten year average scrap value of $6.38M. By projecting the $2.185M per year depreciation beyond the twentieth year, and by using the 20-year old value and the scrap value, we can calculate the average expected scrapping age of a cape. This value turns out to be 28.009 years which is what we have been assuming so far (28 years). Therefore, we can calculate the value of a ship in the long term based on historical averages using a linear depreciation of $0.18 per month from an initial value of $67.6M.

4.6.5 Other Costs

Other costs vary depending on the type of failure. In the case of a sinking, these can include ship replacement costs (in order to carry out charter obligations), "Increased Value" as termed by insurance companies (stores, spares, bunkers and other items on board), crew compensations, cargo claims, reputation costs (particularly for listed companies) etc. Insurance companies grossly approximate "Increased Value" at about 20%-30% of the vessel value. In practice, however, these cannot vary so dramatically with ship age. The value of the cargo can be approximated using a typical price of $70/t for iron ore and assuming the ship is loaded 55.8% of the time (based on the earlier ship loading survey analysis). For emergency repairs, other costs again include reputation costs (particularly loss of business with the particular charterer), potential delay claims by cargo owners and charterers etc. The total other costs were estimated to be about $20M for a sinking and about $2M for an emergency repair. The weighted average is $3M

4.6.6 Total Financial Implications of Expected Crack Failures

The repair costs, loss of hire, sink costs and other costs can be calculated for each ship age using the above procedure and added to give an estimated cost of failure for each ship age. By multiplying this with the hazard function (probability of a failure in the given month), we get the expected cost of failures as a function of ship age. This is shown in Fig. 4.6-3.

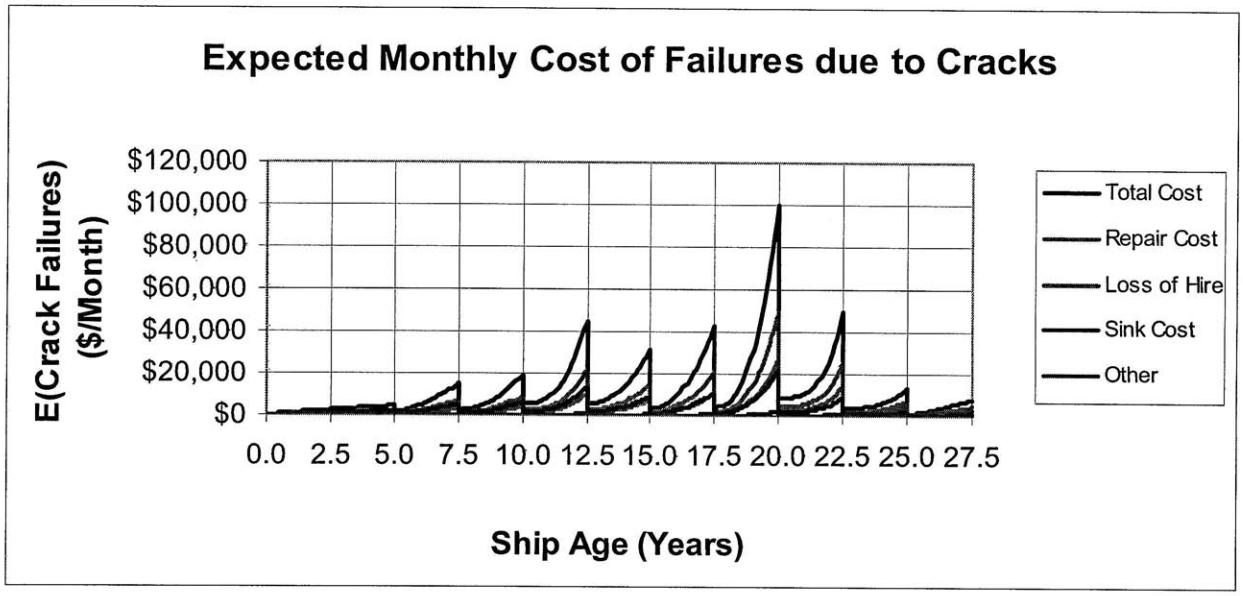


Fig. 4.6-3: Expected Costs due to Potential Crack Failures

As shown, the expected costs curve has a similar shape to that of the hazard function. The peak is at $101,057 per month when the ship is twenty years old just before carrying out its repair for the fourth special survey. This curve shows an estimation of how much a shipowner should be willing to spend if it were possible to insure against all the financial implications of a failure due to cracks for each month of the ship's life.

To calculate the impact on the ship value, we need at each point in time to consider all the future expected financial implications and discount them to the present. Since we are concerned with a long term estimate as opposed to the current market, it is relevant to use a typical discount rate of 10%. The present value of future potential failure costs until the end of the ship's life are shown as a function of ship age in Fig. 4.6-4.

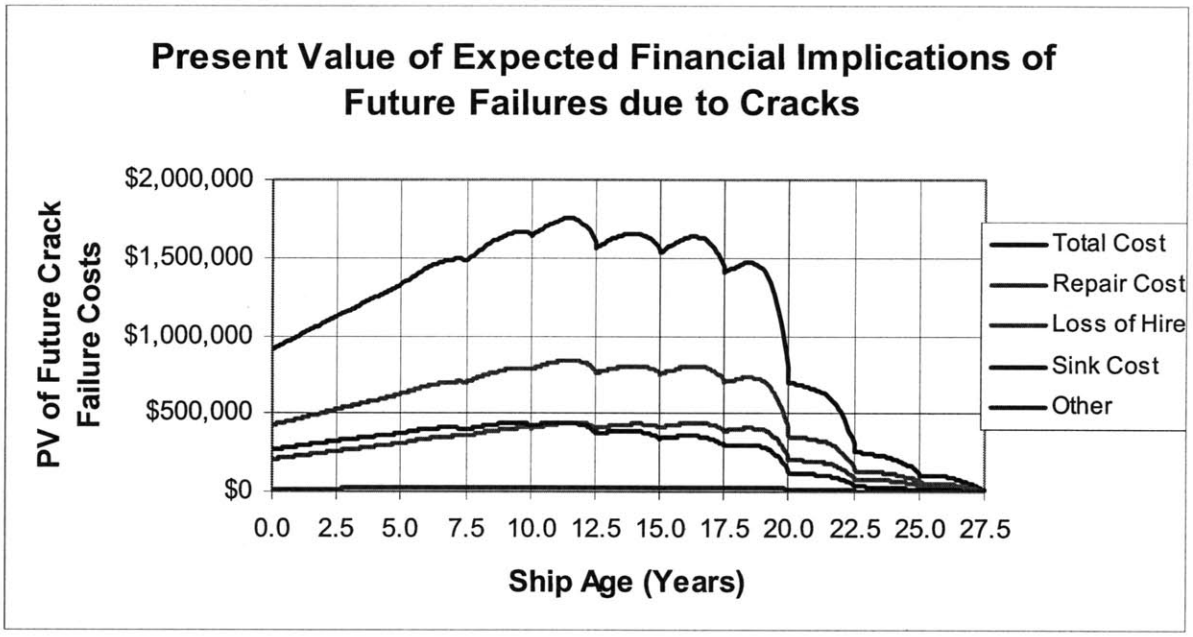


Fig: 4.6-4: Present value of all future potential crack failures as a function of ship age

The total cost value is the value that one should account for when valuing a ship in order to account for the possibility of crack failures. When a ship is new, this amounts to $916,933. The breakdown of this value is 23% repair costs, 46% off-hire costs, 29% potential sink costs and 2% other costs.

As a ship gets older, even though the number of future years (cumulative future probability of failure) and the failure cost decreases, the present value of future potential repairs increases until it hits a maximum of $1,769,015 at the age of 11.5 years. This is because the years with a disproportionately higher hazard function get closer and the corresponding high expected costs are discounted over fewer years. After the age of 11.5 years the present value of future expected crack failures gradually decreases as expected. They gradually decrease to zero at the point when the ship is scrapped since there is no future time left (the cumulative future probability decreases to zero).

Finally, Fig. 4.6-5 shows the total present value of future expected crack failures as a percentage of the ship's current value.

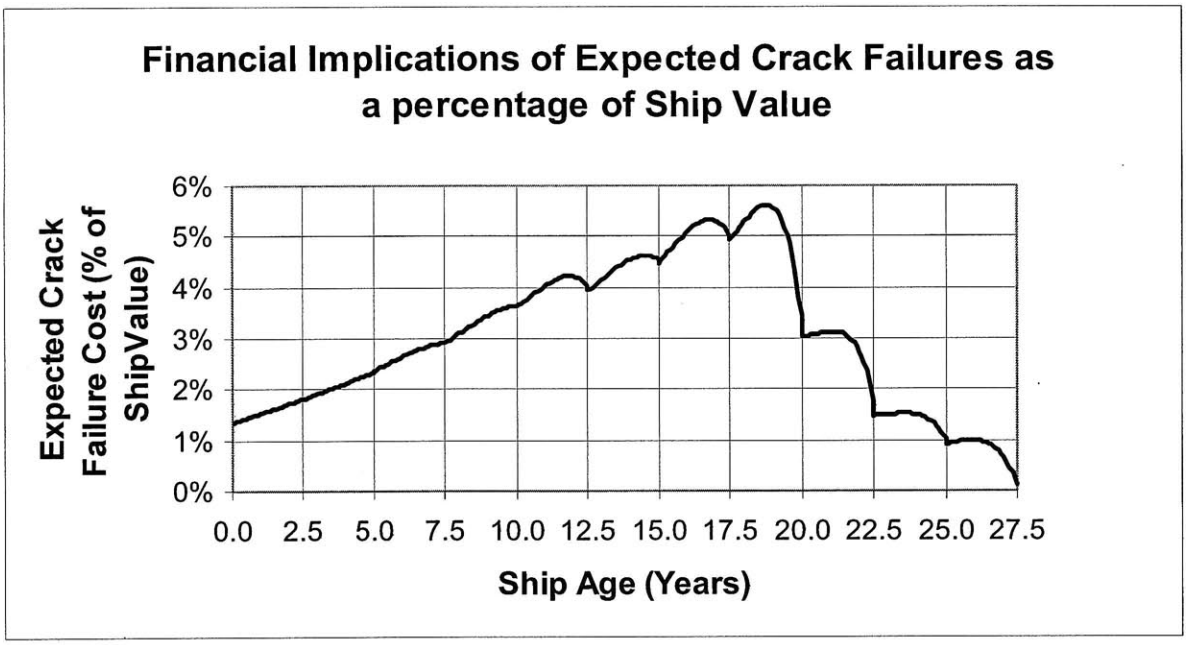


Fig 4.6-5: Financial Implications of future potential crack failures on Ship Value as a percentage

This graph shows the potential magnitude of ship valuation miscalculations if the possibility of crack failures is ignored. Given a particular point in time, one can use current ship prices and earnings as well as discount rates based on the current risk free rate to obtain a more relevant impact on valuation. The above analysis, however, is based on historical averages and provides an average long term estimate of the financial implications of potential failures due to cracks.

At its peak value, the graph shows that the financial implications of future potential crack failures amount to 5.67% of the value of an 18.75 year old ship. Therefore, including the impact of expected crack failures would reduce the valuation of a ship of that age by about 5.67%.

4.7 Overall Conclusions

An extensive literature survey was carried out focusing on several aspects related to cracking. The stresses acting on the hull were examined in order to observe any similarities between the distribution of hull stresses and that of cracks throughout the hull. This consisted of a survey analysis which was carried out to determine the average still water bending moment distribution, acting along the hull throughout a cape's service life. The wave induced bending moment distribution is observed by tabulating the values predicted by classification societies.

A coding system for locations was devised in order to conduct the crack survey and many modifications were made until it was finalized. This is recommended for further use in future similar projects and is easily adaptable to a variety of applications. A sample of 29,567 cracks from 240 ships was investigated using this system and proved to be representative of the world fleet. Measures which were taken to ensure the validity of the data include the sourcing of data from owners in many cases where class records seemed incomplete.

The crack distribution throughout the hull was shown to be resembled by the stress distribution to some extent. Some discrepancies are observed due to a variety of other causes of cracking and the enhancement of the highly stressed regions. It is thus concluded that crack incidences can be greatly reduced by ensuring that certain stress limits are not exceeded. This can be achieved by avoiding heavy weather, sailing at a speed and direction according to the weather, caring not to cause damages during discharging, and by reducing loading and discharging rates in order to reduce the chances of deviating from a loading plan.

Similar trends to other crack surveys have been observed in many cases while discrepancies were often attributed to the different focus of each work cited. An example of this is in the analysis of the number of cracks per ship with respect to ship age where the data of [Yamaguchi, I. 1968] only focuses on relatively young ships. Another case is in the mean and median crack size with respect to ship age where [Antoniou, 1977] has probably not captured the initial slope of the graph in oil tankers. Classification societies only record a small number of cracks which pose a threat to the ship and this is evident by the small number and large size of cracks reported in their surveys and investigations.

Significantly different results were occasionally observed compared to those reported in the literature. The importance of sample size is thus highlighted but more importantly, it leads to the conclusion that cracks follow different patterns to other damages and that capes exhibit a different cracking behavior to other ships. This emphasizes the importance of projects based on a large sample, which are highly specific, focusing on a particular type of damage in a specific ship type and size range.

Cracks are usually located in secondary components but if unattended, they can propagate by fatigue onto the primary structure and pose a threat to the structural integrity of the vessel. The majority of cracks develop in the mid-ship section where the wave induced bending stresses and deflections are greatest.

The types of repairs and design modifications for the various cracks have also been recorded and analyzed. This analysis led to conclusions regarding the general approach depending on the crack size, cause and location. Some of the recommended repairs by classification societies such as the use of a face plate instead of a collar plate in manholes were reported very rarely or not at all as they are presumably less practical than others.

Regarding crack growth rates, Paris Law was found to be over-conservative compared to the data, in line with recent findings. Three alternative, less conservative approaches were introduced and tested on data using cracks on shell frame brackets. Crack growth rates were estimated from the data as a function of ship age and location. They were determined to follow a bathtub curve with respect to age, which is the superimposed effect of an initial value, design modifications during repairs and corrosion as the ship ages. These effects were decomposed by making some assumptions based on the data and on results of previous research.

A Danger Model was developed using the crack growth rates derived from the database and the criticality of each location based on previous accidents and a survey of surveyors and superintendents. The Model was applied to the ships of the database and an average safety parameter was determined as a function of age. Safety was found to decrease with age until about 20 years, after which it gradually increases again. This is partly because the data available in older ages is from ships that were of better quality on average since bad quality ships are scrapped.

A reliability model was developed by modifying the Weibull duration model to start from a non-zero value and then combining a series of modified Weibull models to represent repair intervals. The model was calibrated in terms of data from the danger model and from a database of 82 capes, 740 ship years, 34 emergency repairs and two sinkings. The hazard function was thus derived as a function of ship age, yielding the expected probability of failure in each month throughout a cape's life. This was found to gradually increase between repairs with sudden drops to a finite value during each repair, and with a peak just before the fourth special survey at 20 years of age.

The present value of the expected failure cost was finally determined as a function of ship value throughout the ship's life. Historical average values of ship earnings and prices were used to do that, along with the cost of repairs as of Sept 2008, the hazard function throughout a ship's life, average bunker costs and repair times etc. Almost half of the cost was accounted for by expected loss of hire and the total present value as a percentage of ship value was found to peak at 5.7% at 19 years of age based on historical data.

Although it hasn't been the main focus of this investigation to distinguish between the various cape designs and shipbuilding yards, this is an interesting and important area for future research. An investigation which examines the frequency of cracking with respect to the shipbuilding yard would be of great interest to ship owners while one which examines the effects of design aspects would also interest classification societies and shipyards.

Owners and classification societies would also be interested in the effects of hull maintenance on cracking while the effect of corrosion and wear of scantlings would be useful to IACS and individual classification societies for the development of new rules.

Further research in the effect of cracking with respect to ship age would mainly be of interest to underwriters, charterers and cargo terminal operators which recently imposed an age limitation of 25 years on capes that are used for the transportation of iron ore.

Another aspect which has lately become of outmost concern is that of high loading and discharge rates. An investigation into the influence of loading rates on cracking would, therefore, be of great interest to parties involved such as ship owners, cargo terminal operators and the IMO.

CHAPTER 5

RAFL Ship Valuation Model

5.1 Crack Repair Costs and the Total Cost of Cracks

5.1.1 Introduction

Cracking in ships is controlled by improving design, minimizing operating stresses and through regular inspections and repairs. Cracks often develop due to design flaws that are already known in the design stage. The big trade-off which designers and owners have to face in the construction of a new ship is whether to invest in a fatigue resistant design, or to keep the construction cost low and incur the repair costs as cracks emerge later in the ship's life. When it is decided that construction costs outweigh the benefits of a more crack resistant design, modifications are made to solve the problem permanently after cracks appear. This choice has to be made for hundreds of components throughout the ship's hull. Many of these have been discussed in Chapters 3 and 4.

In this section, a method is developed to quantify the total cost of cracks in order to assess the cost effectiveness of new fatigue resistant designs that promise to reduce the number of cracks and future repair costs. It is based on comparing the additional cost of a proposed new design in a newbuilding, or of a design change during a repair, with the present value of all the projected crack repair costs of the corresponding location. If the present value of the repair costs of the cracks that will be avoided with the new design exceeds the additional cost of implementing that design, then the design is cost effective.

The present value of the repair costs has to be determined for the various locations. A general model was developed to do that and then several assumptions were made to give a simplified version. First, the projected cracks for a given location have to be estimated and then, the repair costs of these cracks and their present value have to be determined. The model was applied to the reduced crack database (140 capes and 17,435 cracks) and coding system of Chapter 4.

5.1.2 Developing the Model

Crack repair costs can involve several components depending on the location and size of the crack. Some of these cost components including staging and steelwork are specific to each crack whereas others such as cleaning, venting and testing are specific to the location. For example, the repair cost of 3 cracks far apart in one ballast tank will involve the staging and steelwork cost for each individual crack, plus the cleaning, venting and testing of the ballast tank. Introducing some nomenclature:

Parameters

CP: Cost Parameter for Ship

CT: Cost of time ($/day)

RC: Repair Cost

RT: Repair Time

$RT_{NoCracks}$: Repair time without cracks

Subscripts

i: Crack

j: Ship Location with crack

k: Repair Process

s: Ship

Crack-Specific Costs

k=1: Staging

k=2: Steelwork

Location-Specific Costs

k=3: Cleaning

k=4: Venting

k=5: Testing

k=6: Gas Free

In order to capture all these crack repair costs throughout the hull, a summation has to be carried out over the total number of cracks and another summation over the total number of locations that involve one or more cracks. A high component of the crack cost may be associated with the repair time besides the cost of the repair itself. This may be particularly important in the case of large bulk carriers or tankers which at time are earning hundreds of thousands of dollars per day. The following model accounts for these effects.

$$CP = RC + (RT - RT_{NoCracks}) * CT \qquad (5.1\text{-}1)$$

$$RC = \sum_{i} \sum_{k=1}^{k=2} RC_{ik} + \sum_{j} \sum_{k=3}^{k=6} RC_{jk} \tag{5.1-2}$$

$$RT = \sum_{i} \sum_{k=1}^{k=2} RT_{ik} + \sum_{j} \sum_{k=3}^{k=6} RT_{jk} \tag{5.1-3}$$

This captures both the repair costs and the cost of time lost during repairs. In the great majority of cases, the additional time due to cracks is equal to zero. This is because the crack repairs are usually carried out in conjunction with other repairs such as sandblasting, replacement of corroded steel, coating etc. Since, all this additional timely work has to be carried out as part of the dry docking or special survey regardless of the presence of cracks, one cannot attribute the time spent to the shipyard and the consequent loss of hire to the cracks. In other words, since $(RT - RT_{NoCracks}) \approx 0$ most of the time, the total cost associated with cracks can be approximated as follows:

$$RC = \sum_{i} \sum_{k=1}^{2} RC_{ik} + \sum_{j} \sum_{k=3}^{6} RC_{jk} \tag{5.1-4}$$

Furthermore, the cost to gas free a fuel tank can probably be neglected because it is very rarely incurred since the locations in which it is required show extremely low cracking frequency. This essentially makes k=6 redundant. By eliminating this, the final simplified crack repair cost for a given ship "s" is given as follows:

$$RC_s = \sum_{i} \sum_{k=1}^{2} RC_{ik} + \sum_{j} \sum_{k=3}^{5} RC_{jk} \tag{5.1-5}$$

5.1.3 Model Assumptions

The major assumptions involved in this model are summarized below:

1. The cost of time is neglected since cracks are usually not the determining factor.
2. Cost to Gas Free is neglected because it is very rarely incurred because the locations in which it is required show extremely low cracking frequency.
3. Cost of ultrasonic measurements are neglected since only a few measurements are usually taken and they are relatively cheap.
4. The final cleaning cost (required before painting) is included in the cost of steel. This is done on the whole area to be coated – not just for cracks.
5. Coating is also neglected since a very small area is required for cracks. For example if $40m^2$ of coating is required for the cracks of a whole ship repair, that corresponds to about 12 liters of paint or about $100 which is negligible. The coating is carried out by the repair yard if the crack is in a highly corroded area and by the crew if otherwise.
6. It is assumed that in order to ballast the top side tanks of a ship, it is not required to first ballast the double bottom and the lower wing tanks. This may not be true for all in service, but since ships today are built that way and since this model is intended for future predictions (a ship that will be designed and built), that makes this assumption necessary.

5.1.4 Model Calibration

5.1.4.1 Basis for Calibration

In order to calibrate the model, the actual costs for each of the items have to be determined. The actual numbers used in this case are based on what Chinese Shipyards were charging on average in September 2008. Chinese shipyards were chosen because that is where the great majority of big ship repairs for capes are carried out. Different numbers can be used depending on when and where a particular ship will be operating and repaired.

5.1.4.2 Staging Cost (k=1)

Staging and de-staging is required in order to provide access to the location of the crack for its repair. There is a charge per m^3 that includes both staging and de-staging. In some circumstances, when a crack is very high (e.g. in the upper part of a cargo hold) it is more appropriate to construct a hanging staging which provides access through the hatch opening. This saves a great deal of volume but the cost per m^3 is much higher. Shipyards also charge a different price on normal staging depending on the location (e.g. higher for staging inside ballast tanks). Table 5.1-1 below shows the staging costs for closed and open spaces and Table 5.1-2, gives a summary of the staging costs for each location using the same coding system introduced in Chapter 4.

Staging Costs Charged At Each Location		
Region	Stage/De-staging	Hanging Staging
	$/m3	$/m3
Ballast Spaces	4	**12**
Open Spaces	3.5	**12**

Table 5.1-1: Staging Costs per m^3

Staging Costs Charged At Each Location		
Region	Stage/De-staging	Hanging Staging
	$/m3	$/m3
1	4	**12**
2	3.5	**12**
3	4	
4	4	
5	3.5	
6	4	

Table 5.1-2: Staging Costs per m^3 for each location

The average staging cost required per crack depending on its location must be determined. The average dimensions of each location are known since the model is applied on capes. The amount of staging in m^3 that would be required to repair a crack can therefore be deduced. Since however the same amount of staging could be used to repair more than one crack when cracks are close together, an adjustment or a "staging factor" must be applied in order to avoid double counting. This factor depends on the frequency and proximity of the cracks in each location and is approximated based on the crack distribution of the database. The staging cost of each crack can therefore be determined using the amount of staging required to access the crack depending on its location, the relevant staging factor and the corresponding price per m^3. Some additional approximations were required in some of the locations as described in Table 5.1-3.

Staging Cost Calculations					
	Region	S Factor	m3	$	$/Crack
	1A	0.7	48	192	**134.4**
	1B	0.7	48	168	**117.6**
	1C	0.05	792	3168	**158.4**
	1D Hang. Staging	1	9	108	**108**
Hatch Coamings	1E Hang. Staging	1	9	108	**982.8**
Hatch End Beam	1E	1	864	3024	
	1F	1	144	576	**576**
Half Length (<10cracks)	2A and 2B	-	3200	11200	**Function**
Full Length (=>10cracks)	2A and 2B	-	6400	22400	**Function**
	2C	0	0		**0**
	3A	0.7	80	320	**224**
	3B	0.5	64	256	**128**
	3C	0.8	112	448	**358.4**
	3D	0	0		**0**
	4A	0	0		**0**
	4B	0	0		**0**
	4C	0	0		**0**
	4D	0	0		**0**
	5A	1	828	2898	**2898**
	5B	2	792	2772	**5544**
	5C	2	576	2016	**4032**
	5D	2	216	756	**1512**
	5E	2	32	112	**224**
	5F	1	640	2240	**2240**
Aft Peak (Full)	6A	1	192	768	**768**
Aft Peak (Full)	6B	1	300	1200	**1200**
Aft Peak (1 crack only)	6A	1	100	400	**400**
Aft Peak (1 crack only)	6B	1	100	400	**400**
	6C	0	0	0	**0**

Table 5.1-3: Calculation of staging cost per crack for each location

5.1.4.3 Steelwork (k=2)

The base price charged by the Chinese yards considered in Sept 2008 ranged between from 2.8 to 3 $/kg. This varied depending on parameters such as the size of the repair or the relationship with the client and it was more often close to $2.8/kg. $2.8/kg is therefore assumed in the following calculations.

On top of the base price, yards charge a premium for 4 things as follows. An additional 20% for high tensile steel, 20% for a bend, 30% for a corner or stiffener, and 20% if it is in a closed space (e.g. ballast tank). They therefore come up with a $/kg value based on the above and charge accordingly. They also charge a minimum of 15kg per piece. This gives 16 different combinations giving 16 different prices of steel depending on the requirements. Table 5.1-4 below provides a list of those categories and uses the above information to determine a $/kg amount for various category of crack repairs.

Using the typical dimensions of the component that has to be replaced in each location when repairing a crack, the amount of steel in kg was calculated. By combining this with the corresponding price per kg, the $/crack amount was calculated for each location and summarized in Table 5.1-5.

Steel $/kg Calculation					
Region	HTS (20%)	Bent (20%)	Angle-bar / Stiffener (corner) or Holland Profile (30%)	Closed Space (20%)	$/kg
1A				YES	**3.36**
1B	YES		YES	YES	**4.76**
1C	YES		YES	YES	**4.76**
1D	YES	YES		YES	**4.48**
1E	YES				**3.36**
1F	YES			YES	**3.92**
2A	YES				**3.36**
2B	YES				**3.36**
2C	YES				**3.36**
3A				YES	**3.36**
3B	YES		YES	YES	**4.76**
3C	YES		YES	YES	**4.76**
3D	YES			YES	**3.92**
4A	YES		YES	YES	**4.76**
4B				YES	**3.36**
4C	YES		YES	YES	**4.76**
4D	YES			YES	**3.92**
5A				YES	**3.36**
5B	YES	YES			**3.92**
5C	YES	YES			**3.92**
5D	YES	YES			**3.92**
5E	YES			YES	**3.92**
5F	YES			YES	**3.92**
6A				YES	**3.36**
6B				YES	**3.36**
6C					**2.8**

Table 5.1-4: Steelwork cost in $/kg for each location

Steel Cost per Crack Calculation			
Region	$/kg	Kg	$/Crack
1A	3.36	30	100.8
1B	4.76	35	166.6
1C	4.76	35	166.6
1D	4.48	50	224
1E	3.36	50	168
1F	3.92	100	392
2A	3.36	15	50.4
2B	3.36	50	168
2C	3.36	30	100.8
3A	3.36	30	100.8
3B	4.76	50	238
3C	4.76	50	238
3D	3.92	100	392
4A	4.76	70	333.2
4B	3.36	50	168
4C	4.76	200	952
4D	3.92	50	196
5A	3.36	50	168
5B	3.92	100	392
5C	3.92	100	392
5D	3.92	100	392
5E	3.92	100	392
5F	3.92	150	588
6A	3.36	100	336
6B	3.36	100	336
6C	2.8	0	0*

Table 5.1-5: Steelwork Cost in $ per Crack for each Location

* The original piece was used in all such cases identified (6)

5.1.4.4 Compartment-Specific Components (k = 3, 4 & 5)

When considering compartment specific components, it is important to be careful to avoid potential errors with the coding system. The coding system used is such that each zone along the length of the ship, from zones 2 to 9, corresponds to a cargo hold. This however is not also the case with ballast tanks since there are only 5 ballast tanks in addition to the after peak and the fore peak tank. To avoid confusion, Table 5.1-6 shows the compartment name corresponding to each zone (of the coding system) and tank.

BALLAST TANK CONFIGURATION		
Compartment	ZONE	Ballast Tank
After Peak	1	After Peak
Cargo Hold 9	2	5
Cargo Hold 8	3	5
Cargo Hold 7	4	4
Cargo Hold 6	5	4
Cargo Hold 5	6	3
Cargo Hold 4	7	3
Cargo Hold 3	8	2
Cargo Hold 2	9	2
Cargo Hold 1	10	1
Fore Peak	11	Fore Peak

Table 5.1-6: Ballast Tank Configuration and Corresponding Zones

The cost that shipyards typically charge is summarized in Table 5.1-7. They charge a total dollar amount for cleaning and testing whereas they charge a per day amount for venting. Venting is usually required for two days in a typical repair.

COMPARTMENT COSTS	
CLEAN	1 $/m^3
TEST	1.2 $/m^3
VENT	50 $/tank/day

Table 5.1-7: Compartment Costs

The typical size of each tank is shown in Table 5.1-8 based on the average capesize bulk carrier. Note that these correspond to either the port or the starboard side.

BALLAST TANK SIZES	
	Volume (m^3)
Top Side Tank (1 side)	2500
Half Double Bottom & 1 Wing Tank	3000
Fore Peak (Half)	4000
After Peak (Half)	400

Table 5.1-8: Compartment Volumes

The testing procedure (k=5) after the repair involves pressurizing the compartment and checking for leaks. This however is not always necessary and it is only carried out if a crack is beyond a critical length. Critical crack lengths for testing each location are therefore required in order to decide whether to include this cost. These are shown in Table 5.1-9.

A simple IF function was used when going through the summation throughout the hull in order to determine whether to step up the total cost by the necessary amount. The argument of the IF function involves the number of cracks being greater than zero for the case of cleaning (k=3) and venting (k=4), while it is the largest crack being larger than the critical length for the Testing component (k=5). The amount added to the summation if the IF function is satisfied, is calculated using Tables 5.1-7 through 5.1-9. A summary is shown in Table 5.1-10.

TEST - Critical Lengths	
	Critical Length (mm)
1B	450
1C	450
1D	0
1F	450
3B	400
3C	400
4A	450
4C	450
ZONE 1 (ALL)	300
ZONE 11 (5A-F)	300

Table 5.1-9: Critical Crack Lengths for Pressure Testing the various Compartments

SUMMARY OF COMPARTMENT COSTS ($)			
	IF CRACKS > 0	IF CRACKS > 0	IF MAX(SIZE)>CRIT
	CLEAN	**VENT**	**TEST**
deck/tst (1)	5000	200	6000
cargo hold (2)	0	0	0
wing tanks (3)	3000	200	3600
double bottom (4)	3000	200	3600
Bulkheads (5)	0	0	0
(6) FORE PEAK (Zone 11)	8000	200	9600
(6) AFT PEAK (Zone 1)	800	200	960

Table 5.1-10: IF Function and Amount by which Summation is increased for Location-Specific Costs

5.1.5 Results and Discussion

By applying the above model on the detailed database of 140 capes and 17,435 cracks, a wide range of results can be produced in order to assess the cost effectiveness of design modifications. The average crack repair cost as a function of ship age is first determined and presented in Fig. 5.1-1.

This is the average cost to repair all cracks during a repair as a function of ship age. It should be noted however that these only represent a fraction of the total repair cost which would include other components such as corroded steel renewals. It can be seen that the costs incurred gradually increase and after a point they start to decline again since there are fewer and smaller cracks to repair. Repair costs due to corrosion however would be much higher and would heavily outweigh this decline if measured.

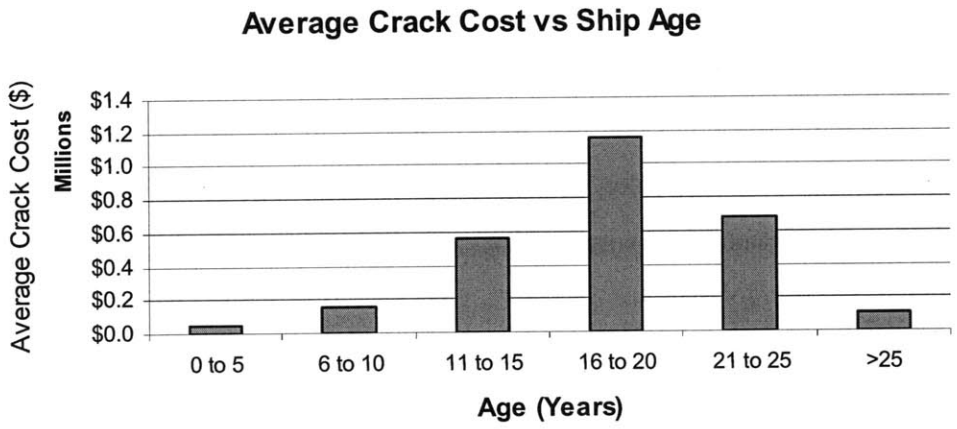


Fig. 5.1-1: Average Crack Repair Cost for Ship Age Groups

The average repair costs are decomposed into the various repair processes (k=1 to k=5) for each individual year and shown in Fig. 5.1-2. This may be used when deciding which repair yards to go to depending on the ship's age. In a more refined analysis, one may then choose to apply the corresponding price-parameters to each ship depending on its age.

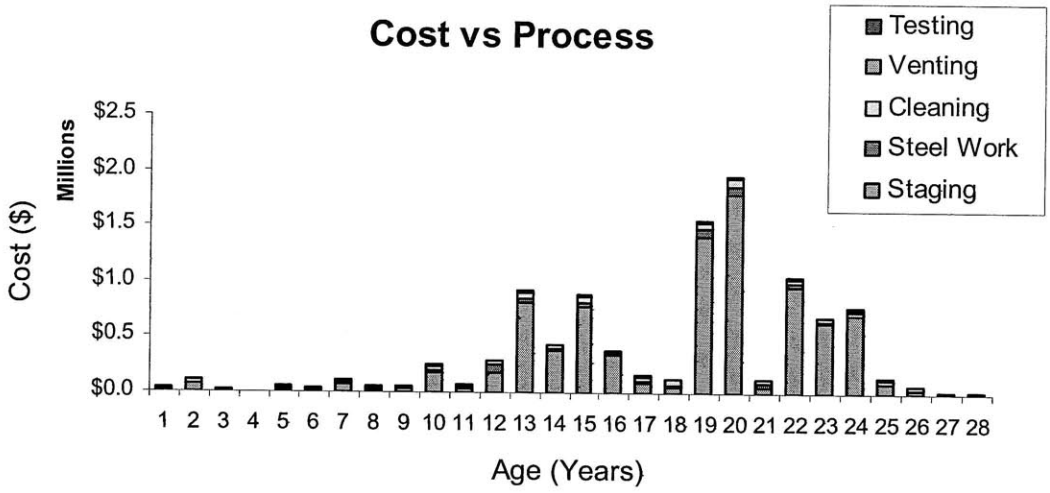


Fig. 5.1-2: Average Crack Repair Cost vs. Ship Age by Process

Here we see that the average crack repair cost is relatively high during the intermediate dry-docking surveys at 13 and 22 or 23 years and peak on the 4th special survey at the age of 20 years. The average crack repair cost is about $0.49M in 2008 dollars. Staging (k=2) on average accounts for 86% of the crack repair costs.

The average repair cost can also be decomposed into the various locations of the ship or the compartments along its length for each individual year throughout its life. This provides a picture of what an owner should expect to spend for crack repairs and where throughout a ship's life on average.

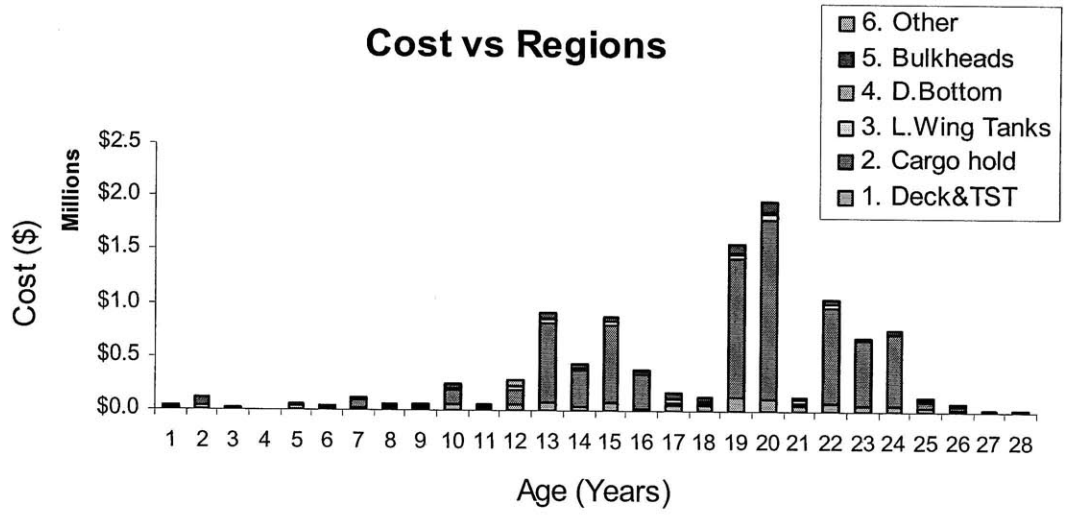


Fig. 5.1-3: Average Crack Repair Cost Decomposed into Regions for each Year

Fig. 5.1-3 shows the average repair cost decomposed into the various locations (regions 1 through 6) for each individual year, while Fig. 5.1-4 shows how the costs are distributed on average throughout the ship's length.

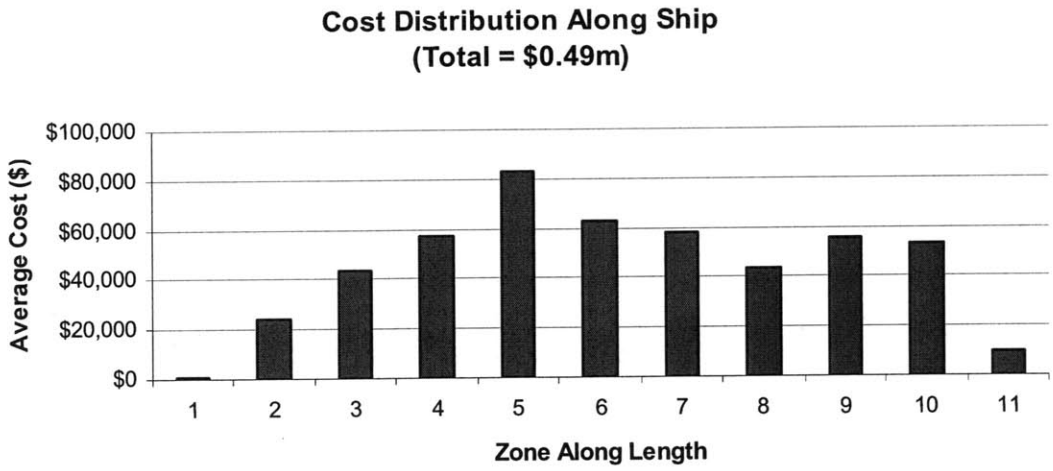


Fig. 5.1-4: Average Crack Repair Cost Decomposed into Zones Along the Ship's Length

There are two ways to calculate the percentage distribution of total cost by region as a function of ship age. One can calculate the percentage accounted for by a location or repair process for every ship, and then plot the mean of the percentages for each age. Alternatively, the total amount spent in each location or repair process for all ships of a given age can be plotted as a percentage of the total amount spent on those ships. The second method would give a more accurate picture of what one should expect for a typical ship because the results of the first method would be distorted by insignificant repairs.

Fig. 5.1-5 and 5.1-6 show how the costs are distributed among the various locations on the ship as it ages. In Fig. 5.1-5, the percentage accounted by a location for every ship is calculated and then the mean of the percentages is plotted for each age. In Fig. 5.1-6, the total amount spent in each location for all ships of a given age is plotted as a percentage of the total amount spent on those ships. In both figures, a linear regression curve of each plot is being presented as opposed to the data points in order to emphasize the trends and compare them.

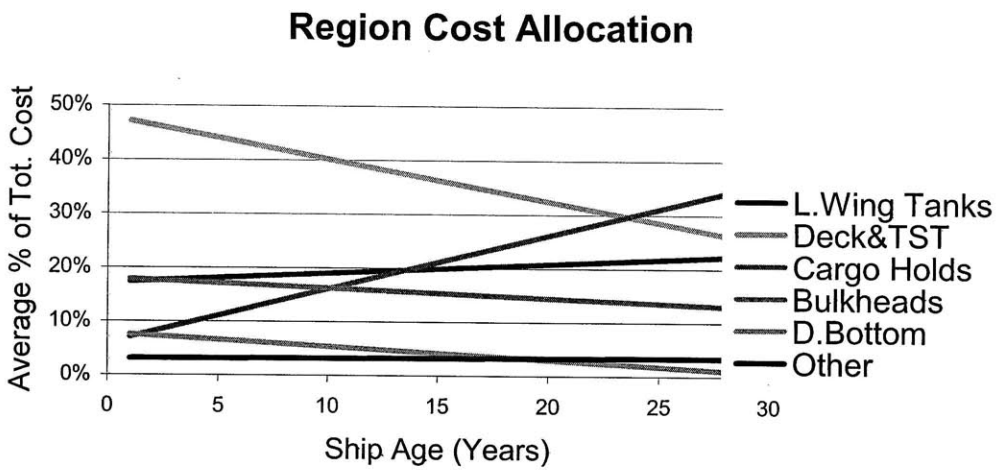


Fig. 5.1-5: Average Percentage of Total Repair Cost for Each Location as a function of Ship Age

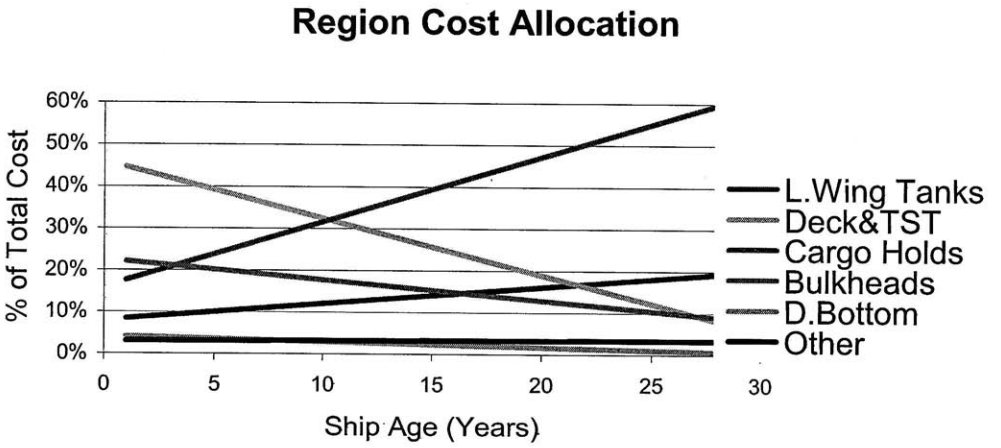


Fig. 5.1-6: Percentage of Total Cost Accounted by Each Location as a Function of Ship Age

It can be seen in both graphs that as a ship becomes older, cargo holds account for an increasing amount of the total repair cost whereas the deck and top side tanks account for a decreasing fraction. This can be explained by also examining Fig. 5.1-7 and 8 which are similar plots to Fig. 5.1-5 and 5.1-6 but for the repair process as opposed to the location. Fig. 5.1-6 and 5.1-8 give a more accurate picture of what one should expect for a typical ship because the results shown in Fig. 5.1-5 and 5.1-7 are distorted by insignificant repairs. Fig. 5.1-5 and 5.1-6 are complementary to Fig. 5.1-3, whereas Fig. 5.1-7 and 5.1-8 are complementary to Fig. 5.1-2.

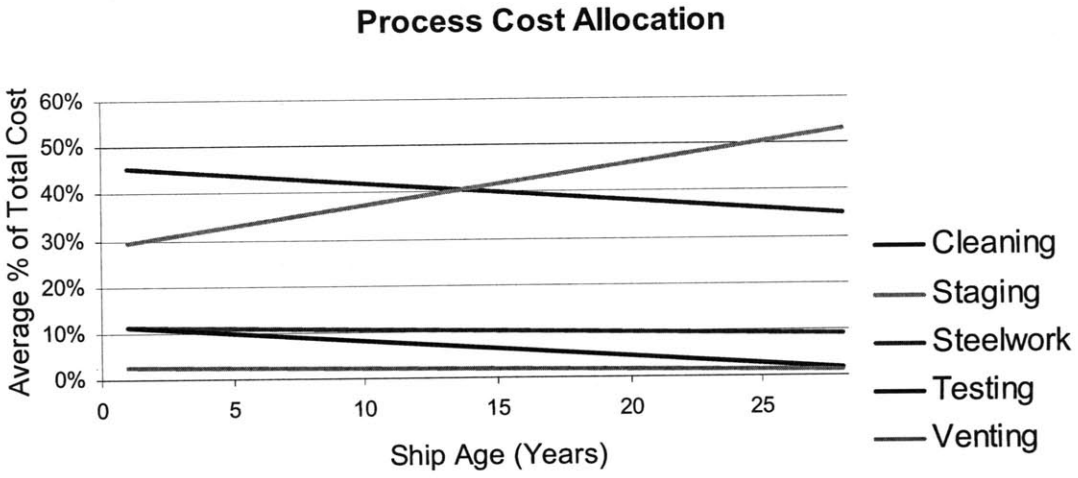


Fig. 5.1-7: Average Percentage of Total Repair Cost for Each Process as a function of Ship Age

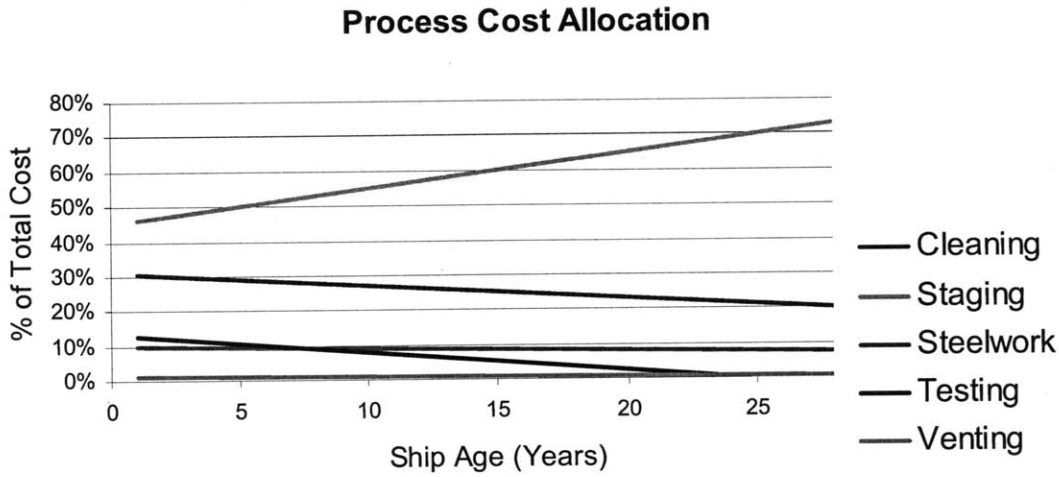


Fig. 5.1-8: Average Percentage of Total Repair Cost for Each Location as a function of Ship Age

When a ship is young, there are relatively few and relatively large cracks. These cracks usually develop due to high stresses at locations where there are high stress concentrations and residual stresses that have not been relieved through operation and repairs. As a result, some of these cracks are on the deck and in the ballast tanks which are subjected to relatively high stresses as they are located at the upper and lower ends of the hull. Due to their location, these cracks do not require a lot of staging but cleaning is essential in order to carry out crack repairs in ballast tanks, even just for a few cracks. As a

result, due to the small number of cracks and their location, cleaning accounts for a relatively high fraction of the cost.

As a ship gets older on the other hand, the average number of cracks increases and they are more evenly distributed throughout the hull. Cracks develop not only due to high stresses but also as a result of wear from operation and corrosion in areas such as the cargo holds. Therefore, cleaning costs reach a plateau much faster than staging which keeps increasing with the number of cracks, particularly in the cargo hold area.

For young ships, therefore, the deck and ballast tanks account for a relatively high fraction of the cost and a lot of that is cleaning while as a ship gets older, the cost shifts to the cargo hold areas in terms of location and to staging in terms of process. This trend is evident in Fig. 5.1-5 through 5.1-8.

In order to evaluate proposed design modifications or improvements, one needs to know the present value of the repair costs that will be avoided. Shipping companies often use a discount rate of about 10% (always higher than the bank interest rate). Certain shipping companies often require a 15% return on investments but today interest rates are significantly lower than what they have been in the previous couple of years. Either way, Fig. 5.1-9 and 5.1-10 show the present value of crack repairs for each location on the ship (Regions 1 through 6) using a 10% and 15% discount rate respectively.

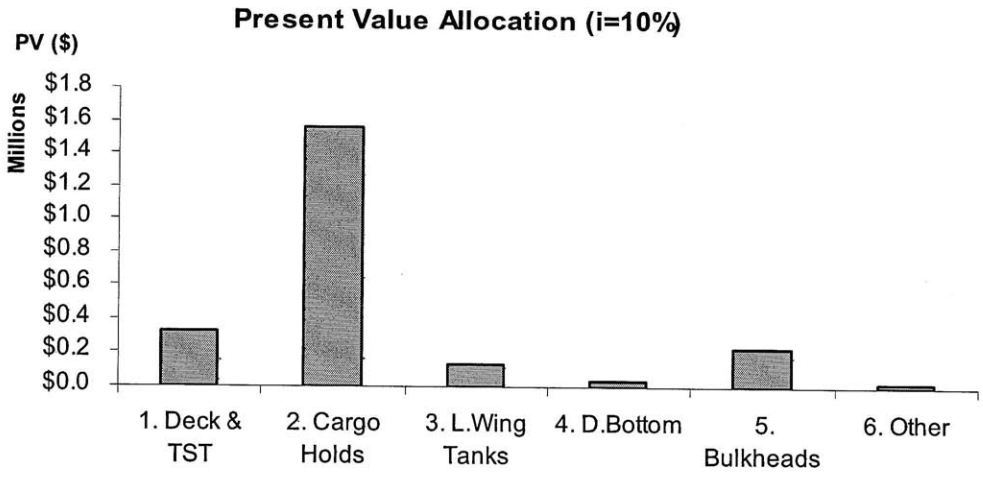


Fig. 5.1-9: Present Value of Crack Repair Costs for Each Location Using a 10% Discount Rate

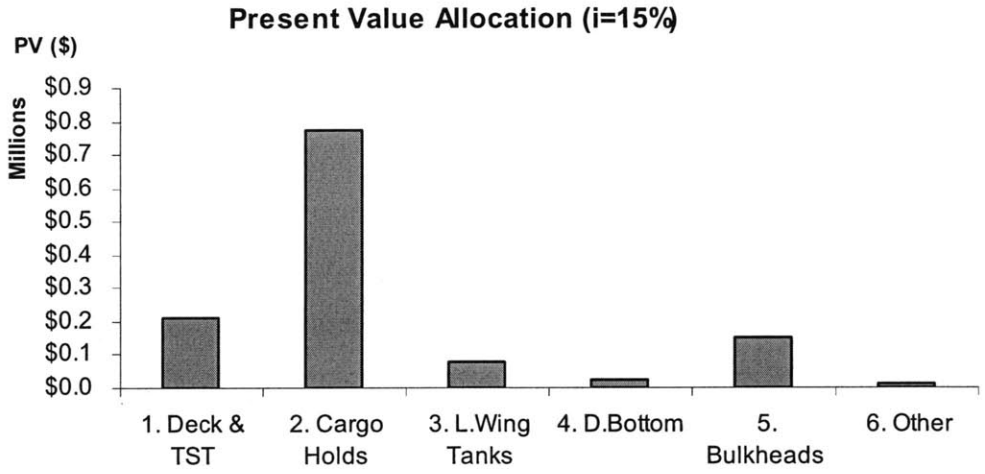


Fig. 5.1-10: Present Value of Crack Repair Costs for Each Location Using a 15% Discount Rate

The average total present value of crack repair costs for the ship's life was calculated to be -$2.3M using a discount rate of 10% and -$1.2M using a discount rate of 15%. This in effect limits what an owner should consider investing against cracks in the design stage. Owners who use a lower discount rate, meaning that they value money today compared to later less than other owners, can afford to pay more against cracks in the design stage in order to save on later repairs.

The break down of the present value into the various regions of the ship allows choices about specific design modifications to be made. Using a discount rate of 10% for example, the present value of the crack repairs in the cargo hold region amounts to -$1.5M. Using this value, if a new design promises to eliminate all the cracks in the cargo hold region throughout the ship's life, one should theoretically invest in it if it costs less than $1.5M above the current design.

There are other considerations which would push this limit higher. For example, cracks may also pose a safety issue requiring an emergency repair which involves additional costs. Those might involve the whole ship, cargo and possibly the crew if the ship sinks, or they might involve off-hire and high repair costs in the event of an emergency repair. The present value of these safety issues has been quantified as a function of ship age in Section 4.6, using reliability analysis to determine probabilities of emergency repairs or loss due to

cracks. The consideration of repair costs alone, serves as a lower limit i.e. it is worth investing at least up to $1.5M in the design that will eliminate cracks in the cargo holds.

An interesting result is that even though ballast tanks accounted for about 60% of the cracks by number, using a 10% discount rate, the cargo holds account for about -$1.6M or 68% of the present value of the total repair cost. That is because the repair of cracks in cargo holds involves a lot of staging which is a high component of the cost. The big open space of the cargo holds requires large volumes of staging and in many cases a hanging staging in order to repair the cracks which increases the cost disproportionately.

When applied correctly, the above analysis should give a wide perspective of the crack costs associated with each location. This is a guideline that is very useful when making high level decisions or a series of minor choices. An example is when choosing materials (e.g. high tensile steel) or weld specifications for large areas or for the whole ship. It is also handy when having to make fast decisions during repairs.

If an important decision or design choice has to be made, the above procedure can be used to address the issue more directly. If two widely used designs are to be compared, the ships in the database can first be divided between those with each design type. By conducting a separate analysis for each set of ships, an accurate estimate of the saved crack costs can be determined and then evaluated against the cost of each design. An example of a design choice for which such analysis would be suitable is the choice between a double hull or a single hull configuration.

5.1.6 Combined Cost and Safety Implications of Cracks

In Section 5.1.5, we determined the average repair cost of cracks as a function of ship age. In Section 4.4.5, we derived the average safety parameter due to cracks with respect to ship age. Fig. 5.1-11 combines those into one graph.

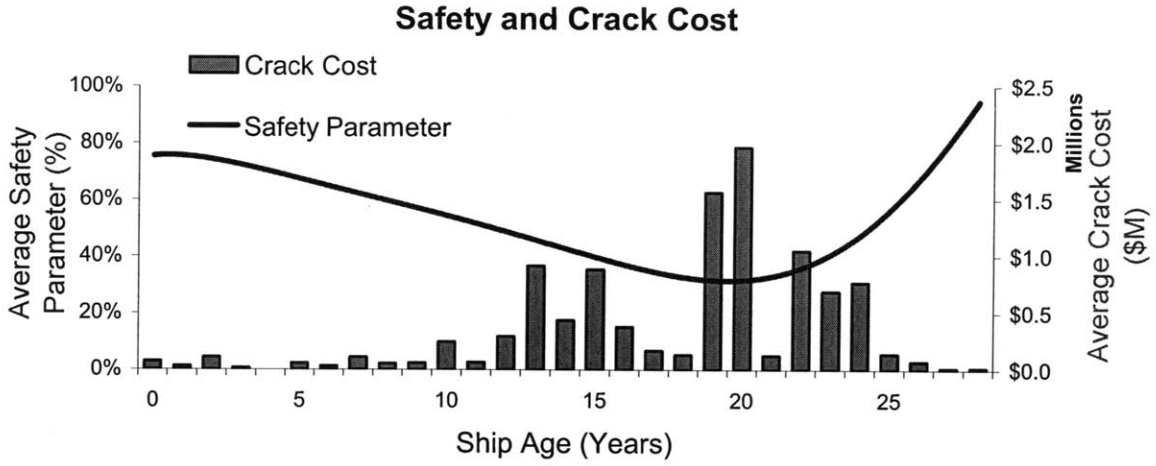


Fig. 5.1-11: Average Crack Repair Costs and Ship Safety Parameter vs. Ship Age

We see that young ships deteriorate, requiring more expensive crack repairs and their safety decreases as time progresses. The maximum of crack repair costs coincides with the minimum of safety due to cracks at the age of 20 years. This implies that 20 is the worst age to own a cape. Older ships are probably in a better condition and require fewer crack repairs, either because a lot of money has been poured into their repairs already, or because they had a good design to start with, helping them get this far without being scrapped.

The idea that the high repair costs actually impact the safety level is more clearly demonstrated when we consider the continuous hazard function, developed in Section 4.5.6, in conjunction with the annual crack repair costs. This is shown in Fig. 5.1-12.

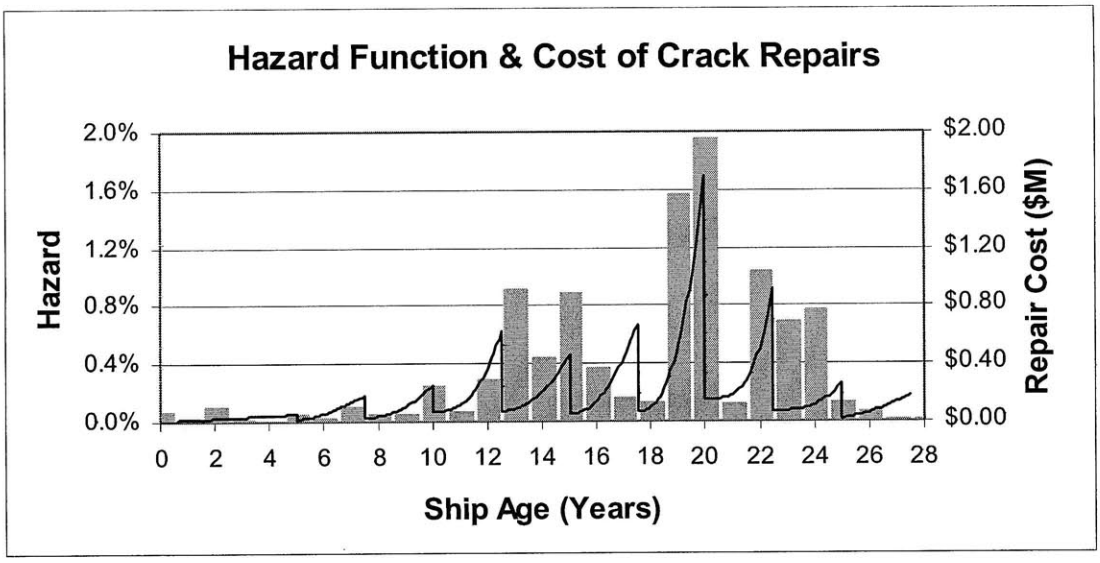


Fig. 5.1-12: Average Crack Repair Costs and Hazard Function vs. Ship Age

The big dips in the hazard function coincide with the heavy repair expenses during the scheduled ship repairs. The most notable example is the fourth special survey at the age of 20 years. The minor discrepancies are owed to the fact that not all ships carry out the repairs at the exact scheduled date since there is typically a time window giving the operators some freedom of choice in deciding when to take a ship out of service.

When deciding whether to modify a design during a crack repair or whether to opt for a new fatigue resistant design in a new ship, one has to consider the present value of the repair costs of projected cracks in the corresponding location. This was analyzed in Section 5.1.5. One also has to add to that, the present value of the expected failure costs due to cracks. These are analyzed at an aggregate level in Section 4.6. A break down of these costs into the various locations can be obtained based on the percentage contribution of each location to the total danger value. This has been analyzed in detail as a function of ship age in Section 4.4.8. Therefore, the total present value of the expected repair and failure costs can be obtained for any ship location and ship age.

An interesting result, for a variety of purposes, would be to calculate the full financial implications of cracks as a function of ship age, both as a monetary sum, and as a percentage of the ship value. This can be done by extending the analysis of Section 4.6.6, to include projected repair costs. The same set of assumptions as in section 4.6.6 is used, along with Sep-2008 Chinese repair yard prices (as have been assumed throughout Section 5.1). Fig.

5.1-13 gives a breakdown of the present value of projected future costs due to crack failures (emergency repairs and losses), repeated in Section 4.6.6. Fig. 5.1-14 shows the breakdown of the present value of projected scheduled crack repairs based on the analysis of this section. Fig. 5.1-15 combines these results, to give the present value of total crack costs as a percentage of the ship's value, using 10-year average data as in Section 4.6.6.

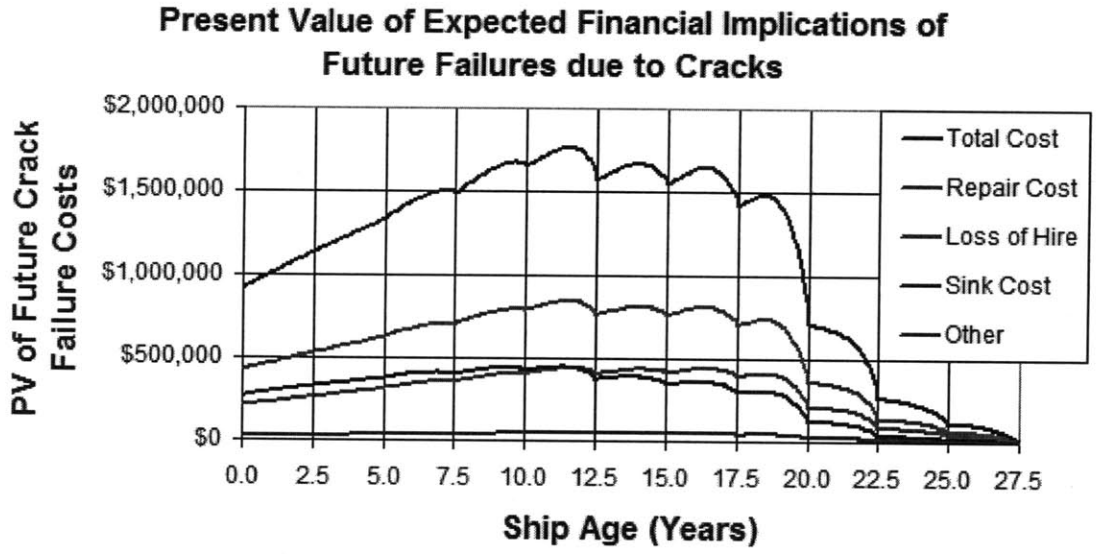


Fig. 5.1-13: Break Down of the Present Value of Expected Crack Failure Costs vs. Ship Age

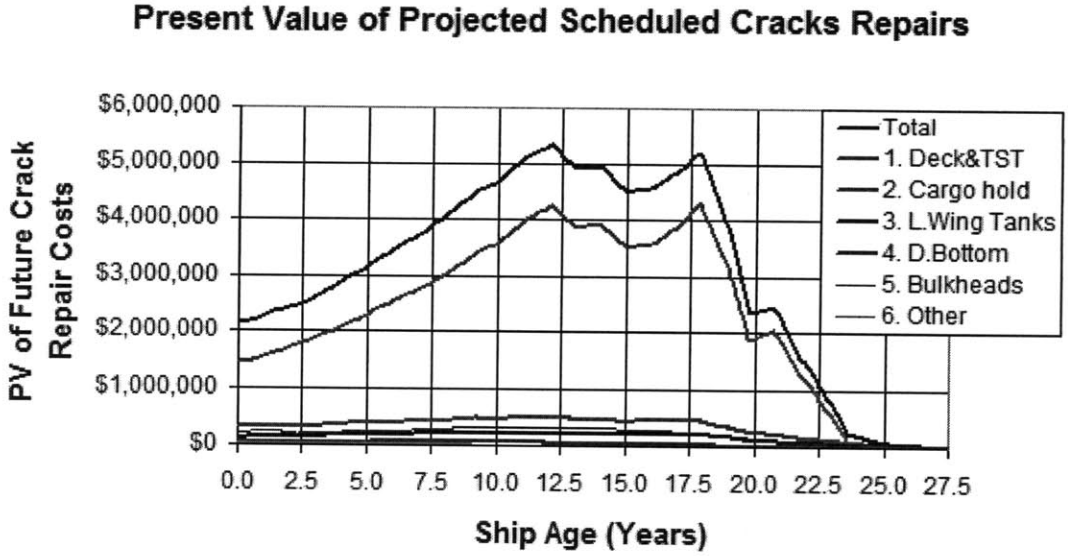


Fig. 5.1-14: Break Down of the Present Value of Scheduled Crack Repair Costs vs. Ship Age

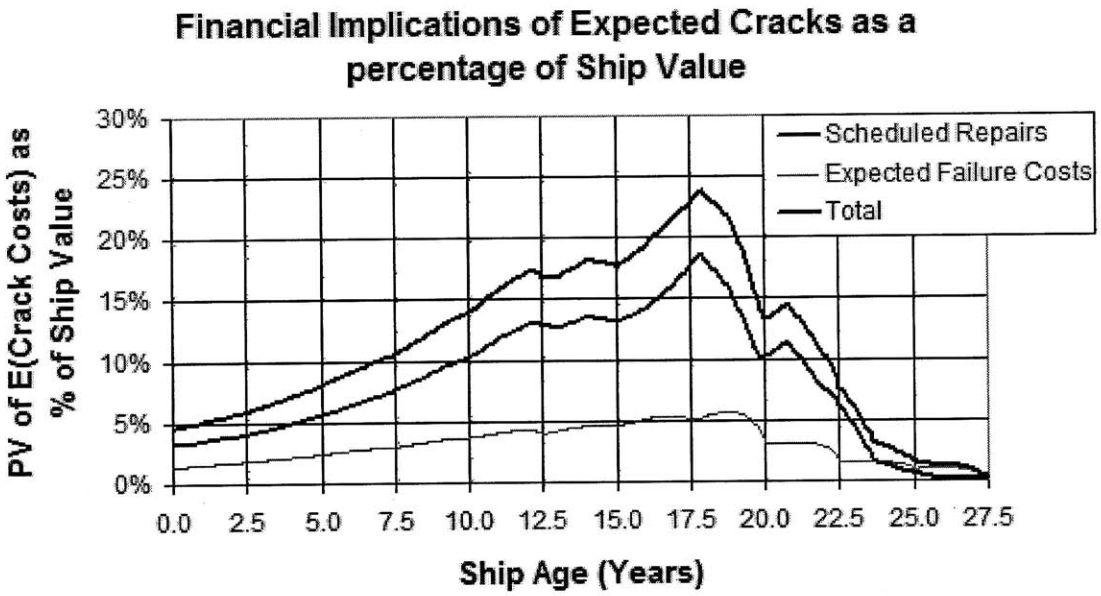


Fig. 5.1-15: Present Value of Total Crack Costs as a Fraction of Ship Value vs. Ship Age

The cost of future cracks accounts for just under 5% of a new ship's value, while the peak is just under 25% for a ship ~18 years old. These values are overstated because the analysis assumes crack repair costs based on prices in China in Sept 2008. Repair prices at the time were unusually high because of market conditions. Freight rates and newbuilding prices were at record levels and increasing. This led to a high demand for repairs, because of the increasing fleet size, and to a shortage of supply because shipyards were more keen on lucrative shipbuilding projects. As a result, there were massive queues of ships waiting for repairs and Chinese repair yards had significant market power. The price of scheduled repairs (blue line in Fig. 5.1-15) is therefore quite exaggerated. On the other hand, the projection of expected failure costs (pink line), and the ship values, are based on 10-year averages.

The 10-year average data of crack repair prices, required to carry out the full analysis of this chapter, is not available. However, a large database of repairs carried out in China (used in Section 5.2) was used to estimate the 10-year average cost of repairs relative to September 2008. The result was 42.15% and the analysis can be found in Section 5.2. This value can be used to scale down the cost of scheduled repairs (blue line in Fig. 5.1-15), and

repeat Fig. 5.1-15 to reflect 10-year average data. Using the 10-year average repair costs and a discount rate of 10%, the net present value of projected scheduled crack repair costs for a new ship is $0.9M. Fig. 5.1-16 shows how this value varies throughout the ship's life, along with expected failure costs.

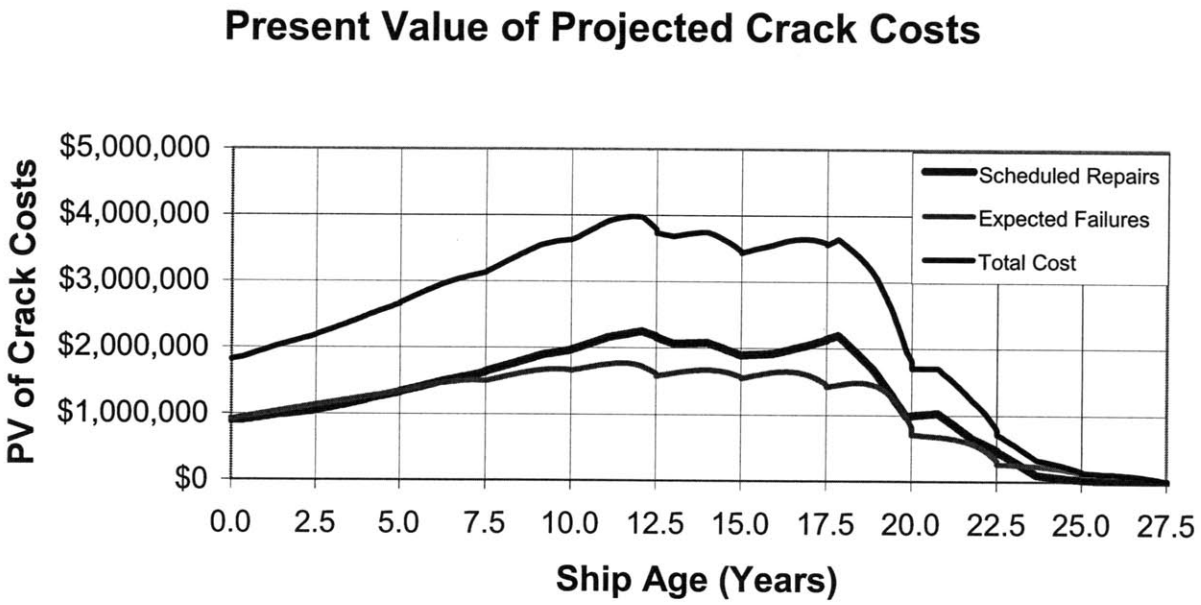


Fig. 5.1-16: Present Value of Projected Crack Costs Using a 10% Discount Rate and 10-Year Avg. Values

Throughout the ship's life, the present value of scheduled crack repairs is similar to that of expected crack failures. The total is $1.82M for a new ship and peaks at $3.98M for a 11.8 year old. Fig. 5.1-17 repeats Fig. 5.1-15, using 10-year average repair prices (as opposed to Sep-2008 data). The total financial implications of cracks account for ~2.7% of a new ship's value and 13.1% of a 17.8 year old vessel's value.

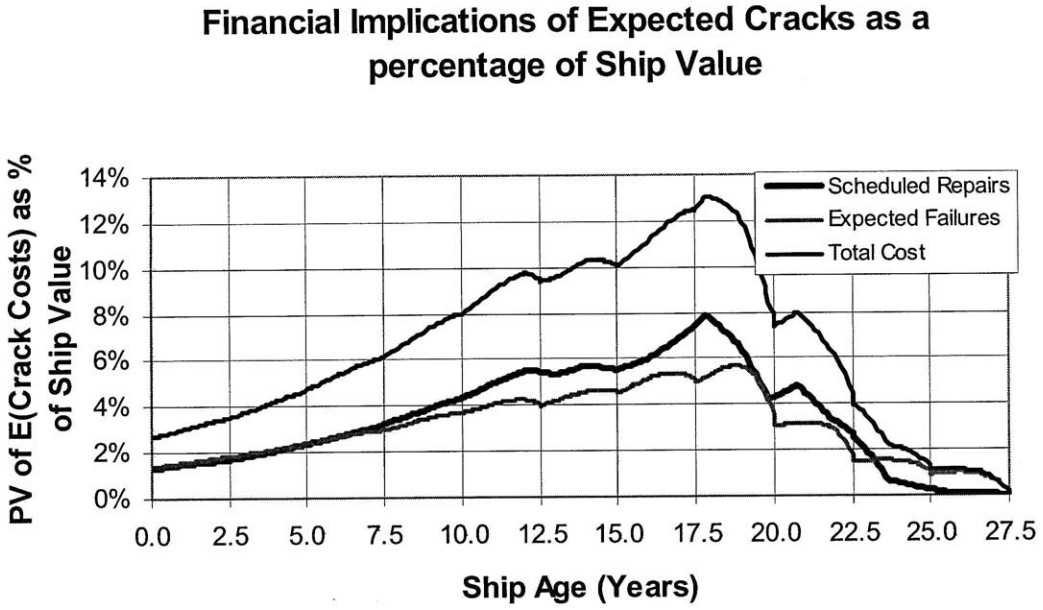


Fig. 5.1-17: Present Value of Projected Crack Costs as a % of Ship Value, Using 10-Year Avg. Data

5.2 Steel Renewals and Repairs

5.2.1 Introduction

The purpose of this section is to use a large sample of capesize bulk carrier dry dock repairs, to deduce statistics that can be used to predict the requirements throughout a ship's life. Data was collected from shipyards, shipowners and shipyard agents who work as intermediaries between shipyards and shipowners. Approximately half of the data came from agents who represent the major Chinese shipyards.

5.2.2 Repair Database

Data was collected for a total of 346 repairs. Each data sample includes the repair date and duration, ship age, tons of steel replaced and surface area sandblasted and coated. Some data also includes the total cost of the repair, and the travel time to and from the shipyard. Table 5.2-1 summarizes the main statistics of the data sample.

Summary Statistics	
Number of Repairs	346
Mean Ship Age (years)	14.7
Mean Ship Size (dwt)	162,753
Mean Steel Replaced (tons)	392
Mean SB/Coating Area (m^2)	21,490
Mean Repair Duration (days)	39

Table 5.2-1: Summary of Statistics for Repair Data

The price paid to the shipyard was available for 187 of the repairs and the mean was $1.3M. Travel time ranged between 0.5 and 4 days each way (to and from the repair yard). 13 of the repairs were carried out in the 1990s and the rest were from the 2000s. Fig. 5.2-1 shows the number of repairs carried out each year.

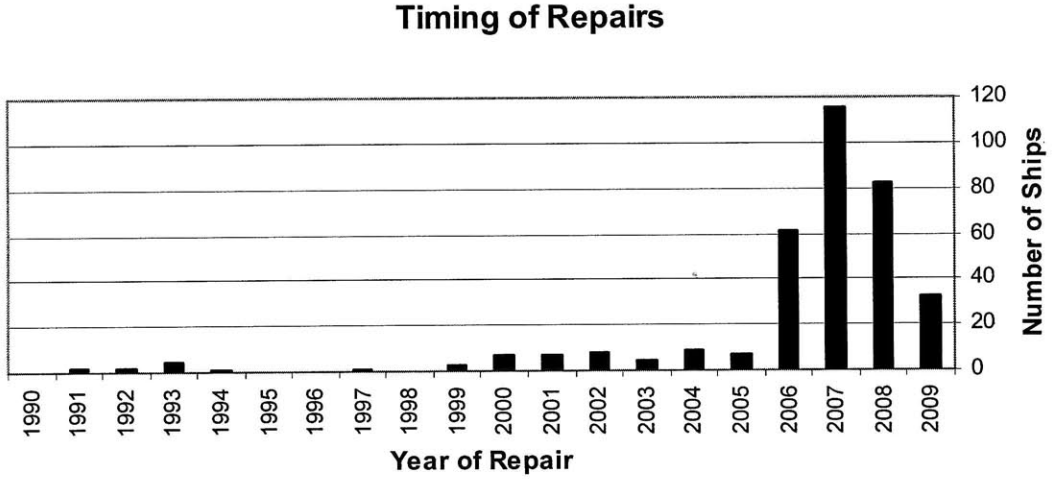


Fig. 5.2-1: Distribution of Data of by Year of Repair

Fig. 5.2-2 Shows the age of ships at the time of repair. The number of ships repaired is shown for each ship age.

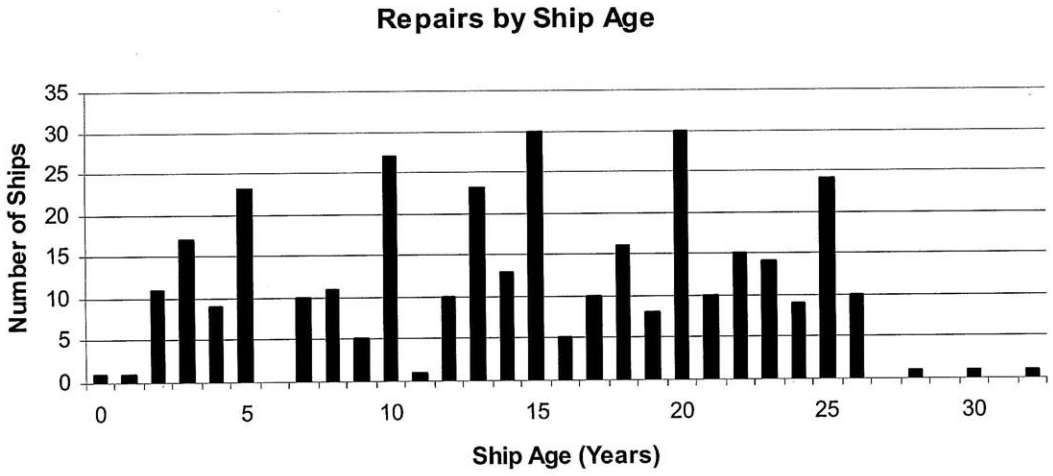


Fig. 5.2-2: Distribution of Data of by Ship Age at Repair

The data is well distributed across ships of all ages and most of the dry docks occur at the scheduled ages which are multiples of 2.5 years. The average tons of steel replaced, area sandblasted and repair duration were calculated for each ship age and the results are presented in Fig. 5.2-3, 5.2-4 and 5.2-5 respectively.

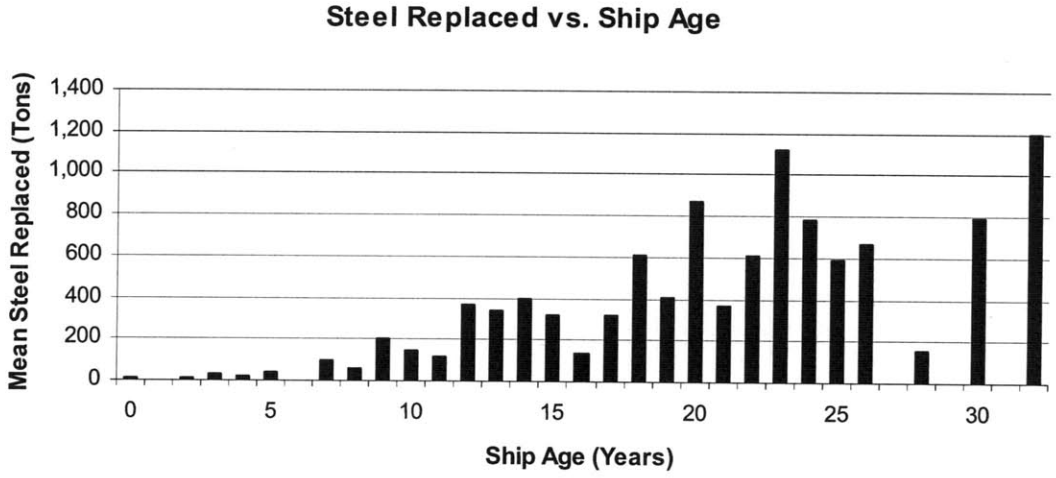


Fig. 5.2-3: Average Tons of Steel Replaced as a Function of Ship Age

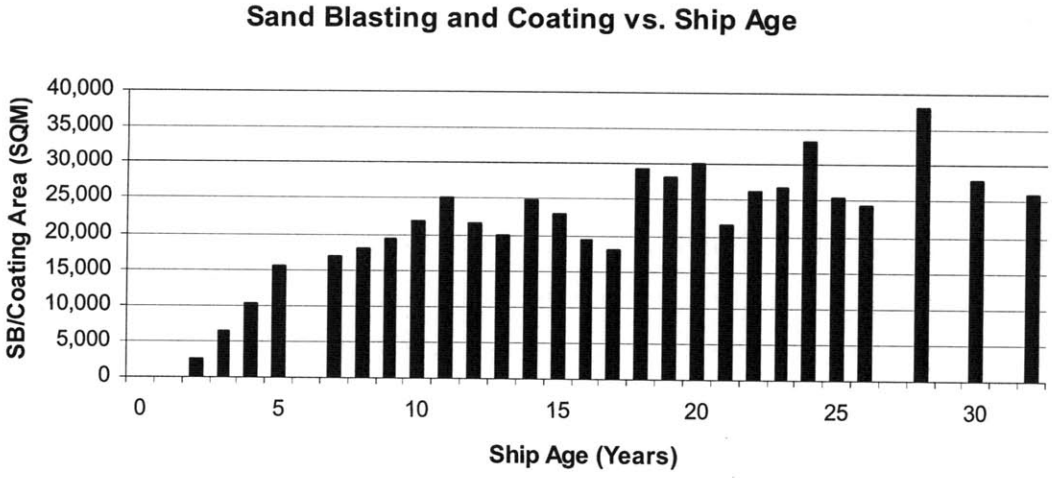


Fig. 5.2-4: Average Area Sandblasted as a Function of Ship Age

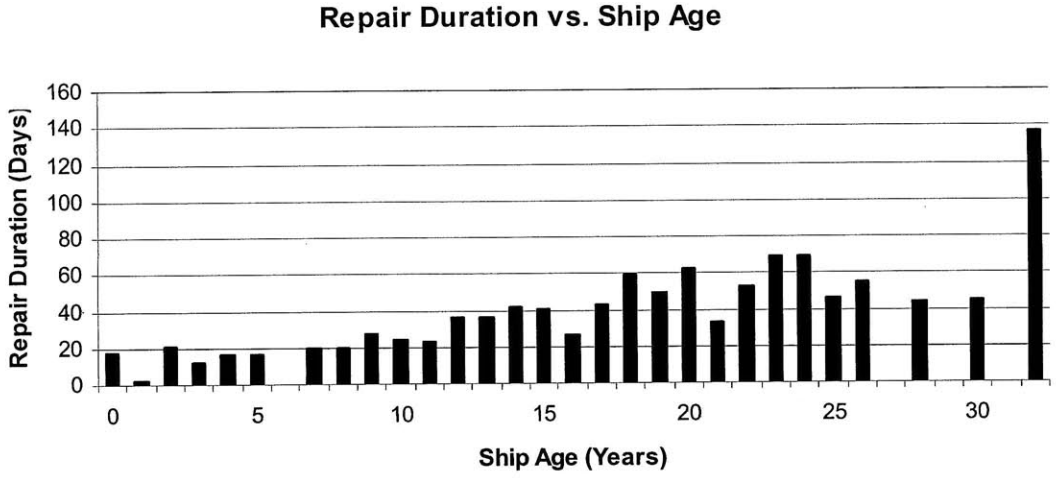


Fig. 5.2-5.2-5: Average Repair Duration as a Function of Ship Age

5.2.3 Cost of Repairs

The total price paid to the shipyard was available for 187 of the repairs, which is slightly over half the database. These were used to calibrate a formula that gives an estimate of the repair cost based on the remaining parameters that are available for the whole data set. The formula chosen to describe the whole repair cost is:

$$P = A(Tons) + B(m^2) + C(Age) + D(Days) + E \qquad (5.2\text{-}1)$$

The constants A, B, C, D and E were calibrated to fit the data, and then a repair cost index was developed based on the average differences of data points from the formula over time. The chosen time interval varied between a quarter and a year depending of the availability of data. The index was developed for the past 10 years and adjusted as a percentage of the September 2008 value, which seems to be the peak based on the data. This part of the analysis had to be carried out because similar statistics are not available in the open literature. These results have to be relied upon for the remainder of the analysis. The results are shown in Fig. 5.2-6.

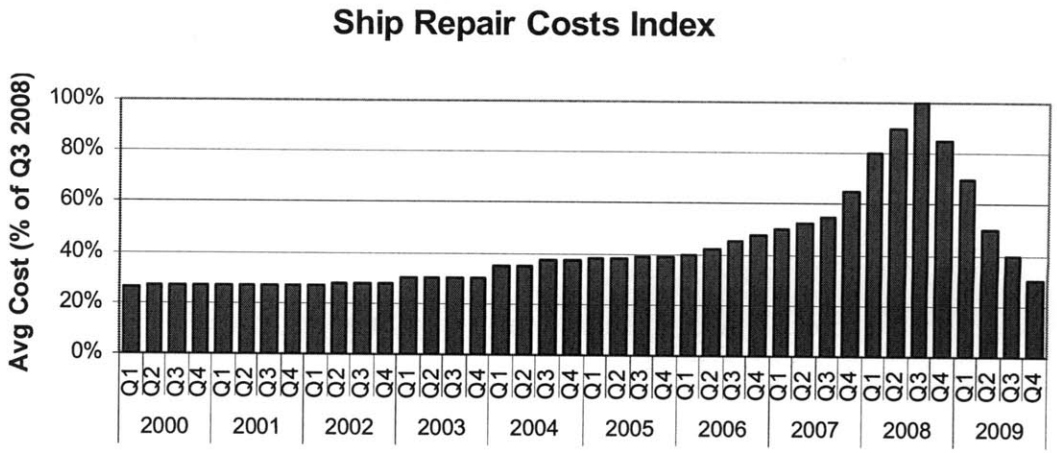


Fig. 5.2-5.2-6: China - Cape Repair Cost Index

The average over the past 10 years is 42.15% of the September 2008 value and 71.17% of the current value (End 2009). The formula constants for Sept 2008 are summarized in Table 5.2-2.

Constant	Value
A	5,064
B	14.1
C	8,222
D	2,846
E	335,224

Table 5.2-2: Repair Pricing Formula Calibration Constants for Sep 2008

It is important to note the significance of these values as they are not prices charged directly by the shipyards. As discussed in Section 5.1.4.3, the base price of steel in Sep-2008 was close to $2.8/kg and ranged up to $4.76/kg with surcharges. The value of $5,064/ton in Table 3, however, includes the amount of staging, labor and other factors, that varies directly with the amount of steel. The formula does not serve as a breakdown of costs into steel, sandblasting etc. It simply estimates the total cost of a repair based on the inputs, when used in combination with Fig. 5.2-6.

It is interesting to note that the peak in ship repair costs roughly coincides with the peak in orderbook size. As discussed in Section 2.7.1, the orderbook size peaked at 855 capes, or 105% of the world fleet, in October 2008. These numbers exclude the ships that were being converted from single hull tankers to bulk carriers.

Ship repair prices peaked due to a combination of increasing demand, decreasing effective supply, and increasing costs. Demand for ship repairs was increasing because the fleet was expanding rapidly and no ships were being scrapped. Due to the extremely high freight rates, it was worthwhile repairing old ships rather than scrapping them. Supply was decreasing although new shipyards were being built, because they were shifting their resources to shipbuilding since newbuilding prices were also at record high levels. Newbuilding prices peaked at $99M for a typical Cape in August 2008. This was all at a time when steel prices, labor costs and the cost of other raw materials was also relatively high and increasing.

Another finding was that shipyards in the south were relatively more expensive than in the north of China. Eight major Chinese shipyards were chosen and their average prices charged were compared. The results are shown in Table 5.2-3.

Shipyard	Price as % of Typical
YIU LIAN	108
XINYA	100
IMC	100
COSCO	106
SHANHAIGUAN	96
CHENG SHIN	107
CHANG SHIN	92
GOUANGZHOU	109

Table 5.2-3: Repair Prices by Chinese Shipyard

5.2.4 Crack Cost as Fraction of Total Repair Cost

Table 5.2-2 can be combined with the data of Fig. 5.2-3, 4 and 5.2-5 to produced a $ amount for each year based on Sep-2008 prices. This can then be compared with the results on cracks costs from Section 5.1.5, which are also based on Sep-2008 prices. Since no repairs are available for year 27, there is only one repair for each of years 28, 30 and 32, and the crack cost data only extends to 28 years. The average of the 3 data points of 27+ years was used for the age of 27 and 28. The crack cost was calculated as a percentage of the total repair cost for each year and the results are shown in Fig. 5.2-7.

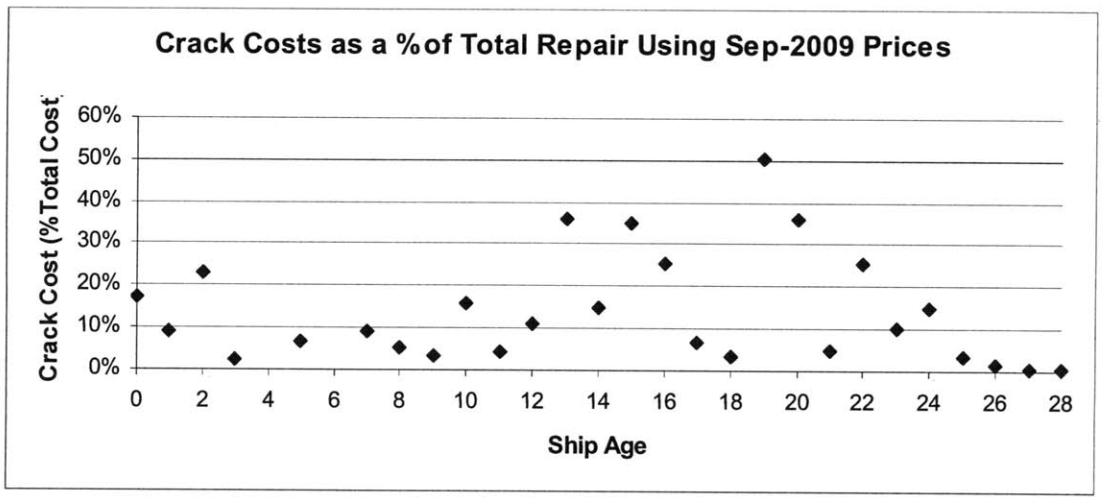


Fig. 5.2-7: Crack Repair Cost as a % of Total Repair Cost for each Ship Age using Sep-2009 Prices

The data of Fig. 5.2-7 implies that crack costs account for approximately 14% of total repair costs as calculated by various ways. Excluding year 4, for which there is no data on crack costs, and year 6, for which there is no data on total repair costs, the average fraction of crack costs was 13.98%. Crack costs, summed over the 28 years account for 14.05% of total summed repair costs, and the discounted crack costs, using a discount rate of 10% account for 14.58% of the discounted total repair costs.

It is important, however, to note that the results for crack costs and total repair costs come from two different data samples (different repairs). It is also important to note that the result depends on how you distribute some of the repair costs that are shared between crack-

related and non-crack-related works. For example, staging was included in the cost of cracks but will also be necessary for other work such as sandblasting and coating.

Since the ship repair cost index of Fig.5.2-6, affects both the cost of cracks and the total repair cost, the result of Fig. 5.2-7 which shows one as a percentage of the other, should not be expected to change for another time period.

5.2.5 Prediction of Lifetime Repair Costs for Typical Cape

When examining Fig. 5.2-3, 5.2-4 and 5.2-5, there are several factors to keep in mind. First, as shown in Fig. 5.2-2, there are no data samples for some ages and only one for others. There is only one sample for the age of 32, which distorts the results as it is an extreme case that lasted over 4 months. Second, a ship only goes on dry dock every 2 or 3 years, so no single ship would undergo a repair pattern as depicted by those figures. Both these problems are solved by grouping the ships and calculating an average for every survey type, as opposed to every ship age. For example, all the ships aged 9 to 11 years are grouped under one category, the second special survey (SS2) which is typically passed at the age of 10 years. That is because a 9 year old ship would typically not go on dry dock again during the next two years. The results of this analysis are summarized in Table 5.2-4.

This shows that an average cape would spend approximately 14 months at repairs, replacing 4,325t of steel (roughly 20% of its lightship) and sandblasting 228,444m^2 of its surface area throughout its lifetime. Furthermore, time travelling to and from shipyards would amount to an additional 45 days, assuming an average trip time of 2.25days (based on the available data) of over the 10 scheduled repairs. The total time lost to repairs therefore amounts to 476 days, or 16 days per year, assuming the ship is scrapped when 28 years old. This leaves a remainder of 349 earning days, which is surprisingly close to the rule of thumb of 350 earning days per year.

Survey Type	Age Range	Typical Age	No. of Ships	Steel (Tons)	Area SB (m^2)	Duration (Days)
SS1	0 to 6	5	62	25	9,371	16
DD	7 to 8	7.5	21	77	17,381	20
SS2	9 to 11	10	33	154	21,576	25
DD	12 to 13	12.5	33	346	20,355	36
SS3	14 to 16	15	48	321	23,035	39
DD	17 to 18	17.5	26	497	24,885	53
SS4	19 to 21	20	48	684	27,958	54
DD	22 to 23	22.5	29	860	26,379	61
SS5	24 to 26	25	43	648	26,837	53
DD	27+	27.5	3	713	30,667	75
Total			**346**	**4,325**	**228,444**	**431**

Table 5.2-4: Average Repair Metrics for Scheduled Repairs

Another factor that should be considered is the ship deadweight. Since the purpose of this section is to predict the repair costs for a typical 172,000dwt cape, the data should be adjusted to account for the size. Since the average size of the ships in the database was 162,753dwt, the difference will not be very big, but still worth examining. Since all capes have a similar shape, by assuming that the amount of steel replaced is proportional to the hull surface area and that the deadweight is proportional to the volume, the following approximation can be made:

$$Tons_{172,000} = Tons_{dwt}\left(\frac{172,000}{dwt}\right)^{2/3} \qquad (5.2\text{-}2)$$

Similarly, by assuming that the area sandblasted is also proportional to the hull surface area, we can also relate the area sandblasted of a ship of size "dwt" to that of a 172,000dwt ship as follows:

$$m^2_{172,000} = m^2_{dwt}\left(\frac{172,000}{dwt}\right)^{2/3} \qquad (5.2\text{-}3)$$

The duration of the repair may be assumed to also vary with the deadweight raised to the power of 2/3, because it varies with the amount of steel replaced and area sandblasted. However, one can make the argument that more people would work on a larger ship, thereby finishing at the same time. One way to test this argument is to examine the repair speed with respect to ship size for the whole dataset. Fig. 5.2-8 and 5.2-9 show the steel replacement speed and the sandblasting speed respectively with respect to ship size.

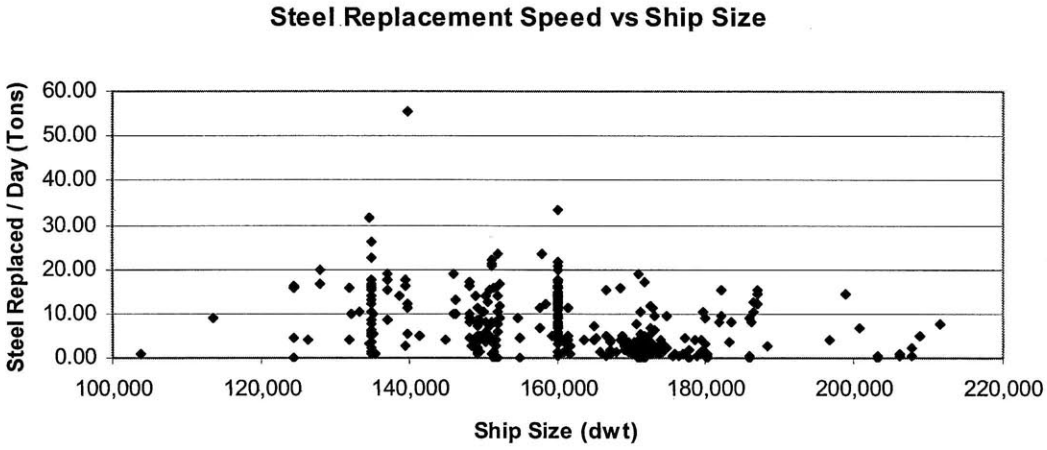


Fig. 5.2-8: Steel Replaced per Day with Respect to Ship Size

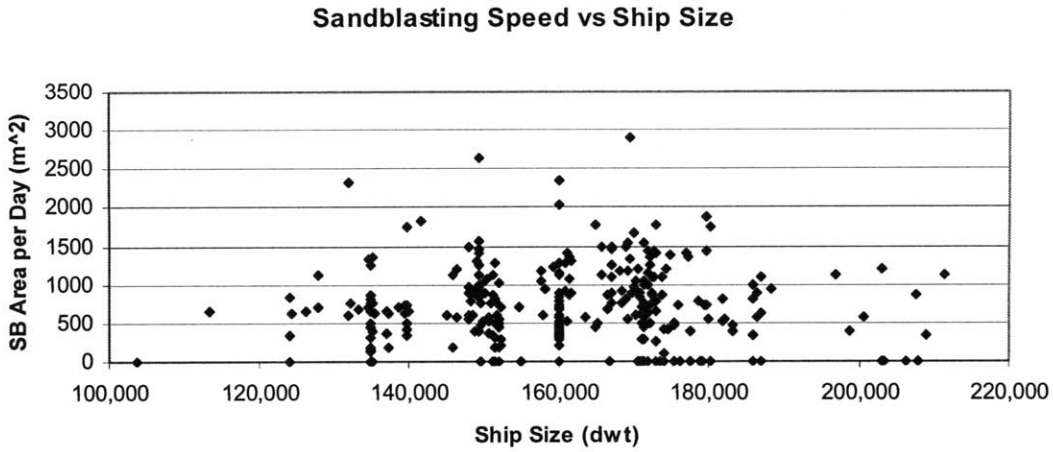


Fig. 5.2-9: Area Sandblasted per Day with Respect to Ship Size

It is clear from Fig. 5.2-7 and 5.2-8, that an argument cannot be made for the speed of repair being higher in larger ships because of the use of more workers. Therefore, the original assumption is maintained and the repair duration is scaled as follows:

$$Days_{172,000} = Days_{dwt}\left(\frac{172,000}{dwt}\right)^{2/3} \qquad (5.2\text{-}4)$$

The data of all the repairs was converted to the 172,000dwt equivalent using the ship deadweight in formulae 5.2-2, 5.2-3 and 5.2-4. The price of these repairs was then recalculated by inputting the updated values in formula 5.2-1. The adjustment to 172,000dwt resulted on average in an increase of tons replaced by 7.8%, area sandblasted by 6.1%, repair duration by 5.7% and total repair cost by 6.3%. The analysis of Table 5.2-4 was repeated using the 172,00dwt equivalent values and the results are presented in Table 5.2-5.

Survey Type	Age Range	Typical Age	No. Of Ships	Steel (Tons)	Area SB (m^2)	Duration (Days)	Cost ($)
SS1	0 to 6	5	62	25	9,338	15	286,705
DD	7 to 8	7.5	21	80	17,969	20	468,512
SS2	9 to 11	10	33	158	21,941	25	673,664
DD	12 to 13	12.5	33	369	21,720	38	1,146,676
SS3	14 to 16	15	48	340	24,868	42	1,117,665
DD	17 to 18	17.5	26	523	26,479	56	1,542,475
SS4	19 to 21	20	48	722	29,112	57	1,992,464
DD	22 to 23	22.5	29	948	28,343	66	2,490,328
SS5	24 to 26	25	43	725	29,804	58	2,022,227
DD	27+	27.5	3	830	35,823	88	2,326,158
Total			**346**	**4,720**	**245,397**	**465**	**14,066,873**

Table 5.2-5: Average Repair Metrics for Scheduled Repairs for 172,000dwt

The revised estimates for a 172,000dwt ship show that it is expected to spend approximately $14M and 1.27 years on dry dock repairs, replacing about a fifth of its steel over its lifetime.

In order to get a more representative result throughout the ship's life, the results of Table 5.2-5 can be distributed across ages 0 to 28. This is done according to the fraction of ships undergoing each scheduled repair, accounted for by each ship age. For example, the 33 ships passing the SS2, comprised of 15% ship aged 9 years old, 82% ships aged 10 years old and 3% ships aged 11 years old. Therefore, the results for age 9 are calculated as 15% of the SS2 values in Table 5.2-5. The three data samples in age groups 28, 30 and 32 years were bundled together in the and distributed evenly between ages 27 and 28, to eliminate the effect of outliers and to accommodate our lifetime assumptions throughout the project.

To accommodate for the lack of data in year 6, the average percentage of ships undergoing a special repair in each of years 11, 16, 21 and 26 (the year following the scheduled date) was calculated. The result was 14.38% and was applied to year 6. The difference was removed proportionately from years 0 through 5 by multiplying the original

values by 85.62%. This was done to satisfy the total of years 0 through 6 adding up to 100% for the first special survey.

As for steel replaced, sandblasting and repair duration, the price column was also calculated by multiplying the percentage of each age by the corresponding repair values in order to avoid double counting. If the price column had been calculated by applying the formula 5.2-1 on the year's data, it would result in double counting of the third and fourth terms (as if a whole repair was carried out every year).

Age (Years)	% of D/D in Year Age	Steel (Tons)	Area SB (m^2)	Duration (Days)	Cost ($)
0	1.38%	0.35	129	0.21	$3,959
1	1.38%	0.35	129	0.21	$3,959
2	15.19%	4	1418	2	$43,550
3	23.48%	6	2192	4	$67,305
4	12.43%	3	1161	2	$35,632
5	31.76%	8	2966	5	$91,060
6	14.38%	4	1343	2	$41,240
7	47.62%	38	8557	9	$223,101
8	52.38%	42	9412	10	$245,411
9	15.15%	24	3324	4	$102,070
10	81.82%	129	17952	21	$551,180
11	3.03%	5	665	1	$20,414
12	30.30%	112	6582	12	$347,478
13	69.70%	257	15138	27	$799,198
14	27.08%	92	6735	11	$302,701
15	62.50%	213	15543	26	$698,541
16	10.42%	35	2590	4	$116,423
17	38.46%	201	10184	21	$593,259
18	61.54%	322	16295	34	$949,215
19	16.67%	120	4852	9	$332,077
20	62.50%	451	18195	35	$1,245,290
21	20.83%	150	6065	12	$415,097
22	51.72%	490	14660	34	$1,288,101

23	48.28%	458	13683	32	$1,202,227
24	20.93%	152	6238	12	$423,257
25	55.81%	405	16635	33	$1,128,685
26	23.26%	169	6931	14	$470,285
27	50.00%	415	17911	44	$1,163,079
28	50.00%	415	17911	44	$1,163,079
Total	**10**	**4,720**	**245,397**	**465**	**$14,066,873**

Table 5.2-6: Repair Metrics for Every Year Adjusted for 172,000dwt

As verification, the values of the row of totals of Table 5.2-6 are identical to those of Table 5.2-5, showing that all we have done is, distribute the data of Table 5.2-5 throughout the ship's life. As explained previously, had the "Total Cost" column been calculated by applying formula 5.2-1 to the data of each row, the total would be greater than that of Table 5.2-5. That is because the 3rd and 4th term would be included 29 times (every year) as opposed to 10 (the typical number of repairs a ship is expected to undergo).

The travel time was also calculated for each year by multiplying the year's percentage value by 4.25 days (to include the trips to and from the shipyard). This is added to the Duration column but does not affect the cost of the repair. The results are summarized in Table 5.2-7.

Age (Years)	% of D/D in Year Age	Repair Days	Travel Days	Total Days
0	1.38%	0.21	0.0586884	0.3
1	1.38%	0.21	0.0586884	0.3
2	15.19%	2	0.645572	3.0
3	23.48%	4	0.9977022	4.6
4	12.43%	2	0.5281953	2.4
5	31.76%	5	1.3498324	6.2
6	14.38%	2	0.6113212	2.8
7	47.62%	9	2.0238095	11.4
8	52.38%	10	2.2261905	12.5
9	15.15%	4	0.6439394	4.5

10	81.82%	21	3.4772727	24.2
11	3.03%	1	0.1287879	0.9
12	30.30%	12	1.2878788	12.9
13	69.70%	27	2.9621212	29.7
14	27.08%	11	1.1510417	12.6
15	62.50%	26	2.65625	29.0
16	10.42%	4	0.4427083	4.8
17	38.46%	21	1.6346154	23.0
18	61.54%	34	2.6153846	36.8
19	16.67%	9	0.7083333	10.1
20	62.50%	35	2.65625	38.0
21	20.83%	12	0.8854167	12.7
22	51.72%	34	2.1982759	36.3
23	48.28%	32	2.0517241	33.9
24	20.93%	12	0.8895349	13.1
25	55.81%	33	2.372093	34.9
26	23.26%	14	0.9883721	14.5
27	50.00%	44	2.125	46.0
28	50.00%	44	2.125	46.0
Total	**10**	**465**	**42.5**	**507.6**

Table 5.2-7: Total Days Spent for Repairs Including Travel Time

Finally, the results of Table 5.2-6 and 5.2-7 can be used to determine the repair cost per day and the number of earning days per month throughout the ship's life. This is done by simply dividing the "Cost" column of Table 5.2-6 by 365 days/year and by subtracting the "Total Days" column of Table 5.2-7 from 365 and the dividing by 12. The results are shown in Table 5.2-8. A row is also added for repair costs per day with End-2009 prices by scaling the results using the index of Fig. 5.2-6.

Age (Years)	Rep Cost (10-yr Avg.) ($/Day)	Rep Cost (End 2009) ($/Day)	Earning Days per Month
0	$10.85	$7.72	30.37
1	$10.85	$7.72	30.37
2	$119.32	$84.92	30.15
3	$184.40	$131.24	30.01
4	$97.62	$69.48	30.19
5	$249.48	$177.56	29.88
6	$112.99	$80.42	30.16
7	$611.24	$435.04	29.45
8	$672.36	$478.55	29.36
9	$279.64	$199.04	30.02
10	$1,510.08	$1,074.79	28.38
11	$55.93	$39.81	30.32
12	$951.99	$677.58	29.32
13	$2,189.58	$1,558.42	27.92
14	$829.32	$590.26	29.35
15	$1,913.81	$1,362.14	27.98
16	$318.97	$227.02	29.99
17	$1,625.37	$1,156.85	28.48
18	$2,600.59	$1,850.95	27.33
19	$909.80	$647.55	29.55
20	$3,411.75	$2,428.29	27.23
21	$1,137.25	$809.43	29.34
22	$3,529.04	$2,511.77	27.37
23	$3,293.77	$2,344.32	27.57
24	$1,159.61	$825.34	29.30
25	$3,092.29	$2,200.92	27.49
26	$1,288.45	$917.05	29.18
27	$3,186.52	$2,267.98	26.56
28	$3,186.52	$2,267.98	26.56
Average	**$1,328.94**	**$945.17**	**28.94**

Table 5.2-8: Daily Repair Costs and Earning Days per Month for Every Year

The results indicate an average of $1,329/day for repair costs and an average of 347.5 earning days per year for a 172,000dwt cape. The present value of the repair costs, assuming that the 10-yr average values of Table 5.2-6 are paid at the end of each year, amounts to $2,306 using a 10% discount rate.

5.2.6 Verification of Results with Other Sources

Very limited data exists on the topic specifically for Capes. Only two reliable sources have been identified for verification of the above results. First, an analysis has been carried out by [Stopford 2009] using 1993 data from Clarksons Brokers, on the repair costs of Capes. Second, a survey was carried out on 6 private and 4 public shipping companies that operate capes. Not all companies have owned capes of all ages, but they submitted estimates of the cost breakdown for the previous decade (average since 2000) and using today's prices. Fig. 5.2-10 presents the results by [Stopford 2009], which cover a wide range of ages and are conveniently broken down in detail.

	Age of ship				
	0–5	6–10	11–15	16–20	
Time out of service (days)	**20**	**23**	**40**	**40**	
Time in drydock (days)	**10**	**14**	**23**	**18**	**Total**
Cost Items (USD)					
Dry-dock charges	62,000	68,000	81,500	74,000	285,500
Port charges, tugs, agency	70,000	73,300	92,000	92,000	327,300
General services	80,000	92,000	160,000	160,000	492,000
Hull blast, clean & painting	102,800	128,800	183,600	99,000	514,200
All dry-dock paint	164,100	175,500	207,000	194,100	740,700
All steel replacement	70,000	350,000	1,190,000	840,000	2,450,000
Cargo spaces	22,200	64,200	126,000	150,000	362,400
Ballast spaces	36,400	23,200	26,000	47,400	133,000
Hatch covers & deck fittings	28,000	56,320	60,560	60,560	205,440
Main engine and propulsion	46,000	42,000	48,000	48,000	184,000
Auxiliaries	27,000	34,000	134,000	44,000	239,000
Piping & valves	18,000	37,000	50,000	34,000	139,000
Navigation & communications	9,000	11,000	11,000	11,000	42,000
Accommodation	6,000	8,000	7,000	7,000	28,000
Surveys & surveyors	70,000	78,500	113,000	108,000	369,500
Miscellaneous	100,000	100,000	100,000	100,000	400,000
Spare parts & subcontractors	70,000	100,000	100,000	120,000	390,000
Owner's attendance	23,800	25,600	35,800	35,800	121,000
Estimated total	1,005,300	1,467,420	2,725,460	2,224,860	7,423,040
Averaged annual cost	201,060	293,484	545,092	444,972	
Averaged daily cost	551	804	1,493	1,219	

Source: Clarkson Research, Capesize Quality Survey (1993)

Fig. 5.2-10: Standard Capesize Lifetime Periodic Repair Costs based on 1993 data [Stopford 2009]

Steel replacement (line 6) is the biggest cost component after the age of 5 years. Unfortunately, it is not possible to compare the cost breakdown of Fig. 5.2-10 to the results produced by Eq. 5.2-1. The items of Fig. 5.2-10 that scale with our regression parameters (tons, area, days etc), have automatically been incorporated in the regression constants (A, B, C) summarized in Table 5.2-2. In our case, for example, the "tons" coefficient (A) includes fractions of the other line items of Fig. 5.2-10 that scale with the amount of steel replaced.

For comparison purposes, the results of Table 5.2-7 have been converted to the same aged groups of Fig. 5.2-10. That way, a direct comparison can be made between our results and the average daily cost (bottom line) of Fig. 5.2-10.

The results of Fig. 5.2-10, are based on 1993 data. Unfortunately, the index we developed in Fig. 5.2-6 does not go that far back, so these cannot be converted to today's prices. Furthermore, the line items in Fig. 5.2-10 are only supplied in terms of $, (as opposed to tons, m^2 etc), so Eq. 5.2-1 cannot be applied on them. However, they can at least be converted from 1993 dollars to today's dollars.

According to statistics of the *Bureau of Labor*, the Consumer Price Index was 144.5 and 214.5 for 1993 (year average) and for December 2009. This implies that $1,000 in 1993 have about the same buying power as $1,484.43 in 2010. The respective levels of the Producer Price Index were 118.9 and 173.0, implying a buying power of $1,455.00 [CDRPC 2010]. The baseline year of the index is 1982. Taking the average, $1,000 in 1993 have about the same buying power as $1,469.78 in 2010. According to [HBrothers 2010], 1000 dollars in 1993 have about the same buying power as $1,521.84 in 2010. The average of the two sources is $1,495.78, so a dollar in 1993 had roughly the same spending power as $1.5 have today. This can be used to convert the numbers of Fig. 5.2-10 to today's prices.

Table 5.2-9 provides a summary of our results using both 10-year average prices and today's prices, the results of [Stopford 2009] from Fig. 5.2-10 in 1993 dollars and converted to today's dollars, and the average results from the 6-firm survey for 10 year average costs and using today's prices.

Ship Age (years)	Our Results: 10-yr Avg. Prices	Our Results: Dec 2009 Prices	Stopford: 1993 Prices (in 1993$)	Stopford: 1993 Prices (in 2010$)	Survey: 10-yr Avg. Prices	Survey: Dec 2009 Prices
0 - 5	$112	$80	$551	$824	$578	$438
6 - 10	$637	$454	$804	$1,203	$786	$602
11 - 15	$1,188	$846	$1,493	$2,233	$1,119	$816
16 - 20	$1,773	$1,262	$1,219	$1,823	$1,465	$1,019
21 - 25	$2,442	$1,738	-	-	$2,176	$1,495
26 - 28	$2,554	$1,818	-	-	-	-
0 - 20	$928	$660	$1,017	$1,521	$987	$719
0 - 25	$1,230.63	$875.84	-	-	$1,224.67	$874.27

Table 5.2-9: Dry Dock Repair Prices in $/Day vs. Age from Various Sources

The results stemming from our analysis of 346 repairs are very similar to those reported in the Survey of 6 firms operating Capes. This is particularly true for the average values between 0 and 25 years using both current and ten year average prices. Furthermore, the Survey results also validate the index developed in Fig. 5.2-6. By comparing the last two

columns of Table 5.2-9 we can get current prices as a percentage of 10-year average prices. The values range from 68.73% to 76.54% with an average of 72.74%. Using the current index value of Fig. 5.2-6 is 71.17% of the 10-year average, which is remarkably close.

When converted to current dollars, the 1993 results of [Stopford 2009] are significantly higher than both the repair analysis results and the survey results. This indicates that repair prices have decreased significantly in real terms. This could be due to technological improvements, less use of HTS, Economies of Scale and other factors, but most importantly due to the shift of repairs to low cost countries where they can be carried out more competitively with cheap labor. To illustrate the latter, it is worth examining the timing of the 346 repairs in our database, which is shown in Fig. 5.2-1. Out of the 8 repairs that were carried out between 1991 and 1993, 5 took place in Singapore, 2 in Greece, 1 in Japan and none in China. Of the 333 repairs from 2000 onwards, 331 were carried out in China and 2 were carried out in Spain in 2001.

Table 5.2-10 shows the "Days out of Service" per year from our repair data and from the data of [Stopford 2009] shown in Fig. 5.2-9.

Ship Age (Years)	Our Results (Days/Year)	Stopford (Days/Year)
0 – 5	2.79	4.00
6 – 10	11.07	4.60
11 – 15	17.03	8.00
16 – 20	22.56	8.00
21 – 25	26.19	
26 – 28	35.52	
0 – 20	**13.36**	**6.15**

Table 5.2-10: Off-Hire Days Per Year

The average days out of service between the age of 0 and 20 years, based on our results, are more than double those of [Stopford 2009]. Again it is worth referring to the timing of the repairs in our database, which is shown in Fig. 5.2-1. 259 of the 346 repairs (75%) were carried out between 2006 and 2008. This was during the high market when

massive queues were building up outside shipyards and ships had to wait in line for days before a dry dock was possible. This explains why the average off-hire time is on average about a week per year higher that than reported by [Stopford 2009], whose results are based on 1993 data (a more regular time period in terms of markets and repairs).

5.2.7 Projection of Repair Costs

By considering the Chinese cape repair cost index developed in Fig. 5.2-6 of Section 5.2, we see that it is inappropriate to assume a steady inflation in repair costs. Repair costs are to a large extent associated with factors that are not closely related to inflation such as freight levels, market outlook, supply of ships, shipyard capacity, newbuilding demand etc. We will assume that both repair costs and associated off-hire time follows the past 10 year average values going forward. In our projection, repair costs and off-hire time are only a function of the ship's age and not time.

Table 5.2-9, shows that we are in good agreement with other sources and the results seem reliable overall. However, for the age group 0 to 5, repair cost per day seems too low compared to corresponding figures from our survey and from [Stopford 2009]. Using 10-year average values, our analysis results show a cost of $112/day, whereas the survey results indicate $578/day which is more reasonable. Results from [Stopford 2009] using 1993 prices in today's dollars indicate $824/day which is even higher. For this age range, the most reliable of the three values seems to be the survey result.

We will assume our database results for the 10-year average values. The cost/day results for the 0 to 5 year range will be scaled by 578/112. This will maintain the ratio of spending for each year but increase the average from $112/day to $512/day which is the survey result. For the remainder of the ship's life, the database cost values will remain unaffected. The database off-hire days will also not be modified. The results are summarized in Table 5.2-11 in terms of $/day and percentage earning time (utilization).

Age (Years)	Rep Cost (10-yr Avg.) ($/Day)	% Earning Time
0	$56	99.93%
1	$56	99.93%
2	$615	99.18%
3	$950	98.74%
4	$503	99.33%
5	$1,286	98.29%
6	$113	99.23%
7	$611	96.89%
8	$672	96.58%
9	$280	98.77%
10	$1,510	93.37%
11	$56	99.75%
12	$952	96.46%
13	$2,190	91.85%
14	$829	96.55%
15	$1,914	92.04%
16	$319	98.67%
17	$1,625	93.70%
18	$2,601	89.91%
19	$910	97.22%
20	$3,412	89.57%
21	$1,137	96.52%
22	$3,529	90.04%
23	$3,294	90.70%
24	$1,160	96.41%
25	$3,092	90.43%
26	$1,288	96.01%
27	$3,187	87.39%
28	$3,187	87.39%

Table 5.2-11: Daily Repair Costs and Earning Days per Month for Every Year

5.3 Operations of Listed and Private Companies

5.3.1 Introduction

In order to understand the operation and costs of capes for valuation purposes, it is important to draw a distinction between Listed and Private Companies. Success in this industry depends on many factors such as timing, the ability to raise finance, operating at a low cost to stay in business throughout market downturns etc. Staying private versus being listed in a major stock exchange gives a completely different set of advantages in terms of these success factors and has a big impact on the way a company operates and expands. This chapter provides an insight of this topic through a case study of a listed and a private company that operates capes. The listed company is Dryships Inc. (DRYS) and the private company is Lifedream Compania Naviera (LCN).

5.3.2 Success Factors in the Cape Market

The market is affected by factors such as countries' GDP growth, demand for final products, terrorism and piracy, capacity constraints leading to congestion at ports or canals, interest and exchange rates, steel and fuel prices etc. making it very volatile and unpredictable. A detailed market analysis is provided in Chapter 2.

In general, when demand is high, orders for new ships increase. Since shipyard capacity is constrained, delivery time also increases. The delivery of these ships then pushes rates down. When rates are below a certain level, old ships which are no longer profitable are scrapped. Supply thereby decreases leading to a recovery of rates. This, combined with demand fluctuations makes the market very cyclical.

A group of panelist brokers keeps track of the average daily earnings of Capes and reports them to the Baltic Exchange which then publishes indices. There is a market where

FFAs are traded on these indices allowing owners and charterers to hedge their market exposure. Fig. 5.3-1 shows the Baltic Average Dry Index since 1985 and Fig. 5.3- 2 shows the corresponding daily earnings over the last 5 years.

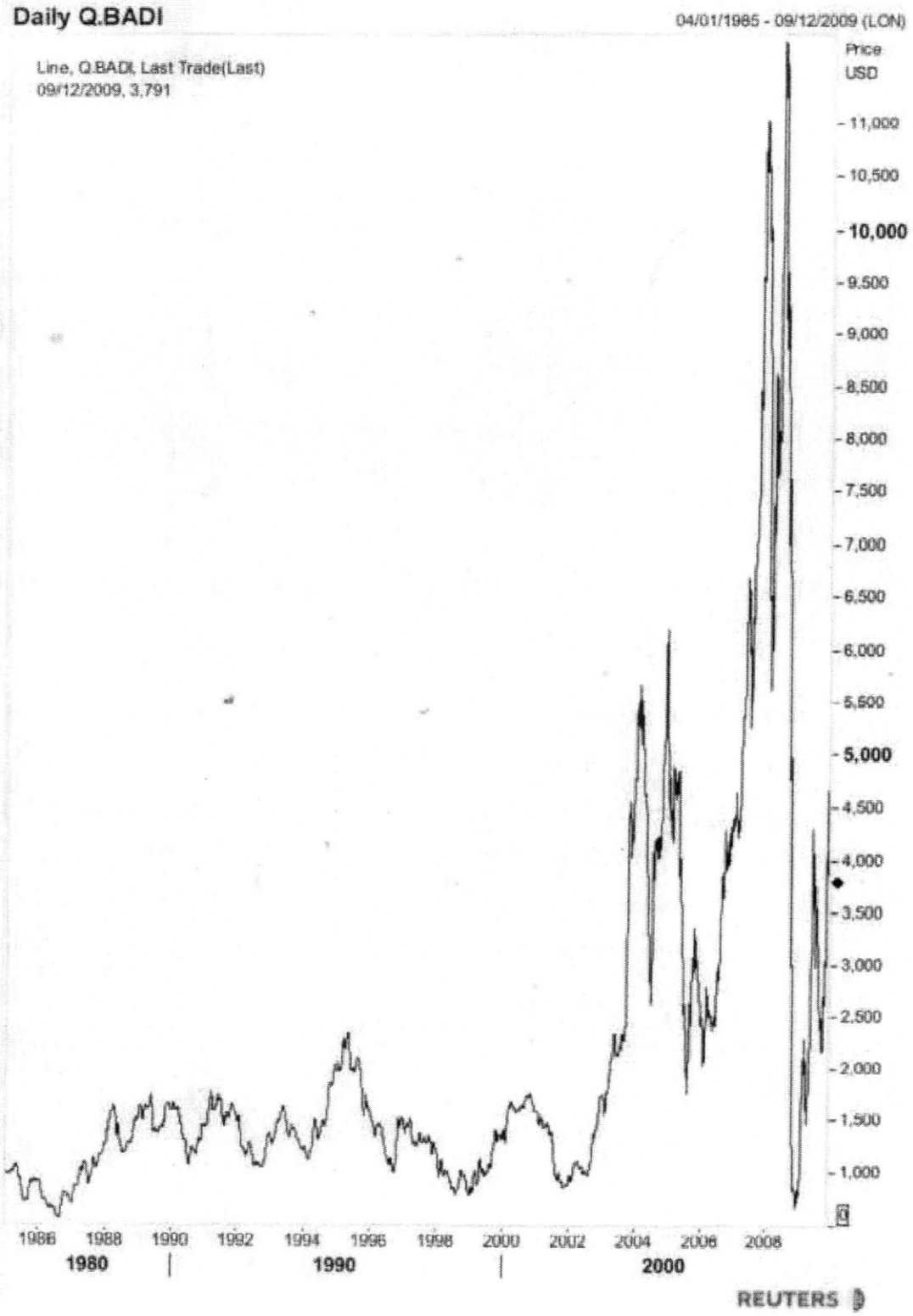


Fig. 5.3-1: Baltic Average Dry Index Jan-1985 – Dec 2009 [Lifedream 2009]

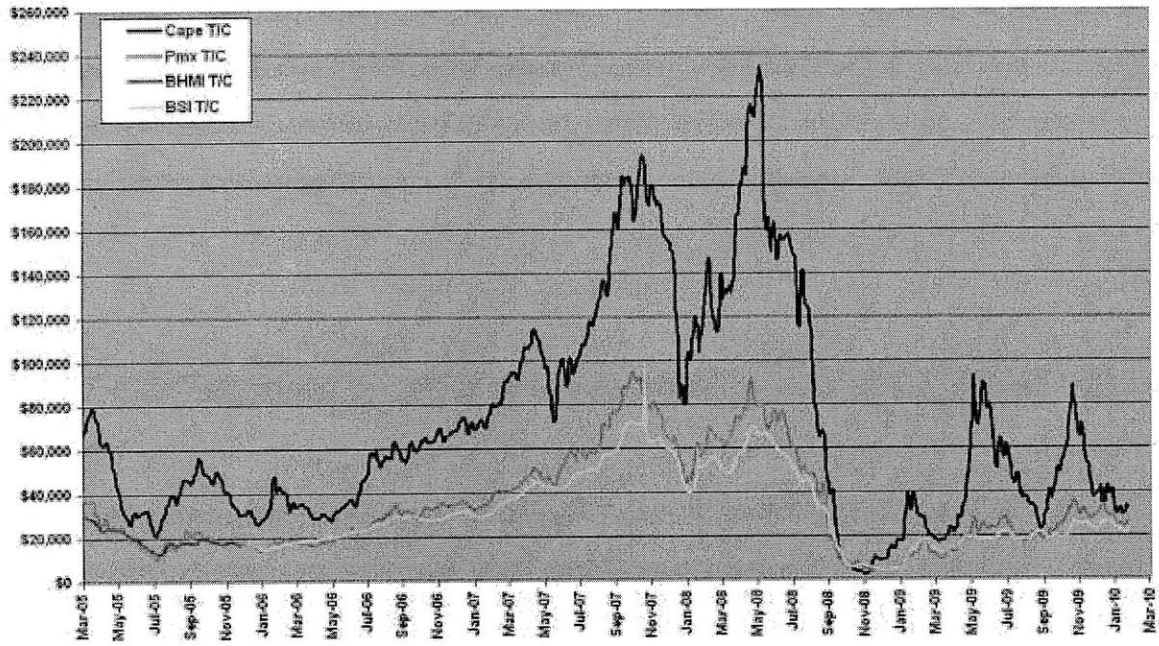


Fig. 5.3-2: Daily Earnings of CAPE (blue), PMX (orange) and SMX (yellow): 0 - $260,000/day [Dryships 2010]

Fig. 5.3-3 shows the index pre-dating the Baltic index, which ranges back to 1976. This Chart is kept at the Headquarters of LCN.

Daily earnings and ship values increased substantially at the end of 2003 due to China's expansion. The introduction of derivatives (on the Baltic indices) around the same period made the market more volatile. The market stayed extremely high compared to pre-2003 levels, reaching a record high in 2008 and then rapidly collapsed after the financial crisis. Average capesize daily earnings decreased by about 99% within a few months and ship values followed. This is clear in Fig. 5.3-4 and 5.3-5 which show the prices of bulk carriers of various sizes.

The market is highly fragmented and very competitive with approximately 1,500 dry bulk operators. The vast majority of these are privately owned like LCN but some, including DRYS have been listed on NASDAQ during this decade. In terms of dry bulk tons moved, the 5 major US listed companies account for 4.29% market share and DRYS accounts for 1.21 [wikinvest 2009a].

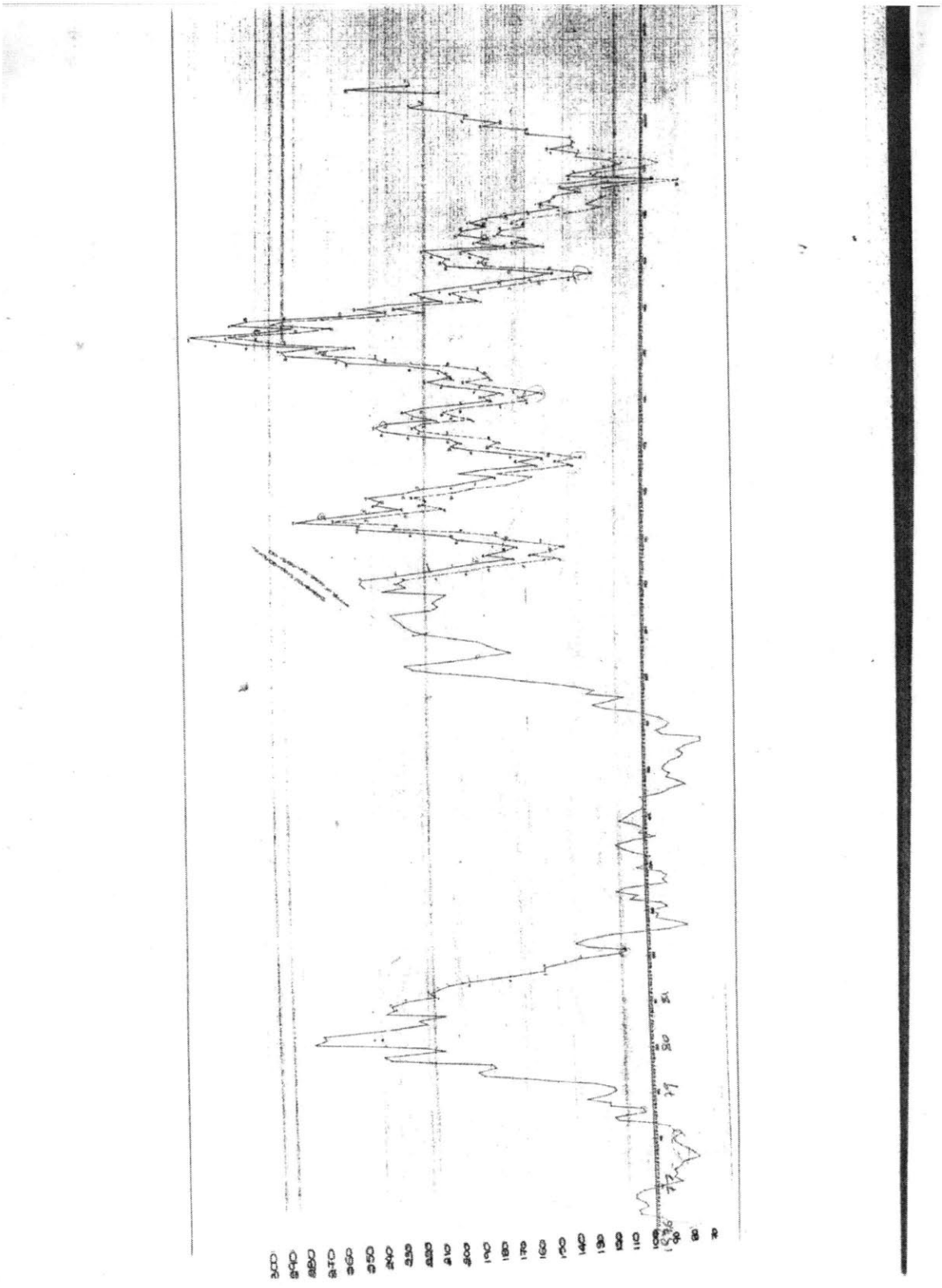


Fig. 5.3-3: Combined Shipping Freight Index 1976 – 2001 [Lifedream 2009]

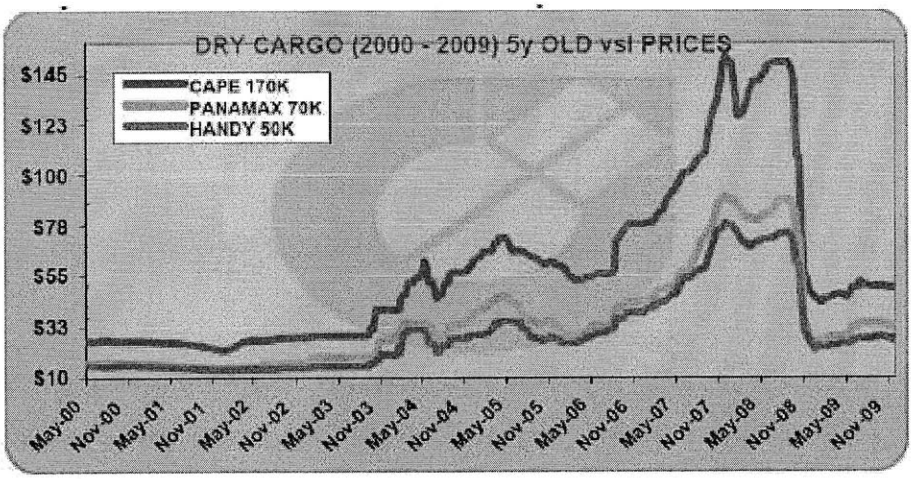


Fig. 5.3-4: Values of 5 year old Bulk Carrier Vessels [Cotzias 2009a]

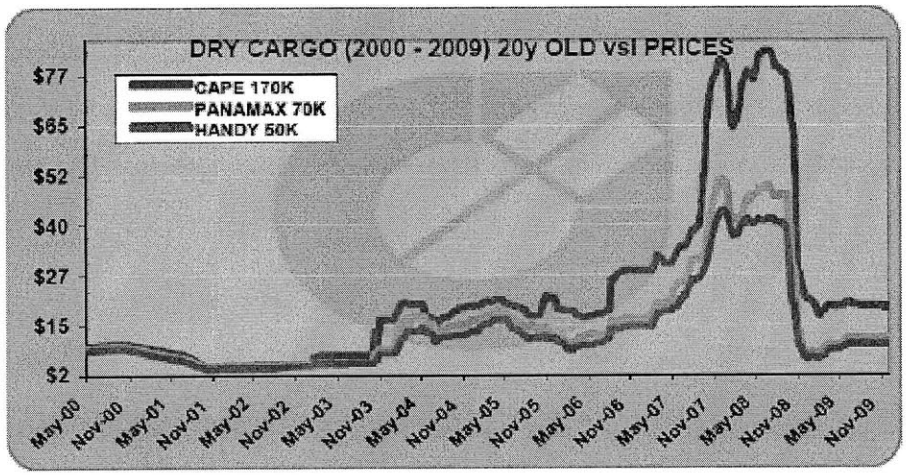


Fig. 5.3-5: Values of 20 year old Bulk Carrier Vessels [Cotzias 2009a]

Success in this cyclical market lies primarily on the timing of investments and chartering. The values of ships are less volatile than daily rates but still very volatile, particularly for older ships. This presents big investment opportunities but is also very dangerous. High charter rates can be locked in via long term contracts with reputable customers but spot rates (short term) are more volatile and higher on average.

Metrics such as fleet utilization show how quickly a company can complete ship repairs and find employment for its vessels. Unlike containerships, bulk carriers have not yet been forced to lay up in the current market. Utilization therefore mainly varies with the length of repairs. Ships undergo annual surveys, special surveys every 5 years and an intermediate surveys between specials. Requirements generally increase with age.

Heavy newbuilding orders were placed during the past five good years. As discussed in Chapter 2, this led to a huge orderbook and increased delivery times to ~4 years due to shipyard capacity constraints. In early 2008, the capesize orderbook exceeded the size of the fleet at the time while scrapping (retirement) was very rare. Huge oversupply is anticipated as these orders are delivered until 2012. Scrapping has increased but this made the fleet younger, thereby limiting future scrapping potential. Order cancellations are expensive and have limited impact since supply is ultimately governed by the shipyard building capacity which has increased dramatically. This is because any cancelled ship will still be delivered, only to another buyer at a lower price, until market prices drop below the variable costs of shipyards. Pushing back deliveries only delays the market recovery, while changing the order to a tanker or a container ship is limited as they also have high orderbooks. In fact, tanker and containership markets are worse so their orders are being changed to bulk carriers. Besides anticipated oversupply, there is a weakening demand for raw materials by China and for finished products by the west due to the bad financial situation.

5.3.3 Company Overview

5.3.3.1 Dryships Overview

DRYS completed an IPO on the New York Stock Exchange in February 2005. Fig. 5.3-6 shows the trend in its share price since then. It has a Market Cap of ~$1.5bn and 254M outstanding shares [Dryships 2009a], up from 30M in 2005 [Dryships 2009e]. Under Code Section 883, the company pays no US taxes [Dryships 2009e]. The financial crisis and the decline in ship earnings and values caused its share price to decline and it stopped distributing dividends in late 2008.

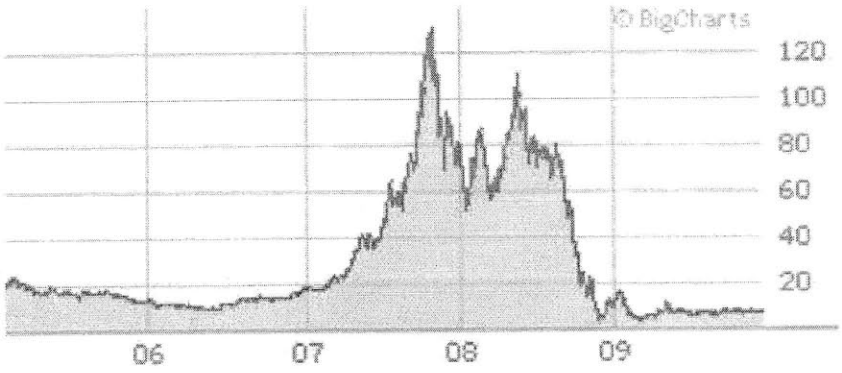


Fig. 5.3-6: DRYS Share Price [CNNMoney 2008]

Its fleet grew from 27 ships in 2004 to 39 ships through a series of acquisitions, financed primarily through subsequent equity offerings [Dryships 2009e]. The fleet includes 7 Capes, 30 Panamaxes and 2 supramaxes totaling ~3.4Mdwt [Dryships 2009b]. A list of these fleets along with their employment are presented in Fig. 5.3-7.

In early 2008, it expanded into ultra deep water drillships via a $1.2bn acquisition of Norwegian OceanRig ASA which owns two rigs and then ordered another 2 for $1.4bn with expected delivery in 2011. Drilling accounts for 20.3% of its revenues while dry bulk accounts for 79.7% [Dryships 2009e]. The oil rig section is managed separately in Norway and DRYS plans to spin it off [Dryships 2009c].

Cardiff Marine is a privately held company which owns 13 dry bulkers and 21 tankers and also operates the ships of DRYS for an annual fee [Cardiff 2009]. The founder of both owns 9.3% of the DRYS (8.6% of common stock) and 70% of Cardiff. The remaining 30% of Cardiff is owned by his sister [Dryships 2009e].

	Year Built	DWT	Type	Gross rate Per day	Redelivery Earliest	Latest
Fixed rate employment						
Capesize:						
Alameda	2001	170,269	Capesize	$21,000	Feb-11	May-11
Brisbane	1995	151,066	Capesize	$25,000	Dec-11	Apr-12
Capri	2001	172,579	Capesize	$61,000	Apr-18	Jun-18
Flecha	2004	170,012	Capesize	$55,000	Jul-18	Nov-18
Manasota	2004	171,061	Capesize	$67,000	Feb-13	Apr-13
Mystic	2008	170,500	Capesize	$52,310	Aug-18	Dec-18
Samsara	1996	150,393	Capesize	$57,000	Dec-11	Apr-12
Panamax:						
Avoca	2004	76,500	Panamax	$45,500	Aug-13	Dec-13
Bargara	2002	74,832	Panamax	$43,750	May-12	Jul-12
Capitola	2001	74,832	Panamax	$39,500	Jun-13	Aug-13
Catalina	2005	74,432	Panamax	$40,000	Jun-13	Aug-13
Conquistador	2000	75,607	Panamax	$17,750	Aug-11	Nov-11
Coronado	2000	75,706	Panamax	$18,250	Sep-11	Nov-11
Ecola	2001	73,931	Panamax	$43,500	Jun-12	Aug-12
Iguana *	1996	70,349	Panamax	$13,456	Sep-11	Sep-11
La Jolla	1997	72,126	Panamax	$14,750	Aug-11	Nov-11
Levanto	2001	73,931	Panamax	$16,800	Sep-11	Nov-11
Ligari	2004	75,583	Panamax	$55,500	Jun-12	Aug-12
Maganari	2001	75,941	Panamax	$14,500	Jul-11	Sep-11
Majorca	2005	74,364	Panamax	$43,750	Jun-12	Aug-12
Marbella	2000	72,561	Panamax	$14,750	Aug-11	Nov-11
Mendocino	2002	76,623	Panamax	$56,500	Jun-12	Sep-12
Ocean Crystal	1999	73,688	Panamax	$15,000	Aug-11	Nov-11
Oliva	2009	75,000	Panamax	$17,850	Oct-11	Dec-11
Oregon	2002	74,204	Panamax	$16,350	Aug-11	Oct-11
Padre	2004	73,601	Panamax	$46,500	Sep-12	Dec-12
Positano	2000	73,288	Panamax	$42,500	Sep-13	Dec-13
Rapallo	2009	75,000	Panamax	$15,400	Aug-11	Oct-11
Redondo	2000	74,716	Panamax	$34,500	Apr-13	Jun-13
Saldanha	2004	75,500	Panamax	$52,500	Jun-12	Sep-12
Samatan	2001	74,823	Panamax	$39,500	May-13	Jul-13
Sorrento	2004	76,633	Panamax	$17,300	Sep-11	Dec-11
Toro	1995	73,034	Panamax	$16,750	May-11	Jul-11
Xanadu	1999	72,270	Panamax	$39,750	Jul-13	Sep-13
Supramax:						
Pachino (ex VOC Galaxy)	2002	51,201	Supramax	$20,250	Sep-10	Feb-11
Paros I (ex Clipper Gemini)	2003	51,201	Supramax	$27,135	Oct-11	May-12
Spot rate employment						
Panamax:						
Delray	1994	71,862	Panamax			
Primera	1998	72,495	Panamax			
Sonoma	2001	74,786	Panamax			

Fig. 5.3-7: Dryships Fleet Employment Oct-2009 [Dryships 2009b]

5.3.3.2 Lifedream Overview

LCN was founded in the mid-1970s and has since remained a private company, wholly owned by one of the founders. It acquired its first ship in 1978 and has steadily grown its fleet to 24 ships. These include Capes, panamaxes, handies and also 3 containerships, of total capacity 1.6Mdwt. The fleet size decreased during the market boom and is now beginning to expand again. In 2002, it peaked at 27 ships of 1.8Mdwt. A detailed account of the company's ship investments is shown in Table 5.3-1 and the current fleet along with current employment contracts is shown in Table 5.3-2.

NAME	dwt	Age	Acq	Sold	Ind%up	Price	%Eq	Op.Prof	PriceS	Prof	mos	ROE	ROI
VIRGIN STAR	8000	20	Aug-78	Apr-80	**200%**	0.25	100%	0.2	0.7	0.65	20	116%	116%
LOBITO	8000	20	Mar-79	May-80	**184%**	0.6	33%	1.61	1	2.01	14	684%	253%
CITY OF DUNDEE	9000	18	Jan-80	May-84	**-50%**	1.2	25%	3.03	0.3	2.13	52	62%	27%
CITY OF LEEDS	9000	18	Jan-80	Jan-81	**5%**	1.2	25%	1.2	2.8	2.8	12	933%	233%
CITY OF CREMON	9000	20	Feb-81	May-84	**-54%**	1.05	14%	3	0.5	2.45	39	141%	45%
LOBITO PAL	9000	20	Oct-82	Aug-83	**0%**	0.6	100%	0.4	1.2	1	10	226%	226%
SEA ZEPHIR	18000	10	Jan-83	Feb-89	**112%**	1.6	19%	7.02	4	9.42	73	77%	37%
NICHOLAS H	17000	15	Mar-84	Oct-88	**64%**	1	0%	0	2.8	1.8	55		25%
LEO ONE	18000	10	Sep-85	Mar-89	**100%**	0.6	17%	6.54	4	9.94	42	275%	127%
AH	75000	17	Sep-85	Jan-	**6%**	2.5	0%	0	2	-0.5	16		-15%

				87									
EMIL S	16000	10	Oct-85	May-99	**16%**	0.6	17%	7.41	0.5	7.31	163	37%	21%
EMMA F	18000	11	Apr-86	Mar-89	**129%**	0.6	17%	3.03	4.2	6.63	35	325%	135%
MARIE H	18000	11	Apr-86	Apr-00	**129%**	0.6	17%	9.08	0.6	9.08	168	38%	22%
CITY OF RIO	17000	10	May-86	Jun-89	**133%**	0.7	14%	10.17	0.5	9.97	37	347%	142%
VANYA	30000	12	Jan-87	Mar-89	**88%**	1.5	20%	7.31	5	10.81	26	433%	165%
EMIL S II	18000	16	Jun-90	Jun-99	**-45%**	1.8	100%	5.04	0.5	3.74	108	13%	13%
LARGO	13000	20	Jul-90	Mar-91	**38%**	0.4	100%	0.1	0.6	0.3	8	132%	132%
NATALIE	19000	11	Jun-92	Jun-97	**18%**	2.8	29%	2.92	4	4.12	60	44%	20%
AKAKI	19000	11	Jun-92	Oct-98	**-9%**	2.8	29%	2	0.6	-0.2	76	-4%	-1%
SANTA MARGHERITA	17000	12	Aug-92	Aug-98	**-9%**	2	25%	1.42	1	0.42	72	11%	3%
GREENOCK	18000	10	Sep-92	Jan-96	**60%**	2.8	29%	1.03	3.6	1.83	40	43%	16%
PANAMAX PRIDE	65000	16	Jun-94			7.5	20%	18.56					
STEFF	60000	20	Jun-96	Oct-02	**13%**	3	33%	4.7	1.5	3.2	76	25%	12%
PANAMAX PEARL	61000	18	Aug-96	Oct-00	**-17%**	5	20%	4.95	1	0.95	50	17%	4%
PRINCE	42000	12	Jun-98	Jan-	**458%**	5	20%	3.52	5	3.52	67	31%	10%

NICHOLAS (cont)				04									
HELLEN C (cont)	42000	12	Jun-98	Jan-04	**458%**	5	20%	3.01	5	3.01	67	28%	9%
MP TRADER	19000	18	Jun-98	Sep-02	**58%**	1.1	91%	2.52	3.5	4.92	51	52%	49%
WESTERN TRADER	70000	10	Jan-99			8	25%	20.19					
PANAMA EXPRESS	25000	17	Feb-99			2	100%	10					
PACIFIC EXPRESS	25000	17	Feb-99			2	100%	10.42					
CAPE MARIA	180000	17	May-99	Oct-07	**1100%**	6.8	9%	50.22	42	85.42	101	81%	36%
PANAMAX POWER	65000	16	May-99			8	0%	23.71					
PANAMAX STAR	65000	17	May-99			8	0%	27.26					
PANAMAX STRENGTH	65000	16	May-99			8	0%	20.01					
PANAMAX OTTER	61000	18	May-99	Jun-09	**350%**	5	0%	23.02	2.6	20.62	121		18%
PIONEER EXPRESS	20000	18	Jun-99	Jun-01	**106%**	1.5	100%	1	1.5	1	24	29%	29%
DELMAS JACARANDA	25000	20	Jan-02			1.6	100%	9.77					
DELMAS ALOE	25000	20	Jan-02			1.6	100%	6.09					
DELMAS ACACIA	25000	20	Jan-02			1.6	100%	8.14					
DELMAS CARTIER	25000	20	Jan-02			1.6	100%	7.59					

PRINCESS NATALIE	70000	12	Feb-02			7	7%	27.45					
CAPE MAXIM	150000	17	Feb-02	Dec-09	**344%**	7.2	10%	37.18	10.2	40.18	94	68%	27%
LAKE SUPERIOR	32000	20	Feb-02	Mar-09	**120%**	2.2	23%	22.03	1.7	21.53	85	71%	40%
CMC DIAMOND (cont)	40000	20	Feb-02	May-04	**240%**	3.3	15%	2.04	5	3.74	27	160%	40%
CMC PEARL (cont)	40000	17	Feb-02	Dec-04	**450%**	7	7%	3.02	10.5	6.52	34	155%	26%
CAPE ATHOS	140000	21	Sep-02			9.5	0%	26.59					
CAPE LORD	140000	20	Sep-02			9.5	0%	34.37					
CAPE COSMOS	140000	21	Sep-02			9.5	0%	36.74					
PANAMAX SUN	65000	20	Sep-02			8	0%	27.15					
PANAMAX DAWN	70000	19	Sep-02			8.5	0%	33.07					
MEXICO CITY	60000	25	Dec-08			2.7	100%	2.8					
PANAMAX APPLAUSE	70000	12	May-09			20	10%						
CSL MARIE (cont)	50000	16	Mar-09			6.5	100%						
CSL STEFANIE (cont)	50000	16	Mar-09			7	100%						
ALEXANDER (cont)	50000	16	Mar-09			7	100%						
CSL PATMOS (cont)	5000	17	Apr-09	Sep-09		5	100%	0	6	1	5	55%	55%
CSL PACIFIC (cont)	5000	17	Apr-09	Sep-09		5	100%	0	6	1	5	55%	55%
CAPE OLIVE	170000	13	Sep-09			30	10%						
CAPT. ORE	46000	19	Sep-09			10	100%						

Table 5.3-1: Lifedream – Account of Ship Investments – Based on Data from [Lifedream 2009]

The columns of Table 5.3-1 represent (in order), the ship's name, deadweight, age when acquired, date of acquisition, date sold, % increase in BDI Index between acquiring and selling (using pre-BDI index where shaded), acquisition price, % equity (cash) in acquisition (remainder is bank loan), profit by operation, selling price, total profit, months held, annualized return on equity, and annualized return on investment.

NAME	*DWT*	*AGE (AQ.)*	*CHARTERED YRS FROM DEC'09*	*NET RATE (=GROSS-5%)*
CAPE OLIVE	170000	13	5	30,000
CAPE ATHOS	140000	21	0.5	15,000
CAPE COSMOS	140000	21	2	18,000
CAPE LORD	140000	20	-	-
WESTERN TRADER	70000	10	5	15,000
PRINCESS NATALIE	70000	12	5	30,000
PANAMAX APPLAUSE	70000	12	3	16,000
PANAMAX DAWN	70000	19	6	20,000
PANAMAX POWER	65000	16	4	20,000
PANAMAX STAR	65000	17	6	20,000
PANAMAX STRENGTH	65000	16	2	50,000
PANAMAX SUN	65000	20	6	20,000
MEXICO CITY	60000	25	2.9	30,000
PANAMAX PRIDE	65000	16	2	10,000
CAPT. ORE	46000	19	5	22,000
PANAMA EXPRESS	25000	17	2	9,000
PACIFIC EXPRESS	25000	17	2	9,000
DELMAS JACARANDA	25000	20	1	9,000
DELMAS ALOE	25000	20	1	9,000
DELMAS ACACIA	25000	20	1	9,000

DELMAS CARTIER	25000	20	1	9,000
CSL MARIE (cont)	50000	16	-	-
CSL STEFANIE (cont)	50000	16	-	-
ALEXANDER (cont)	50000	16	-	-

Table 5.3-2: Lifedream Fleet Employment Dec-2009 – Based on data from [Lifedream 2009]

Fig. 5.3-8 shows the growth in number of ships and carrying capacity. The operation management of the fleet is done in house and no additional vessels are managed on behalf of other companies [Lifedream 2009].

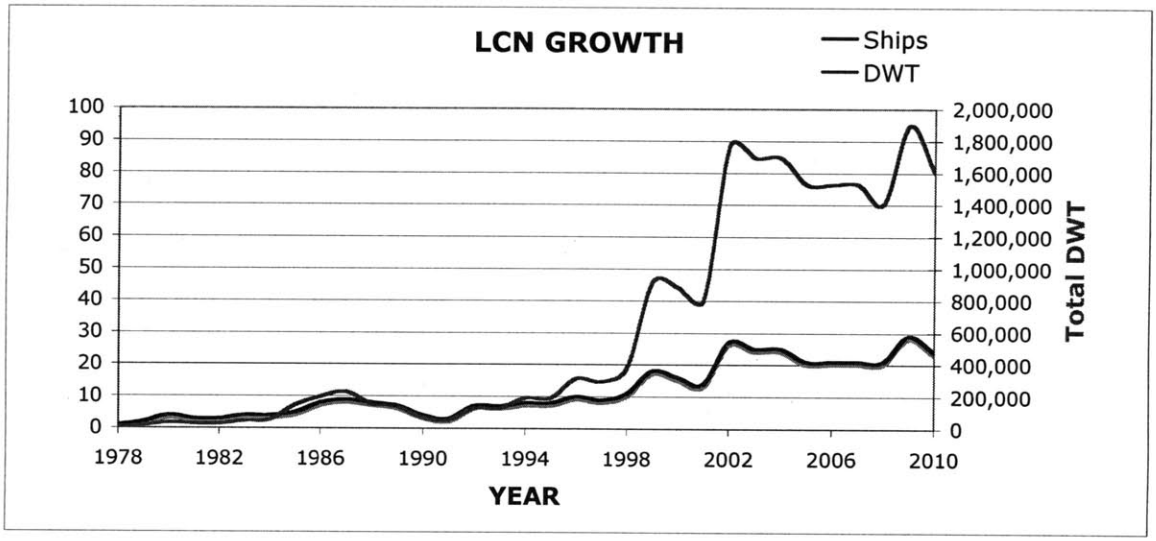


Fig. 5.3-8: LCN Fleet Growth - Developed using data from [Lifedream 2009]

5.3.4 Company Objectives and Growth Strategy

5.3.4.1 Objectives and Growth Strategy of Dryships

DRYS's strategy is to offer safe and reliable transportation and make acquisitions in a manner that adds shareholder value. The dynamics of the stock market are quite unique and affect the company's strategy directly. Share prices are highly governed by earnings per share and ROE, so listed companies are under pressure to keep making acquisitions in order to boost earnings and demonstrate continuous growth. This is true particularly when the market is high which means that acquisitions will inevitably be made at high prices. In 2008, at the peak of the market, this need for fast earnings to boost ROE was one of the factors leading the price of 5-year old vessels to be about 1.5 times that of a newbuilding order which would be delivered after 3 years [Cotzias 2009c]. Besides having to make the next quarter's numbers, listed companies are under a pressure to make big acquisitions of high publicity, maintain a brand name and top quality personnel and directors, have full disclosure of what they do, avoid bad press and keep the average age of their fleet low compared to their competitors to impress their shareholders.

This handicap however, comes with a big advantage, namely the ability to raise equity to finance acquisitions, and DRYS has taken full advantage of this. Since its listing, DRYS has made a series of equity issuances and acquisitions of new secondhand ships, keeping the average age of its fleet to about 8 years. It acquires ships in a good market and charters them under long period contracts at high market rates to bring down the book value and boost sales. It balances these with short term charters that allow for higher earnings in good markets and regularly hedges its exposure via the futures market [Dryships 2009e].

By maintaining a reputation for performance, reliability and safety with its modern fleet, DRYS has strong relationships with charterers and financial institutions. This minimizes the number of disputes with charterers who are locked into high rate contracts after the market declines, and maximizes the probability of obtaining loan covenant waivers when the fair value of assets declines below a fixed percentage of the outstanding debt.

5.3.4.2 Objectives and Growth Strategy of Lifedream

In contrast to DRYS, LCN is a low-cost operator with a long term view on growth. It tries to invest at the bottom of the market and lock in high rates during market highs, thereby maintaining low market exposure. This strategy means it may remain idle over years while planning for a huge ROE as the cycle turns. Table 5.3-1 shows a detailed account. Following this strategy, the company has managed to sell vessels on average at 45% higher than the acquisition price, after operating them for an average of 4.6 years. The index was on average 145% higher on the selling date compared to the acquisition date. In ships that it has sold so far, it has achieved an average annualized return on investment of 61% and, excluding some projects which it financed by 100% debt, an average ROE of 155% - Based on data from [Lifedream 2009].

Fig. 5.3-9 shows the fleet growth of the company, in number of ships, along with the price of a 5-year old panamax, which is an indication of price levels. A big contrast with DRYS is that LCN made no acquisitions throughout the market boom since 2003. Between 2005 and 2008, it made no acquisitions and only sold a cape which it had acquired for $6.2M, for $42M commanding an annual ROE of 81% over 8.5 years (including operating profits). This has caused the average age to increase to 23 years and the company is now renewing its fleet. New additions are made, replacing older vessels in the long term contracts that have been secured before the market decline [Lifedream 2009].

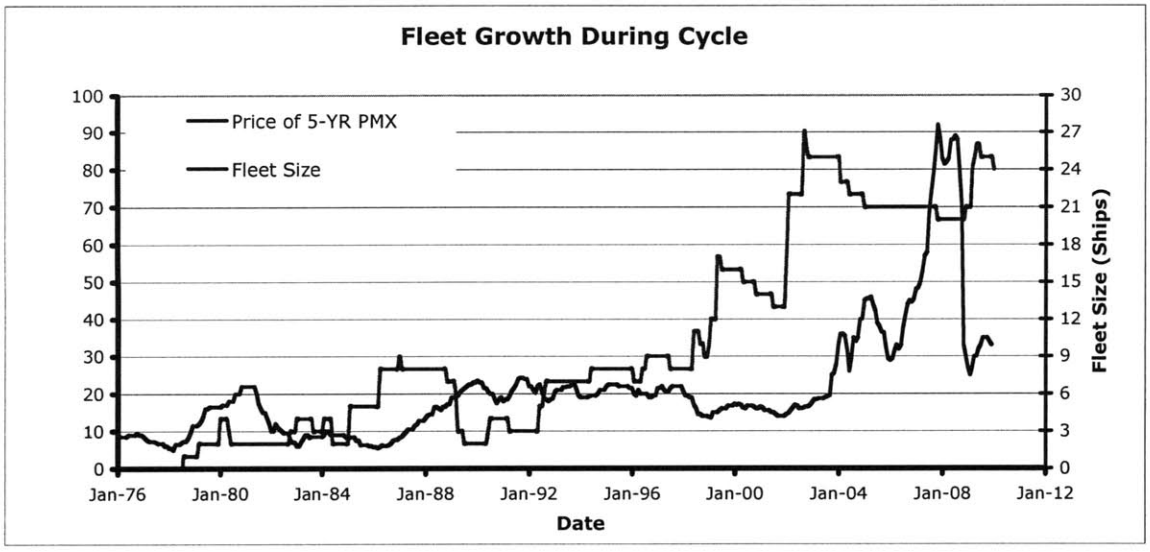


Fig. 5.3-9: LCN Fleet Growth along with Asset Values –
Based on data from [Lifedream 2009] and [Clarksons 2009a]

This strategy is complemented by strong, long-term relationships with key charterers and financial institutions. LCN is in no danger of breaching any covenants as it maintains a leverage of only 10% to save cash for acquisitions during downturns. However, it relies on banks for financing of ships (along with its equity) since it doesn't have the option to raise finance from the public markets [Lifedream 2009].

In contrast to DRYS, LCN is a low profile company that avoids publicity. LCN does no advertising and maintains a structure that avoids cross liability of vessels. It often tries to prevent reporting of its acquisitions in order to avoid signaling investment opportunities to the market [Lifedream 2009].

5.3.5 Fleet Additions / Removals

5.3.5.1 Fleet Additions and Removals of Dryships

As discussed earlier, in a high market, Dryships often pays a high premium for fast delivery of vessels that it acquires in order to boost EPS. Since it is a listed company, the board of directors has to approve all transactions and this may take several days during which the market may change considerably. Since it has to make all its offers with a subject to BOD approval when closing a deal, it has to effectively pay a premium to make its offer more attractive than that of a competitor who has no subjects. This applies both when selling or buying a vessel.

Though less competitive than private companies in its bids, DRYS takes advantage of the equity markets to finance acquisitions. Tables 5.3-3 and 5.3-4 show the recent amounts of equity DRYS raised, net of commissions and fees, along with vessel acquisitions and disposals. DRYS also raised $387M net of expenses and commissions by issuing 400M in 5% convertible senior notes in Nov 2009 [Dryships 2009d].

Date	Raised Equity (Net)
Dec 07	127.1M
Mar 08	352.7M
08	101.6M
08	41.9M
Dec 08	167M

Table 5.3-3: DRYS Late Equity Raising [Dryships 2009e]

Year	Acquisitions	Disposals	Equity Issue Proceeds
2007	779,374	222,712	127,104
2008	851,006	253,875	662,664

Table 5.3-4: DRYS Acquisitions, Disposals and Common Equity Proceeds in 2007 and 2008

DRYS tries to maintain its fleet young so it sells mid-age vessels when they age or when earnings decrease. When making acquisitions, it has the flexibility of paying a mixture of cash, raised through debt and equity, with newly issued shares of its stock. This has become a popular trend with listed companies recently.

The company's strategy in making acquisitions at high market prices led to several cancellations after the market decline. In 2008 DRYS acquired 4 panamaxes (two newbuildings) for 400M from Cardiff. These were then cancelled and Cardiff retained a cancellation fee of $105m plus the $55m deposit while DRYS maintained the option to buy the vessels until Dec 2009 at a price of $160m [Dryships 2009e]. Similarly, Dryships acquired 9 capes from Cardiff for $1.17bn (19.4M shares plus 478.3M debt) which were then cancelled at a cost of 6.5M shares. Another fee of 8m was paid and the seller maintained the $6.1m deposit to cancel the $61m panamax MV Petalidi acquisition [Dryships 2009e]. Deal Alterations were also made by parties previously agreeing to purchase DRYS vessels. Samsun renegotiated a lower price to buy the panamax MV Toro while paying an additional $1.5m deposit and DRYS has maintained a $5.6m deposit and is pursuing legal remedies against the buyer of the $55.5M panamax MV Delray [Dryships 2009e]. More recently in 2009, DRYS has cancelled ships after not being able to find employment or finance [Dryships 2009d]. In November it cancelled the acquisition of two panamaxes (at zero cost), and paid $42.8M to cancel a $114M order for a cape in a Korean shipyard which also kept the 20% deposit [Dryships 2009d].

5.3.5.2 Fleet Additions and Removals of Lifedream

LCN's strategy is to make heavy investment acquisitions close to scrap value near the market bottom. Since it is less bureaucratic than listed companies, it can make quick bargain acquisitions by making offers without subjects. Fig. 5.3-10 shows the additions and removals to the fleet along with the market in terms of values.

Since scrap values are less volatile than secondhand vessel prices as discussed in Chapter 2, the acquisitions are more important to look at than the removals (since removals also include a lot of scrapping).

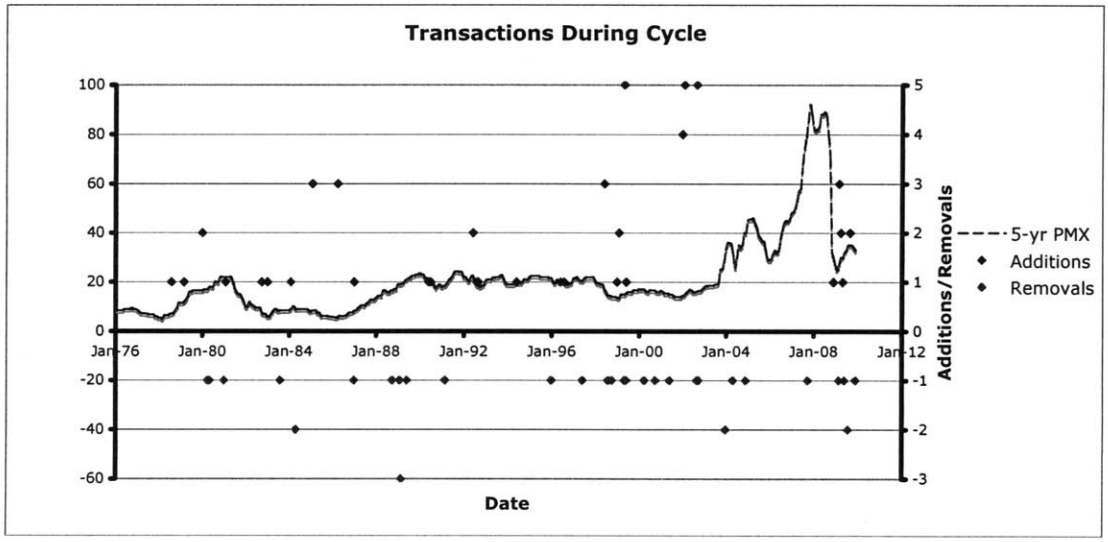


Fig. 5.3-10: Fleet Additions/Removals and price of 5-year PMX – Developed using data from [Lifedream 2009]

LCN occasionally sells ships when opportunities emerge in good markets but it usually operates vessels until scrapping them. So far the ratio of scrapped to sold vessels is 1.23 – Based on data from [Lifedream 2009]. When acquiring vessels, it usually secures bank financing and pays cash, or pays cash and the finances to speed up the process. It also often funds acquisitions with 100% equity. So far, on average it has financed acquisitions with 41% equity and 59% debt – Based on data from [Lifedream 2009]

5.3.6 Chartering Strategy

5.3.6.1 Chartering Strategy of Dryships

Charters are either Voyage charters in which the owner pays CAPEX, OPEX and Voyage expenses (including fuel), time charters in which the owner pays CAPEX and OPEX, or bareboat charters under which the owner only pays CAPEX. There is a trend in the cape market to use short time charters instead of voyage charters.

Dryships has a strategy to balance long term charters with spot market charters (short term) [Dryships 2009e]. It also has 3 ships on bareboat and in some cases has profit sharing agreements whereby the rate is attached to the index beyond a certain level window [Dryships 2009b]. Long term charters are required when acquiring a vessel during a market boom, in order to bring down the high capital investment without the risk of a downturn. On the other hand, by staying on the spot market during peaks, a vessel can command higher rates (long term charter rates are less volatile as discussed in Chapter 2), thereby boosting earnings. There is therefore a pressure by the stock market to stay on short term charters to boost ROE. Short term charters also allow the company the flexibility to sell, and also make the CEO's optimistic view statements more credible.

When the market declined last year, DRYS found itself with 13 ships on the spot market (coming out of charters within 30 days) [Dryships 2009e], which it then secured under long term charters at lower rates [Dryships 2009b]. It also had long term charters at relatively high rates, particularly for its capes. As many other shipping companies, it was forced to renegotiate some of these rates down or go after charterers who failed to make payments [Clarkson 2009]. DRYS tries to avoid such disputes by maintaining good relationships with big clients. As of 2008, Cargill International Ltd accounted for 16% of charter revenues and Shell accounted for 10% [Dryships 2009e].

Today, a lot of the value of its assets still is based on long term charters above current futures level rates for the corresponding periods. This can be seen by comparing the employment of its fleet in Fig. 5.3-7 with the FFA rates for the corresponding periods in

Table 5.3-5. Table 5.3-6 shows typical vessel prices for various ship ages that can be used to approximate the charter-free value of the DRYS fleet.

Period / FFA Rates ($/day)	*PMX*	*CAPE*
Spot	31,000	71,000
2010 Q1	25,000	48,000
2010 Q2	23,000	37,000
2010 Q3	20,000	33,000
2010 Q4	18,000	30,000
Cal 2010	21,500	37,000
Cal 2011	17,000	27,000
Cal 2012	16,000	24,000
Cal 2013	15,000	22,000

Table 5.3-5: Dec 2009 FFA Rates [Lifedream 2009]

Values ($M) / Year Built	*PMX*	*CAPE*
1997	25	40
1998	26	41.6
1999	27	43.2
2000	28	44.8
2001	29	46.4
2002	30	48
2003	31	49.6
2004	32	51.2
2005	33	52.8
2006	34	54.4
2007	35	56
2008	36	57.6
2009	37	59.2

Table 5.3-6: Dec 2009 Ship Prices [Based on Indices and Recent Transactions]

5.3.6.2 Chartering Strategy of Lifedream

LCN's strategy has so far chartered all its vessels under long term charters of 2 to 5 years [Lifedream 2009]. Since it is operating older vessels, it seemingly makes more sense to operate on the spot market in which newer ships don't command as big a premium as discussed in Chapter 2. Furthermore, finding long term charters for older vessels is very difficult. However, if an old ship comes out of a charter in a bad market it rarely finds employment so it is almost certainly scrapped. That is precisely what happens to LCN's ships today as they come out of their long term contracts. This is avoided by securing them under long term contracts, thereby sustaining high ROE level for long periods. Strong long term relationships with charterers help to achieve this and limit market exposure [Lifedream 2009].

When going into long term charters with old ships in a good market, the rates are lower than those for younger ships. When the market declines, therefore, they are not much higher than the spot rates of young ships so there is a much smaller chance of having to renegotiate with the charter. So far, LCN only had to cancel one charter contract and renegotiated one more in which it lowered the rate and extended the time [Lifedream 2009].

5.3.7 Risk Management

5.3.7.1 Risk Management of Dryships

DRYS has significant market exposure as it has many ships on short term contracts. This exposure can be hedged through FFAs on the Baltic Indices. This is essentially the same as chartering a vessel, with the difference being that margin calls are made frequently. These can be very significant due to the high market volatility. After reporting a loss of $22.5M

from FFAs in 2006, DRYS has stayed away from FFAs [Dryships 2009e].

DRYS is also exposed to Euro-Dollar exchange rates since its revenues are all in dollars but it incurs many costs in euros. Furthermore, to indicate its exposure in interest rates, a 1% increase in LIBOR would increase 2008 expenses by $1.1M. DRYS therefore hedges these exposures through interest rate swaps and derivative. In 2008, DRYS reported a loss of $2.512M on forward contracts and a net gain of $0.198M on forward foreign exchange contracts [Dryships 2009e].

Even though equity frequently issued, leverage is also high with debt to equity of approximately 1. This is using the book value of assets as opposed to fair value. DRYS claims that an asset impairment is not required after the market decline by discounting its future cash flows [Dryships 2009e]. It is highly doubted given the magnitude of the decline of market values. This can be observed by looking at the current fleet in Fig. 5.3-7, the current market ship prices in Table 5.3-6 and the long term asset value of $2.7bn in Fig. 5.3-11, which shows the company's consolidated balance sheet.

	2007	2008
ASSETS		
CURRENT ASSETS:		
Cash and cash equivalents	$ 576	$ 1,039
Restricted cash	6,791	14,326
Due from subsidiaries*	316,163	—
Due from related parties	9,813	17,480
Other current assets	372	324
Total current assets	333,715	33,169
NON-CURRENT ASSETS:		
Investments in subsidiaries*	1,465,660	2,692,706
Restricted cash	5,308	—
Total non-current assets	1,470,968	2,692,706
Total assets	$ 1,804,683	$ 2,725,875
LIABILITIES AND STOCKHOLDERS' EQUITY		
CURRENT LIABILITIES:		
Current portion of long-term debt	$ 108,047	$ 669,834
Due to subsidiaries*	—	637,064
Financial instruments	—	31,921
Other current liabilities	2,442	14,916
Total current liabilities	110,489	1,353,735
NON-CURRENT LIABILITIES		
Long term debt, net of current portion	671,560	—
Financial instruments	905	80,568
Total non-current liabilities, net	672,465	80,568
STOCKHOLDERS' EQUITY:		
Common stock, $0.01 par value; 75,000,000 and 1,000,000,000 shares authorized at December 31, 2007 and 2008; 36,681,097 and 70,600,000 shares issued and outstanding at December 31, 2007 and 2008, respectively	367	706
Accumulated other comprehensive loss	—	(44,847)
Additional paid-in capital	454,538	1,148,365
Retained earnings	566,824	187,348
Total stockholders' equity	1,021,729	1,291,572
Total liabilities and stockholders' equity	$ 1,804,683	$ 2,725,875

Fig. 5.3-11: Dryships Inc. Consolidated Balance Sheet [Dryships 2009e]

That means that true leverage is higher than what indicated from its financials. Furthermore the company has very low cash reserves meaning that it must rely on future equity issuing to repay it debt and finance any acquisitions [Dryships 2009e].

In Dec 2008, the company had a total debt of $3.2bn under its credit facilities and was in breach of fair asset value covenants relating to $1.8bn of this debt [Dryships 2009e]. Since May 2009, thanks to the good relationships in the industry, it managed to secure covenant waivers from 5 of its lenders amounting to $1.7bn [Dryships 2009d]. This is important as lenders can accelerate the debt forcing distress sales and causing the company to shrink substantially if waivers are not granted.

DRYS has difficulty in diversifying as it has to defend such moves to investors who invest in DRYS as a means of getting exposure to the dry bulk market. It has diversified its risk by investing in ultra deep oil rigs but this was not well received by investors. It acquired a company to do that for $1.4bn and then ordered another two rigs for approximately $800M each [Dryships 2009e]. It had the intension of spinning that off but it may be difficult in the current market. This was a significant diversification as drillships now account for ~20% of revenues [Dryships 2009e].

5.3.7.2 Risk Management of Lifedream

Being in a position to make large investments on the market downturns is critical to LCN, so it makes a big effort to manage its risks on all fronts. It incurs only a small portion of its expenses in currencies other than the USD so it is not that exposed to foreign exchange fluctuations [Lifedream 2009]. Its policy is to have very high cash reserves and build them up during market booms, until the crisis. As such its leverage is only about 10% until heavy investments are made during downturns [Lifedream 2009]. By maintaining high cash reserves, it mitigates the risk of not being able to secure a bank loan to finance a bargain acquisition.

It is actively involved in the FFA market mainly to be in touch with the market and keep track of where it is going. Its hedging strategy is rather complicated since it operates old

vessels and its exposure is limited. Its FFA positions are very small and it is net even on FFAs as a standalone basis (zero net gain) [Lifedream 2009].

As can be seen in its fleet, it operates ships of a wider range of sizes as well as containerships. With a well diversified fleet, and long term charters it has a steady flow of income and very little risk of having to make distress sales. The 9 containership acquisitions which it has made in the past were all for under $10M each, in contrast to the $800M drillship acquisitions of DRYS – based on data from [Lifedream 2009].

5.3.8 Technical Operations and Performance

5.3.8.1 Technical Operations and Performance of Dryships

A detailed and a simplified version of the organization chart of Cardiff is shown in Fig. 5.3-12 and a simplified version in Fig. 5.3-13.

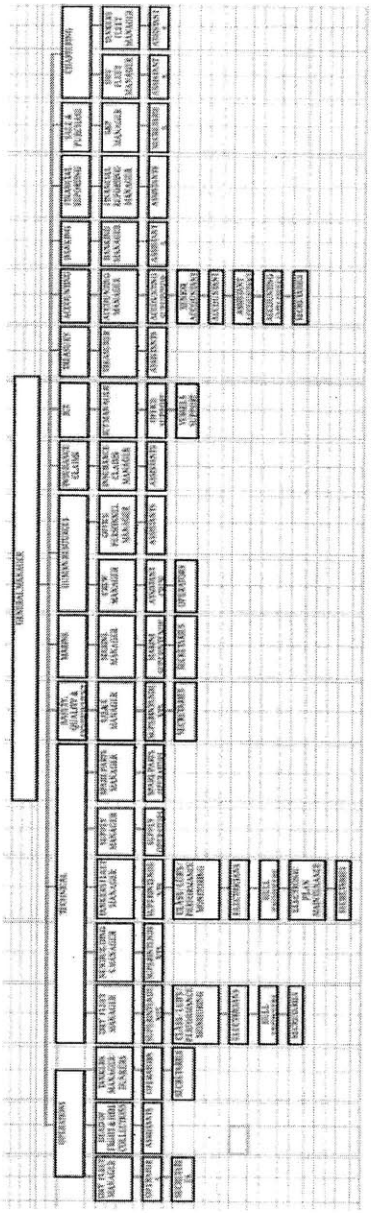


Fig. 5.3-12: Cardiff Marine – Detailed Organizational Chart [Cardiff 2009]

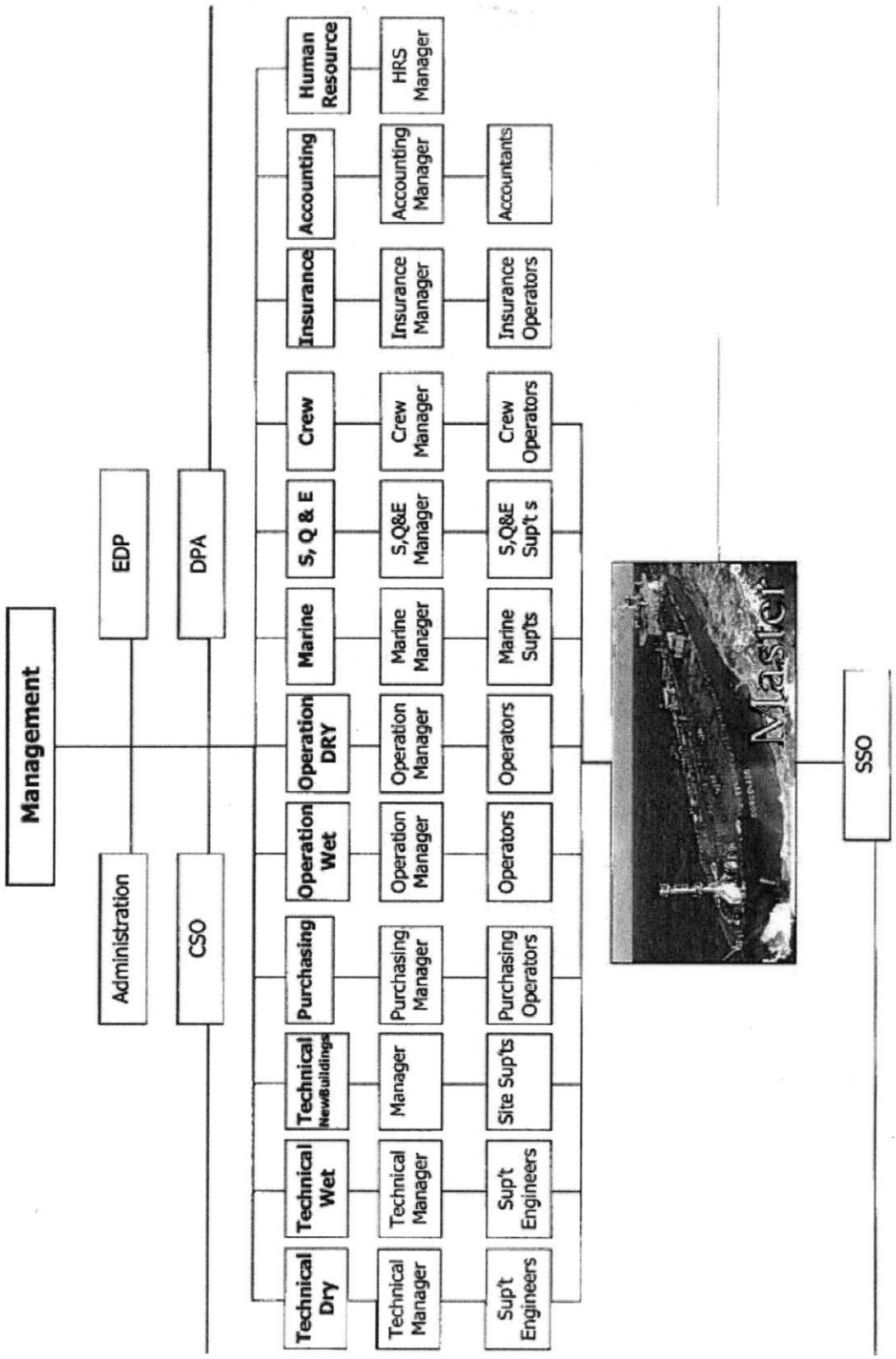


Fig. 5.3-13: Cardiff Marine Simplified Organizational Chart [Cardiff 2009]

Since Cardiff manages around 80 ships including both tankers and dry bulk carriers, there are some departments dealing only with tankers, which have a more complicated operation involving high pollution standards [Cardiff 2009]. The wet and dry fleets are managed separately though they share some common departments such as HR and IT [Cardiff 2009].

Focusing on the dry bulk, most departments, including Supply, S,Q&E, HR, accounting, and crewing, cover the whole fleet. The technical, marine and operations departments divide the ships into fleets of 15 to 20 with different superintendents and assistants working on each sub fleet. There are managers supervising all fleets and "floating" superintendents who attend ships when no-one else is available [Cardiff 2009].

This has several merits, namely sisterships or similar vessels can be put under one sub-fleet so superintendent engineers, naval architects and port captains become familiar with the particular vessels but also specialize on the particular type of vessels. By grouping the sub-fleets the same way across the departments, technical department people deal with the same marine and operations department people [Cardiff 2009]. This sort of team structure is very convenient; it allows for accountability and maximizes employee learning curve benefits.

Furthermore, as acquisitions of whole fleets are made, new teams are created to supervise the new fleet. When several ships are constructed, the same employees work on these ships from start to finish and know every detail on the ship. If ships are added incrementally to the fleet, they go to one of the already existing sub-fleets until enough ships are in the sub-fleets to create a new sub-fleet. That is why the number of ships per sub-fleet varies between 15 and 20. Finally, some ships are more demanding than others and that is taken into account when dividing the ships and adjusting the sub-fleet sizes [Cardiff 2009].

Naturally, as a listed company, DRYS has relatively high expenses. It compensates its directors by amounts that are unheard of in the private sector. Namely, the CEO's pay in 2008 was 2M Euro salary plus 5M Euro bonus plus 1M shares ($75.09 on granting date) vesting over 8 quarters under its "Equity Incentive Plan" which has 1,834,055 restricted common shares reserved. DRYS paid executive directors $9M while non-executive directors received $0.705M. It also pays approximately $1.5M annually for pension benefits [Dryships 2009e].

DRYS also pays a generous amount in euros to Cardiff for the management of its vessels. Fees per vessel day include 575 for management, 100 for compliance with Section 404 of Sarbanes-Oxley Act, 115 for financial accounting and 85 for operations and freight collection. In addition Cardiff receives a 1.25% commission on all charters ($2M in 2007), 1% commission on all sales and purchases ($11.7M in 2007 and $11.8M in 2008), 0.2% commission on all derivatives, 5% of all insurance premiums. DRYS also pays Cardiff 575E/superintendent-day on board a vessel in excess of 5 days per year, 150E/person-hour in claims settling and 1000E annually for reporting. These were all paid based on an average exchange rate for 2008 of 1.41 $/E. On top of that, Cardiff paid $1.4M in 2007 and $1,8M in 2008 for items not covered by the agreement. DRYS also leases its offices from its CEO for E9.23M annually and pays audit fees of $1.55M [Dryships 2009e].

Based on the various exhibits of the 20-F form, I constructed a breakdown of operating costs for DRYS in a way that facilitates easy comparisons with LCN. The breakdown is shown in Table 5.3-7, and the values indicate dollars per vessel per day.

Dryships	*2005*	*2006*	*2007*	*2008*
CREW WAGES		$1,974	$2,294	$2,609
INSURANCES		$433	$459	$540
REPAIRS & MAINTENANCE		$1,164	$834	$1,295
SPARES & STORES		$1,395	$1,534	$1,179
TONNAGE TAX		$21	$24	$37
Operating Expenses	**$5,067**	**$4,986**	**$5,145**	**$5,660**
GENERAL & ADMINISTRATIVE	$631	$609	$780	$1,497
MANAGEMENT FEES	$532	$546	$610	$1,610
Total Operating Expenses	**$6,230**	**$6,141**	**$6,535**	**$8,767**

Table 5.3-7: Operating Expenses for Dryships in $/day per vessel – Based on Data from [Dryships 2009e]

Both general and administrative expenses as well as management fees per vessel increased dramatically in 2008. Operating expenses are relatively high even compared to other US listed dry bulk companies as shown in Fig. 5.3-14.

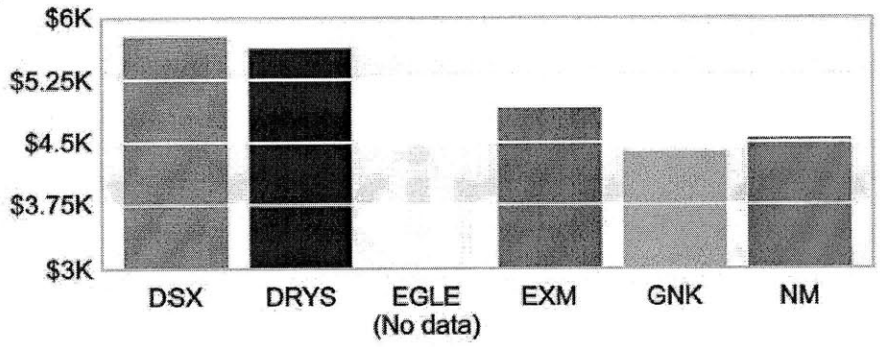


Fig. 5.3-14: Operating expenses per vessel compared to key competitors [wikinvest 2009b]

Table 5.3-8 shows various performance measures of the Dryships Fleet and Fig. 5.3-15 compares the utilization of the fleet to other major US listed companies.

FISCAL YEAR ENDING	31-OCT 2004	31-DEC 2005	31-DEC 2006	31-DEC 2007	31-DEC 2008
Average Age of Fleet	10.0	11.0	9.50	8.80	8.00
Average Time Charter Equivalent per Day	39.5K	28.4K	21.9K	45.4K	58.2K
Earnings Capacity Days	2.53K	7.87K	10.9K	12.3K	
Net Earning Days	2.43K	7.71K	10.6K	12.1K	
Number of Vessels	27.0	28.0	36.0	36.7	38.6
Off-Hire Days	100	156	253	158	
Percentage Utilization	97.5%	98%	97.7%	98.7%	98.5%
Average Vessel Operating Expenses per Day	5.76K	4.67K	4.41K	5.00K	5.64K
Deadweight Tons	2.30M	2.30M	3.00M	4.20M	3.30
Time Charter Equivalent Revenues	72.4M	219M	232M	551M	58.2M
Vessels Owned	27.0	27.0	35.0	38.0	40.0
Vessels Chartered In		1.00	1.00		
Average Age of Fleet in Years				8.80	8.00
Total Revenues	63.5M	229M	248M	583M	1.08B

Table 5.3-8: Performance Measures of Dryships Fleet [wikinvest 2009c]

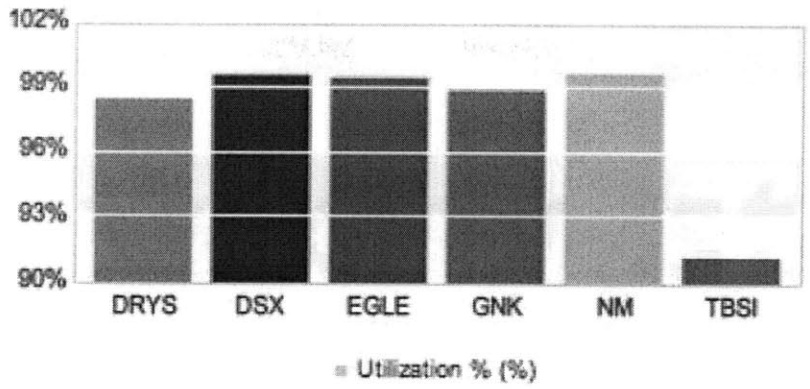


Fig. 5.3-15: Fleet Utilization of Dryships and other major US listed Companies [wikinvest 2009d]

5.3.8.2 Technical Operations and Performance of Lifedream

LCN's organizational chart is shown in Fig. 5.3-16. The operation of containerships and dry bulk carriers is very similar in terms of shore operations. Since LCN is a smaller company than DRYS, operating only dry bulk and container vessels, it has a simpler structure and operates more informally. The major difference regarding operations is that the fleet is not divided into sub-fleets. All superintendents from the technical operations and marine departments are responsible and visit all vessels.

This strategy misses out on all the benefits discussed earlier but there is one major benefit. Superintendents can specialize not on the vessel but on the particular problem/situation. LCN has experts on any given problem and therefore sends superintendents on board depending on the problem. This is very important for LCN because the average age of its fleet is 23 years old, so big problems arise frequently. Given the current fleet size and age profile, this structure is optimal. In 2002, when the fleet size was approaching 30 vessels, the company considered creating two sub-fleets for some of its operations, and it probably will do so in the future if it keeps growing. This presents a kind of diseconomies of scale for LCN.

The number of engineer superintendents who go on board vessels is only slightly less than that of Cardiff which operates 3 times more ships. This is because they spend much more time on board vessels particularly during repairs and when passing safety audits. LCN

has lower wage crews and older ships so it invests more in closer supervision from shore and by superintendents [Lifedream 2009].

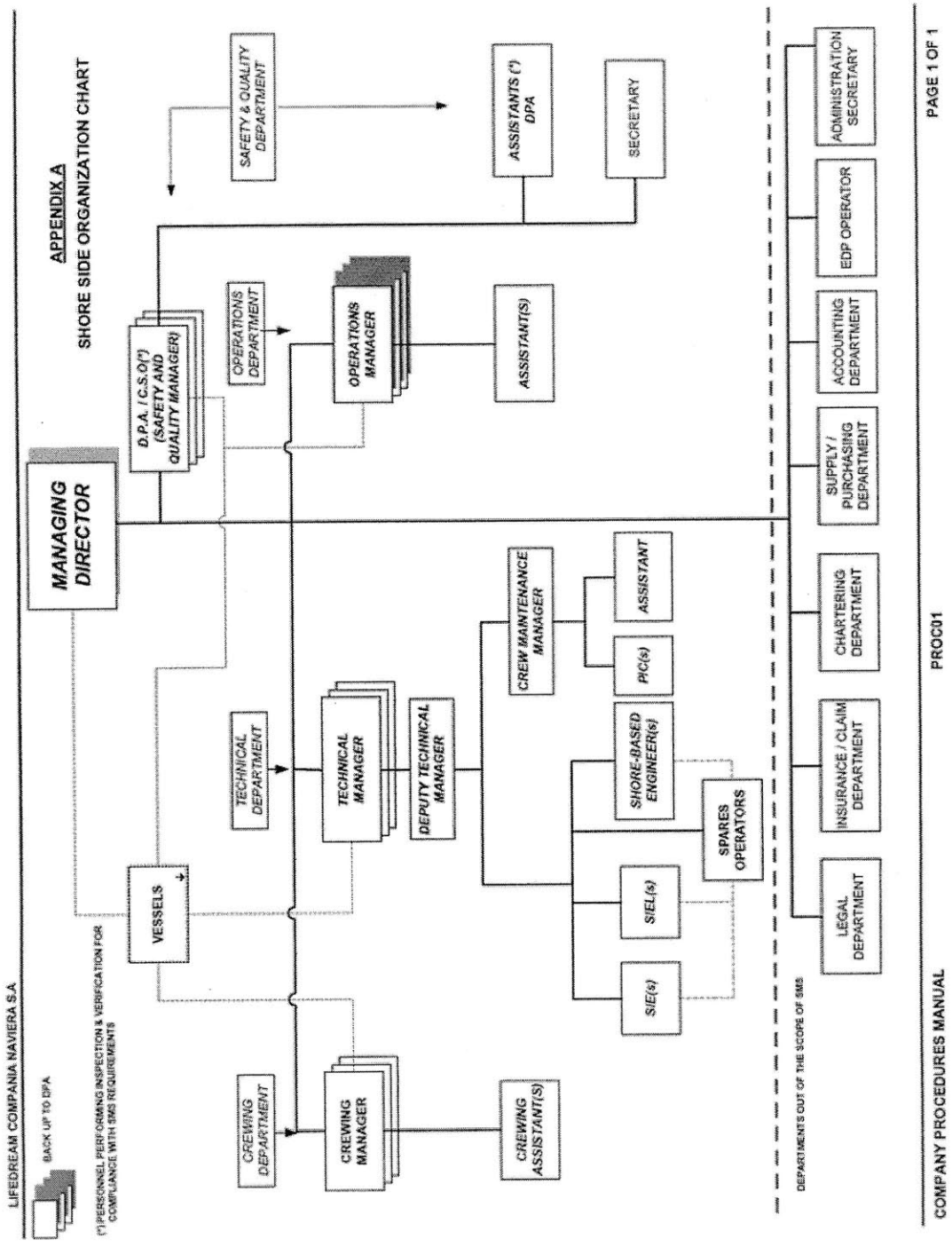


Fig. 5.3-16: Lifedream – Organizational Chart [Lifedream 2009]

Tables 5.3-9 & 5.3-10 summarize the operating expenses and performance metrics for

LCN as Tables 5.3-7 & 5.3-8 do for DRYS. On average, DRYS has a higher fleet utilization because it operates a younger fleet. In 2008, average fleet utilization was similarly high at 98% and 98.5% for LCN and DRYS respectively. Table 5.3-11 summarizes the percentage difference between the two companies for each line item of expenses.

LIFEDREAM	*2004*	*2005*	*2006*	*2007*	*2008*
CREW WAGES	$1,172	$1,316	$1,334	$1,600	$1,921
INSURANCES	$479	$557	$564	$600	$707
REPAIRS & MAINTENANCE	$1,229	$814	$1,321	$596	$2,011
SPARES & STORES	$624	$653	$627	$780	$976
TONNAGE TAX	$29	$37	$35	$38	$42
Operating Expenses	**$3,535**	**$3,378**	**$3,880**	**$3,614**	**$5,658**
GENERAL & ADMINISTRATIVE	$104	$109	$115	$116	$101
MANAGEMENT FEES	$482	$526	$526	$549	$526
Total Operating Expenses	**$4,121**	**$4,013**	**$4,521**	**$4,279**	**$6,285**

Table 5.3-9: LCN Operating expenses per vessel in $/day – Based on Data from [Lifedream 2009]

Lifedream	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
AVERAGE AGE OF FLEET	22.38	23.45	24.45	25.43	26.15	23.38
AVERAGE T/C EQUIVALENT PER DAY	17,156	18,739	17,372	22,06	18,75	17,43K
EARNINGS CAPACITY DAYS	8760	8030	8030	7665	7300	8760
NUMBER OF VESSELS	24	22	22	21	20	24
NET EARNING DAYS	8443	7641	7693	7181	6649	8585
OFF-HIRE DAYS	317	389	337	484	651	175
PERCENTAGE UTILISATION	95.97%	95.20%	95.80%	93.70%	91.10%	98%
AVERAGE VESSEL OPEX/DAY	4620	4667	5308	4754	5356	5517
DWT TONS	1,609,529	1,529,529	1,529,529	1,351,775	1,336,133	1,766,154
T/C EQUIVALENT REVENUES	144,852K	143,118K	133,645K	158,412K	124,668K	149633K

VESSELS CHARTERED IN	0	0	0	0	0	0
AVERAGE AGE OF FLEET IN YEARS	22.38	23.45	24.45	25.43	26.15	23.38
TOTAL REVENUES	144,852K	143,118K	133,645K	158,412K	124,668K	149633K

Table 5.3-10: Performance Measures of LCN fleet – Based on Data from [Lifedream 2009]

(Dryships-Lifedream)/Lifedream	*2005*	*2006*	*2007*	*2008*	*Average*
CREW WAGES		48%	43%	36%	42%
INSURANCES		-23%	-24%	-24%	-23%
REPAIRS & MAINTENANCE (INC D/D)		-12%	40%	-36%	-3%
SPARES & STORES		123%	97%	21%	80%
TONNAGE TAX		-40%	-36%	-13%	-30%
Operating Expenses	50%	29%	42%	0%	30%
GENERAL & ADMINISTRATIVE	480%	430%	572%	1389%	718%
MANAGEMENT FEES	1%	4%	11%	206%	56%
Total Operating Expenses	55%	36%	53%	40%	46%

Table 5.3-11: %Difference by which DRYS Expenses are higher than LCN – Based on data from [Lifedream 2009] and [Dryships 2009e]

With an average age of 8 years compared to 23, Dryships only pays 3% less for repairs and maintenance and its operating expenses are 30% higher. It pays 23% less for insurance and 40% more for crew wages – consistent with its policy of higher quality crews than LCN. Overall, DRYS has total operating expenses 46% higher than LCN which is remarkable given the age profiles of the two fleets. This may not seem important at times capes and panamaxes are earning on average over $200,000/day and $100,000/day respectively, and their expenses are less than $10,000/day. However, at times when revenues are also less than $10,000/day, which is when the biggest growth opportunities emerge, this difference is make or break for LCN.

5.3.9 Conclusions

Dryships follows a growth strategy which is consistent with the pressures and demands of the stock market. It tries to grow irrespective of where the market is and to a great extent uses equity finance to finance acquisitions. This allows for rapid expansion without having to wait years for the markets to bring about good investment opportunities. It comes however at the expense of share dilution.

LCN is a more traditional, low-cost shipping company which grows through the market cycles. It can afford to operate in this low cost fashion in part because it is not listed. By keeping operating expenses below revenues even during bad markets, and by building cash reserves and maintaining low leverage during the upturns, it can take advantage of recessions and make investments with huge ROE.

The structure of DRYS is that of a company which operates many new ships and can afford to split them into sub-fleets. This is easily scalable and offers several advantages including learning. LCN on the other hand operates less formally (being private and not having to report), with a structure that allows it to effectively manage old ships at low cost with relatively high performance. Its structure is optimal for its fleet size and age profile but it may have to be adjusted as the company grows.

5.4 Operating Cost Analysis

5.4.1 Introduction

Shipping costs have decreased dramatically on a per ton basis over the past century due to economies of scale through the use of larger ships. Costs for a given ship size, however, have increased substantially due to inflation, increasing fuel costs etc. Fig. 5.4-1

shows the inflation in major factors affecting shipping costs since 1965. The capital cost, shown as a dotted line, is based on the price of a newbuilding Aframax.

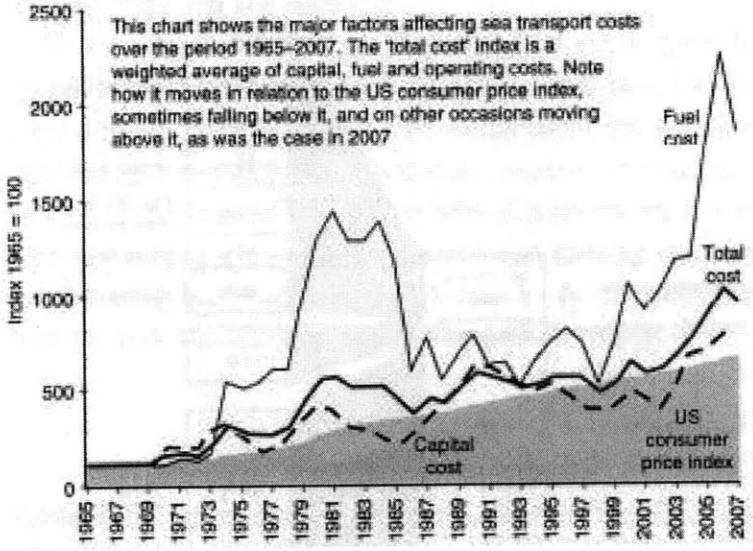


Fig. 5.4-1: Inflation in Shipping Costs 1965 to 2007 [Stopford 2009]

Shipping expenses are classified under Voyage Expenses, OPEX and CAPEX. Voyage expenses include bunkers, canal dues, port and pilot fees etc. Operating expenses include crew, insurance, maintenance and spares, supplies, management costs etc. Capital expenses include the cost of the vessel and repairs, conversions etc.

When a ship is employed under a voyage charter, all the costs mentioned above are covered by the ship owner who receives a payment on a $/ton basis. Under a time charter, voyage expenses are paid by the charter while the owner pays for OPEX and CAPEX and receives payment on a $/day basis. Under a bareboat charter, the charterer pays for both Voyage expenses and OPEX while the owner receives payment in $/day.

Capes are usually chartered on period charters in which all voyage expenses including bunkers are born by the charterer and incorporated into the daily rate. The rates reported on voyage fixtures are converted into a time charter equivalent and taken into account in the BCI which is published daily and on which futures are traded. The BCI will form the basis of our future revenue projections. As a result, the cost of bunkers and other voyage expenses are incorporated in the revenue projections. Therefore, we are not considered with voyage expenses including fuel cost.

The repair costs and off hire time were analyzed as a function of ship age in Section 5.2. Section 5.3 compared the operations of a private and a listed company. This Section is focused on estimating typical operating costs as a function of ship age.

5.4.2 Open Literature Data

Limited relevant research exists on this topic for various reasons. Private companies have no reason to report their data and often treat it as proprietary information. This is because low operating costs are a key competitive advantage that can be of detrimental importance to a company when going through a market downturn. On the other hand, low operating costs may be seen by outsiders as an indication of a compromise on quality or safety.

Management companies have an incentive to exaggerate their costs in order to keep owners happy by performing better, to be conservative and avoid having to give explanations when actual costs end up higher, and to absorb some of the benefits when actual costs are lower than their quoted costs. Public companies usually outsource the management/operation of their ships to professional management firms, so the operating costs they publish are subject to the above biases.

Another reason is that as with dry-dock costs, which were analyzed in Section 5.2, operating costs can vary significantly over time. This means that data which is more than a few years old is obsolete, making it harder to find relevant data. Furthermore, even the data by companies that is available cannot be applied to a specific ship type and age group because it is a blended average of the ships in the company's fleet. In Section 5.3, we looked at the operating costs of a public and a private company that operate capes. These are again summarized in Tables 5.4-1 and 2 respectively.

Dryships	*2005*	*2006*	*2007*	*2008*
CREW WAGES		$1,974	$2,294	$2,609
INSURANCES		$433	$459	$540
REPAIRS & MAINTENANCE		$1,164	$834	$1,295
SPARES & STORES		$1,395	$1,534	$1,179
TONNAGE TAX		$21	$24	$37
Operating Expenses	**$5,067**	**$4,986**	**$5,145**	**$5,660**
GENERAL & ADMINISTRATIVE	$631	$609	$780	$1,497
MANAGEMENT FEES	$532	$546	$610	$1,610
Total Operating Expenses	**$6,230**	**$6,141**	**$6,535**	**$8,767**

Table 5.4-1: Operating Expenses for Dryships in $/day per vessel – Based on Data from [Dryships 2009e]

LIFEDREAM	*2004*	*2005*	*2006*	*2007*	*2008*
CREW WAGES	$1,172	$1,316	$1,334	$1,600	$1,921
INSURANCES	$479	$557	$564	$600	$707
REPAIRS & MAINTENANCE	$1,229	$814	$1,321	$596	$2,011
SPARES & STORES	$624	$653	$627	$780	$976
TONNAGE TAX	$29	$37	$35	$38	$42
Operating Expenses	**$3,535**	**$3,378**	**$3,880**	**$3,614**	**$5,658**
GENERAL & ADMINISTRATIVE	$104	$109	$115	$116	$101
MANAGEMENT FEES	$482	$526	$526	$549	$526
Total Operating Expenses	**$4,121**	**$4,013**	**$4,521**	**$4,279**	**$6,285**

Table 5.4-2: LCN Operating expenses per vessel in $/day – Based on Data from [Lifedream 2009]

Companies don't all report data the same way and it is a complicated task to bring them into the same format. What would be more complicated, however, is to compare two companies on their costs of a single vessel. Dryships owns 7 Capes, 30 Panamaxes and 2 Supramaxes aged 0 to 15 years, while its fleet has varied slightly since 2005. The fleet of Lifedream consists of 4 Capes, 10 Panamaxes, 1 Supramax, 2 Handy's, 4 general cargo ships and 3 container vessels. It has also varied over the years and its age distribution is between 13 and 30 years. The results of Table 5.4-1 and 5.4-2 are affected by the whole fleet, so extracting a $/day amount for a Cape of a certain age from these values is not trivial even though both companies operate Capes.

[Stopford 2009] compiled data on operating costs of Capes as a function of age based on 2007 values from V-Ships (a large management company) and other sources. The results are conveniently broken down into sub-categories and are shown in Fig. 5.4-2. The provided percentage value of each category out of the total cost is of more long term value since the magnitude of costs varies from year to year.

Age of ship	5 Years	10 Years	20 Years	% Total Average
Crew cost				
Crew wages	544	639	688	30%
Travel, insurance etc	73	82	85	4%
Victualling	46	54	64	3%
Total	743	871	956	41%
%	32%	31%	26%	
Stores & Consumables				
General stores	129	144	129	6%
Lubricants	148	148	219	8%
Total	277	292	348	15%
%	12%	11%	9%	
Maintenance & Repairs				
Maintenance	90	169	10	4%
Spares	74	169	181	7%
Total	164	338	393	14%
%	9%	15%	13%	
Insurance				
Hull & machinery & war risks	133	148	303	9%
P&I	63	94	120	4%
Total	196	243	423	14%
%	32%	32%	44%	
General Costs				
Registration Costs	17	17	17	1%
Management Fees	255	223	255	12%
Sundries	57	57	57	3%
Total	330	298	330	15%
%	14%	11%	9%	
Total per annum	1,710	2,041	2,450	100%
Daily Costs (365 days)	4,685	5,591	6,712	100%

Source: Ten-year old ship, Moore Stephens, V Ships; 5- and 20-year-old ship costs estimated from various sources

Fig. 5.4-2: Operating Costs for Capesize Bulk Carriers by age in $000/year [Stopford 2009]

Crew costs appear to be the greatest cost category in Fig. 5.4-2. Fig. 5.4-3 shows a detailed break-down of crew costs as given by [Stopford 2009].

Rank	Note	Basic	Consolidated Allowances	Bonus (officers)	Provident Fund[b]	Totals[c] 2007	1993	% ch
Master	India	1,967	3,933	300	35	6,235	3,644	171%
Chief officer[a]		1,294	3,206	200	35	4,735	3,025	157%
2nd officer		1,077	1,773	—	35	2,885	2,338	123%
3rd officer		1,030	1,320	—	35	2,385	1,650	145%
Radio officer		radio officer no longer required in 2007					1,650	0%
Chief engineer		1,760	3,990	300	35	6,085	3,575	170%
1st asst engr	2nd eng.	1,294	3,206	200	35	4,735	3,025	157%
2nd asst engr	3rd eng.	1,077	1,773	—	35	2,885	2,338	123%
Bosun	Philippines	670	649	—	182	1,501	1,521	99%
5AB		558	542	—	171	6,353	6,479	98%
3 oiler		558	542	—	171	3,812	3,888	98%
Cook/std	chief cook	670	649	—	182	1,501	1,596	94%
Std	2nd cook	558	542	—	171	1,271	1,296	98%
Messman		426	378	—	158	962	1,071	90%
Total crew number modern ship: 20						45,344	37,094	122%
Additional crew for 10-year-old ship								
3rd asst engr	India	1,030	1,320	—	35	2,385	1,650	145%
Electrician	Elec. off.	1,077	1,823	—	35	2,935	2,338	126%
AB	Philippines	558	542	—	171	1,271	1,296	98%
1 oiler		558	542	—	171	1,271	1,296	98%
Total crew number 10-year-old ship: 24						53,205	43,673	122%
Additional crew for 20-year-old ship								
2 ordinary seamen	Philippines	426	378	—	158	1,925	2,142	90%
1 oiler		558	542	—	171	1,271	1,071	119%
1 messman		426	378	—	158	962	1,071	90%
Total crew number 20-year-old ship: 28						57,362	47,956	120%
		Annual crew cost for 20-year-old ship				688,344	575,475	120%

Notes

[a]Senior Officer based on 5 yr senority & Junior Officers 3 yrs seniority.

[b]Includes social costs

[c]1993 data from Stopford (1997, Table 5.3)

Source: V Ships

Fig. 5.4-3: Crew Costs on 160,000dwt bulk Carrier in 2007 ($/month) [Stopford 2009]

With the exception of the last row, the values in Fig. 5.4-2 are in $'000/year. The total values of the major categories are presented in Table 5.4-3 in dollars per day.

	5 years	10 years	20 years
Crew Cost	$2,036	$2,386	$2,619
Stores & Consumables	$759	$800	$953
Maintenance & Spares	$449	$926	$1,077
Insurance	$537	$666	$1,159
General Costs	$904	$816	$904
Total	**$4,685**	**$5,595**	**$6,712**

Table 5.4-3: Operating Costs for Capesize Bulk Carriers (2007) by [Stopford 2009] in $/Day

5.4.3 Company Survey Results

In order to estimate typical operating costs, a survey was performed on 6 private and 4 listed companies that operate Capes. The importance of including both listed and private companies is highlighted by Section 5.3. These companies were asked to provide estimates of daily operating cost items as a function of ship age, using today's prices (End of 2009) and 10-year average prices. The chosen ship ages were 5, 10, 15, 20 and 25 years. The same cost categories chosen by [Stopford 2009] in Fig. 5.4-2 were used to aid direct comparison.

Not all companies operated capes of all ages today and over the past 10 years. However, some provided estimates based on expenses which they incurred on vessels of a different age or of a different type such as Panamaxes. Average values of the responses were then calculated and presented in Table 5.4-4 and 5.4-5.

End 2009 Prices	5 years	10 years	15 years	20 years	25 years
Crew Cost	$2,183	$2,203	$2,412	$2,503	$2,564
Stores & Consumables	$395	$602	$712	$889	$986
Maintenance & Spares	$152	$198	$286	$531	$547
Insurance	$686	$798	$912	$989	$1,113
General Costs	$756	$813	$864	$924	$1,034
Total	**$4,172**	**$4,614**	**$5,186**	**$5,836**	**$6,244**

Table 5.4-4: Survey Results for Cape Operating Costs in $/Day using End-2009 Prices

10-Year Avg. Prices	5 years	10 years	15 years	20 years	25 years
Crew Cost	$1,840	$1,843	$1,964	$2,062	$2,073
Stores & Consumables	$325	$489	$570	$726	$790
Maintenance & Spares	$147	$189	$271	$501	$515
Insurance	$558	$648	$731	$786	$882
General Costs	$640	$683	$724	$767	$858
Total	**$3,509**	**$3,852**	**$4,260**	**$4,842**	**$5,118**

Table 5.4-5: Survey Results for Cape Operating Costs in $/Day using 10 Year Average Prices

Tables 5.4-4 and 5.4-5 show that operating costs increase with age and they have increased from the 10-year average value for all ages. Not every number in the tables is from exactly the same source because some companies could not provide reliable estimates for some of the values. Despite this, all the results, which are based on the average of the available data, continuously increase with age. This is true for both Table 5.4-4 and Table 5.4-5 and it should increase our confidence in the results.

On the other hand, this is not true for the data provided by [Stopford 2009], which seems to be derived from a more diverse variety of sources. For example, as we see in Table 5.4-3, the total general costs for a 10-year old ship are lower than those of both the 5-year old and the 20-year old ship, which makes little intuitive sense. Another example can be seen in Fig. 5.4-2 where the maintenance cost for the 10-year old ship is equal to multiple times that of the 5-year old and the 20-year old ship.

Fig. 5.4-4 shows a plot of the values in Table 5.4-3, 5.4-4 and 5 to facilitate comparison.

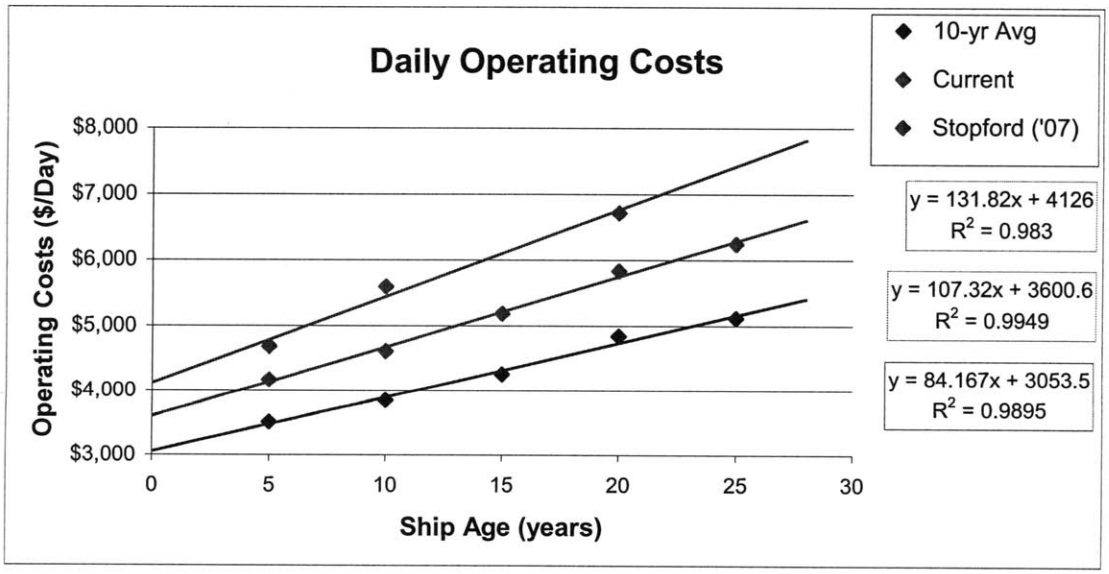


Fig. 5.4-4: Operating Costs vs. Ship Age using Current, 10-year Average and 2007 Prices

The results for each set of data are remarkably linear with respect to ship age, with R^2 values exceeding 0.98 in all three cases. This is particularly surprising given the fact that some distortion is inherent due to the variation of sources within each data set.

Comparing across data sets, the linear regression curves are approximately parallel, diverging slightly as the ship age increases. This is natural because higher costs are incurred at higher ages, so one would expect the difference to also increase. In other words, the percentage difference is fairly constant. Comparing Current-Price results to the [Stopford 2009] results, it varies between 12.3% and 21.3% with a mean of 16.2% and a standard deviation of 4.6%. Comparing the Current-Price results to the 10-Yr Avg. price results, the difference varies between 18.9% and 22.0% with a mean of 20.6% and a standard deviation of 1.3%.

On average, operating costs using 10-year average prices are 82.93% of operating costs using current prices. The operating costs provided by [Stopford 2009], which are shown in Green, are based on 2007 data and are higher than both the survey results based on End-2009 prices and those based on 10-year average prices. This is perhaps because 2007 may have been a relatively expensive year or because operating costs sourced from management companies such as V-Ships are higher than the typical for reasons discussed under Section 5.4.2.

5.4.4 Monthly Operating and Dry-Dock Costs

Since the regressions in Fig. 5.4-4 are quite accurate, we can interpolate to get an estimate of the operating costs for every ship age. This is done using both 10-year average and End-2009 prices, and the corresponding values are combined with dry-dock costs from Table 5.4-8 of Section 5.2 to produce the total in $/day. The results are summarized in Table 5.4-6.

Fig. 5.4-5 shows a regression plot of the combined operating and dry dock costs with respect to ship age.

	10-yr Avg Prices			End-2009 Prices		
Ship Age (Years)	Operating	Dry Dock	Total	Operating	Dry Dock	Total
0	$3,054	$11	$3,064	$3,601	$8	$3,608
1	$3,138	$11	$3,149	$3,708	$8	$3,716
2	$3,222	$119	$3,341	$3,815	$85	$3,900
3	$3,306	$184	$3,490	$3,923	$131	$4,054
4	$3,390	$98	$3,488	$4,030	$69	$4,099
5	$3,474	$249	$3,724	$4,137	$178	$4,315
6	$3,559	$113	$3,671	$4,245	$80	$4,325
7	$3,643	$611	$4,254	$4,352	$435	$4,787
8	$3,727	$672	$4,399	$4,459	$479	$4,938
9	$3,811	$280	$4,091	$4,566	$199	$4,766
10	$3,895	$1,510	$5,405	$4,674	$1,075	$5,749
11	$3,979	$56	$4,035	$4,781	$40	$4,821
12	$4,064	$952	$5,015	$4,888	$678	$5,566
13	$4,148	$2,190	$6,337	$4,996	$1,558	$6,554
14	$4,232	$829	$5,061	$5,103	$590	$5,693
15	$4,316	$1,914	$6,230	$5,210	$1,362	$6,573
16	$4,400	$319	$4,719	$5,318	$227	$5,545
17	$4,484	$1,625	$6,110	$5,425	$1,157	$6,582
18	$4,569	$2,601	$7,169	$5,532	$1,851	$7,383
19	$4,653	$910	$5,562	$5,640	$648	$6,287
20	$4,737	$3,412	$8,149	$5,747	$2,428	$8,175
21	$4,821	$1,137	$5,958	$5,854	$809	$6,664
22	$4,905	$3,529	$8,434	$5,962	$2,512	$8,473
23	$4,989	$3,294	$8,283	$6,069	$2,344	$8,413
24	$5,074	$1,160	$6,233	$6,176	$825	$7,002
25	$5,158	$3,092	$8,250	$6,284	$2,201	$8,485
26	$5,242	$1,288	$6,530	$6,391	$917	$7,308
27	$5,326	$3,187	$8,513	$6,498	$2,268	$8,766
28	$5,410	$3,187	$8,597	$6,606	$2,268	$8,874

Table 5.4-6: Operating and Dry Dock Costs vs. Age

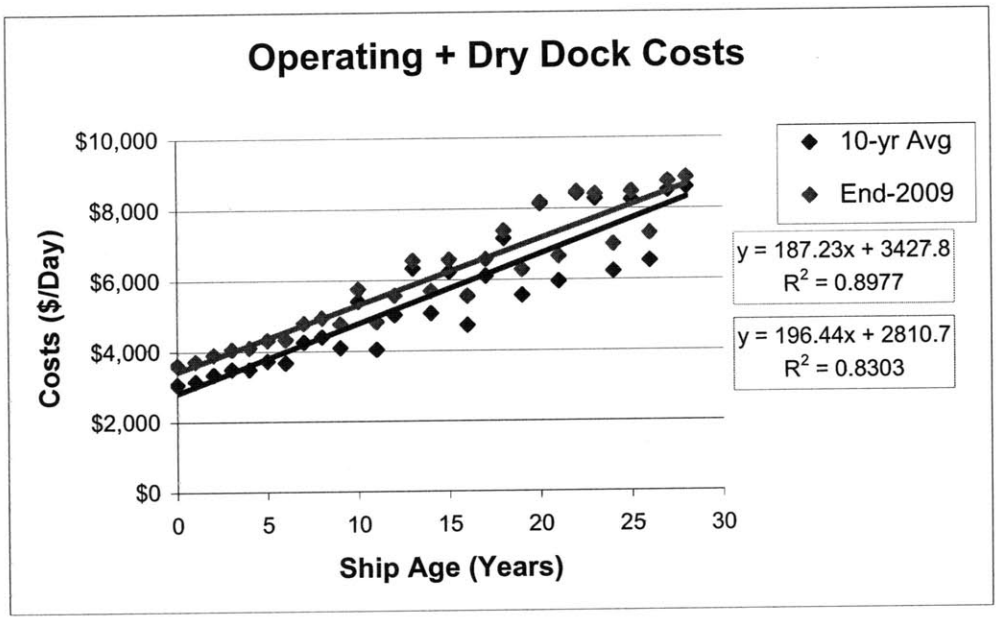


Fig. 5.4-5: Operating and Dry Dock Costs using 10-Yr Average and End-2009 Prices

The R^2 values have decreased from 0.99 and 0.99 for just operating costs in Fig. 5.4-4 to 0.9 and 0.83 for combined operating and dry dock costs in Fig. 5.4-5. Including dry-dock costs adds a lot of scatter to the data.

Focusing on operating costs, we can describe them using a linear function with respect to age, for both sets of prices. For consistency, we use months (M) as the time increment. This is shown in Eq. 5.4-1 and 5.4-2.

$$OC_{10-yrAvg} = 7.013917M + 3053.5 \qquad (5.4\text{-}1)$$

$$OC_{End-2009} = 8.943333M + 3600.6 \qquad (5.4\text{-}2)$$

Where M = age in months

Dry dock costs are not linear due to the irregularity of repairs. To obtain the monthly values we can simply assume the annual value to be constant throughout each given year

5.4.5 Inflation in Operating Costs

The survey results of Table 5.4-4 and 5.4-5 show that average operating costs based on 10-year average prices are 82.93% of average operating costs based on current prices. To get the implied average inflation in operating costs I_{oc}, we can solve Eq. 5.4-3.

$$\frac{\frac{1}{N}\sum_{n=1}^{N} OC_0 \left(1+I_{oc}\right)^{n-1}}{OC_0 \left(1+I_{oc}\right)^{N-1}} = 82.93\% \qquad (5.4\text{-}3)$$

Where: N = Number of years (10 in our case)

OC_0 = Operating cost for the first of the 10 years (Year 2000)

I_{oc} = Operating cost inflation

Solving Eq. 5.4-3 for I_{oc} yields an average operating cost inflation of:

$$I_{oc} = 4.43\%$$

This seems quite high if one compares it directly to US inflation over the same time period. It is important to note that significant variations occur from year to year while this is only an average estimate over a 10 year period. Furthermore, it excludes dry dock costs for which, as we saw in Section 5.2, the 10 year average value is 140.5% of the current value (reciprocal of 71.17%).

We can include dry dock costs to determine an estimate of the average inflation of the combined costs (operating and dry dock costs). Table 5.4-7 shows the combined costs using 10 year average prices divided by the combined costs using current prices throughout the ship's life.

Age (Years)	Combined Costs (10-yr Avg)	Combined Costs (End-2009)	Combined Costs (10-yr Avg.) / Combined Costs (End-2009)
0	$3,064	$3,608	84.92%
1	$3,149	$3,716	84.74%
2	$3,341	$3,900	85.67%
3	$3,490	$4,054	86.10%
4	$3,488	$4,099	85.08%
5	$3,724	$4,315	86.30%
6	$3,671	$4,325	84.89%
7	$4,254	$4,787	88.87%
8	$4,399	$4,938	89.09%
9	$4,091	$4,766	85.84%
10	$5,405	$5,749	94.03%
11	$4,035	$4,821	83.70%
12	$5,015	$5,566	90.11%
13	$6,337	$6,554	96.69%
14	$5,061	$5,693	88.90%
15	$6,230	$6,573	94.79%
16	$4,719	$5,545	85.11%
17	$6,110	$6,582	92.83%
18	$7,169	$7,383	97.10%
19	$5,562	$6,287	88.47%
20	$8,149	$8,175	99.67%
21	$5,958	$6,664	89.41%
22	$8,434	$8,473	99.54%
23	$8,283	$8,413	98.45%
24	$6,233	$7,002	89.02%
25	$8,250	$8,485	97.24%
26	$6,530	$7,308	89.36%
27	$8,513	$8,766	97.11%
28	$8,597	$8,874	96.88%
Average	**$5,561**	**$6,049**	**90.69%**

Table 5.4-7: 10-year Average vs. End 2009 Combined Operating and Dry Dock Costs

The mean is 90.69% with a standard deviation of 5.26% and a range of 83.7% to 99.67%. By replacing 82.93% with 90.69% in Eq. 5.4-3, we can solve for the average inflation of the combined costs I_{oc} instead of I_{oc}. The equation becomes:

$$\frac{\frac{1}{N}\sum_{n=1}^{N} CC_0\left(1+I_{cc}\right)^{n-1}}{CC_0\left(1+I_{cc}\right)^{N-1}} = 90.69\% \qquad (5.4\text{-}4)$$

Where: N = Number of years (10 in our case)

CC_0 = Combined operating and dry dock cost for the first of the 10 years (Year 2000)

I_{cc} = Combined operating and dry dock cost inflation

Solving Eq. 5.4-3 for I_{oc} yields an average combined cost inflation of:

$$I_{cc} = 2.24\%$$

This may seem like a number more closely aligned with US inflation. However, by considering the Chinese cape repair cost index developed in Fig. 5.4-6 of Section 5.2, we see that it is inappropriate to assume a steady inflation in dry dock costs. We have also discussed that dry dock costs are to a large extent associated with factors that are not closely related to inflation such as freight levels, the outlook of the market, the supply of ships, shipyard capacity, demand for newbuildings etc.

On the other hand, operating costs are primarily based on factors that are more closely related to inflation, such as crew costs, supplies and consumables etc. A key factor to note about inflation is that it is sensitive to measurement method and whether it accounts for seasonality adjustments. Another important thing to consider is that the basket of goods and services comprising the operating costs of a Cape derives from a variety of industries and countries around the world, so it is worth looking at inflation beyond the US.

Fig. 5.4-6 and 5.4-7 show estimates of inflation using today's methods and methods that were used in the past.

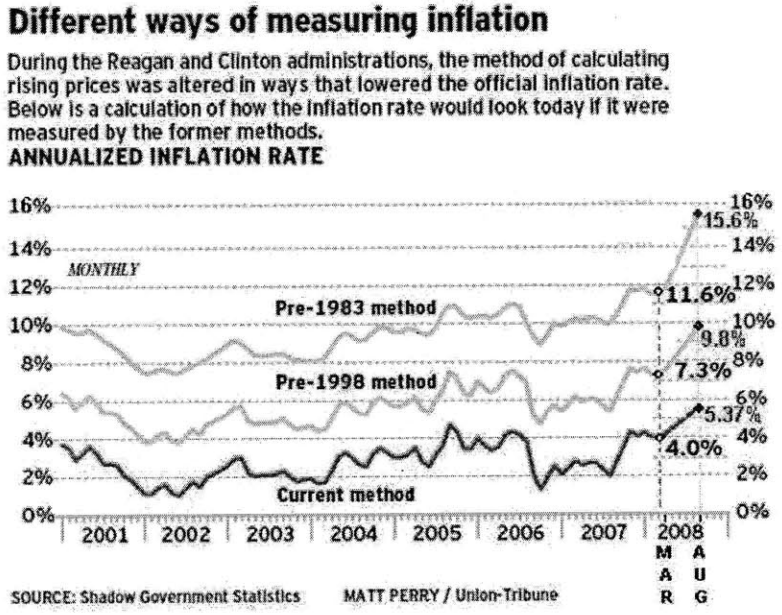


Fig. 5.4-6: US Inflation using Current, Pre-1998 and Pre-1983 Methods [One-Simple-Idea.com]

It is important to note that the lines measuring inflation by the various methods are parallel, meaning that one is roughly a multiple of the other. The pre-1998 and pre-1983 methods yield slightly less than double and triple values respectively relative to the current method.

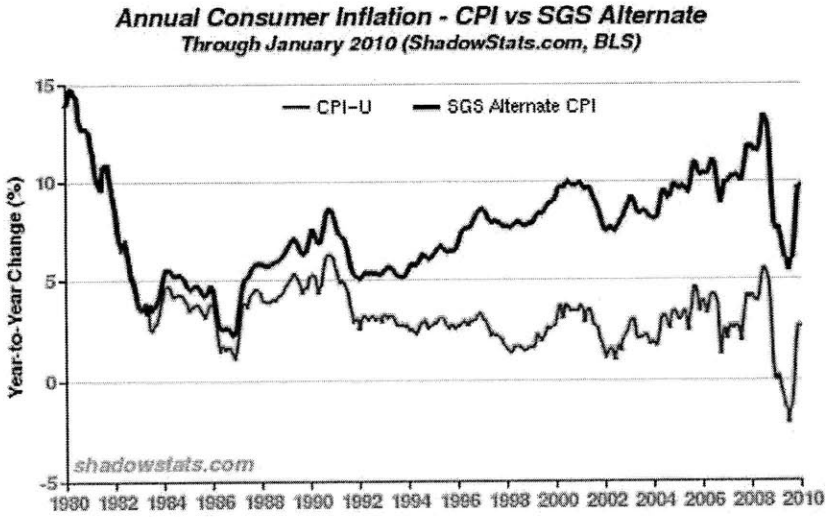


Fig. 5.4-7: US Inflation by CPI-U and SGS Alternative CPI-U [Williams 2010]

The CPI-U is the consumer price index for all urban consumers, which is the broadest in coverage. While the headline number is usually seasonally adjusted, the formal CPI reported, is not. The SGS Alternative CPI-U attempts to adjust for allegedly, methodical changes over the recent decades that have moved concept away from being a measure of the cost of living needed to maintain a constant standard of living.

Fig. 5.4-6 and 5.4-7 clearly show that the measurement methods for reporting purposes have a very significant impact on inflation. It is unclear which of these should be more relevant for our purposes. Furthermore, one can see that there is a big disparity between the buying patterns of urban consumers in the US (the measure of the CPI), and the operating costs of a cape that travels around the world. Fig. 5.4-8 shows the global inflation (inter-quartile range and median) since 1950.

Inflation throughout the world has decreased over time due to several factors such as globalization, better monetary policy, luck, the emergency of a new economy and the attendant acceleration of productivity, lower target rates, greater weight on inflation stabilization than on output stabilization, steeper Philips curves or a decline in wedge between natural and socially optimal output levels [Wynne and Kersting 2007, Sentance 2008]. Another factor as we saw earlier is the change of methods in measuring inflation.

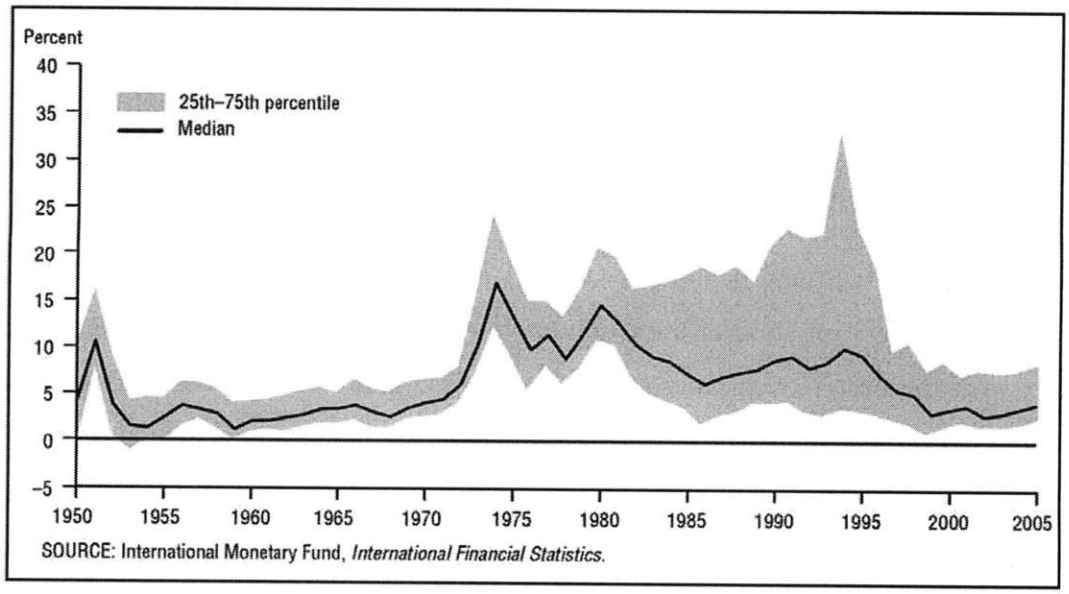


Fig. 5.4-8: Postwar Global Inflation since 1950 [Wynne and Kersting 2007]

Inflation rates in developing countries since 2000 have been approximately 3 times higher than in developed countries (and much higher in previous decades) [Wynne and Kersting 2007]. An important thing to consider is that, at least since 2000, US inflation, global inflation and inflation of various developed and developing countries around the world, move to a great extent in parallel to each other [IMF 2005]. Table 5.4-8 shows US inflation over the past 10 years based on the Consumer Price Index (CPI).

Year	US Inflation Based on CPI-U (%)
2000	3.4
2001	2.8
2002	1.6
2003	2.3
2004	2.7
2005	3.4
2006	3.2
2007	2.8
2008	3.9
2009	-0.3
Mean or CAGR	**2.57**

Table 5.4-8: US Inflation since 2000 [CDRPC 2010, CPS 2010]

5.4.6 Projection of Operating Costs

The mean US inflation or the Cumulative Average Growth Rate (CAGR) of the CPI-U index over the past 10 years has been about 2.6%. The operating cost inflation over the same time period, calculated by Eq. 5.4-3, was 4.43% which is approximately 1.721 times the US inflation rate.

As discussed previously, one of the reasons for this is that cape operating costs are highly affected by inflation rates in other countries, many of which are developing and have significantly higher inflation rates. The mix of countries and mix of goods and services involved in cape operating costs is somewhat intricate and not directly liked to the inflation

of any one particular country. Another reason is the fact that US inflation, as measured by various current and past methods yields a wide range of results, and it is unclear which of those would be most relevant for our purposes.

An important fact that we can use going forward is that, as discussed earlier, US inflation, as measured by the various methods, global inflation, and inflation in various developed and developing countries around the world, move to a great extent in parallel. This enables us to make an assumption that the inflation of operating costs will also move in parallel with US inflation going forward. Thereby, we can approximate the inflation of operating costs as a multiple of the US inflation going forward.

The average multiple over the previous 10 years was 1.721. As time progresses, due to globalization and the improvement in developing countries, we would expect this multiple to decrease. Indeed the gap between inflation in many developing and developed countries around the world has declined over time. As an approximation, therefore, we can assume the multiple to begin at the 10-year average value (1.721) and decline linearly to 1 over 30 years (a decline of 0.002 per month).

A forward view on US inflation can be extracted from the relative pricing of Treasury Inflation Protected Securities (TIPS) and regular US government Treasury Bills (T-Bills). The difference between the two prices is not only an expectation of future inflation but also a level that can be hedged. Fig. 5.4-9 shows the Term structure of real yield (TIPS), nominal yield (T-Bills), and inflation based on prices of March 22, 2010.

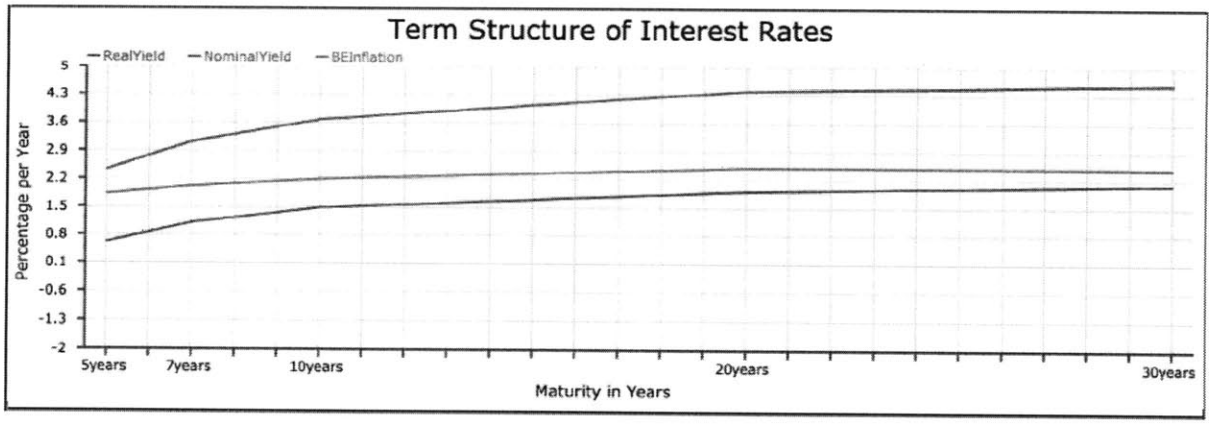


Fig. 5.4-9: Term Structure of Real Yield, Nominal Yield and Inflation as of March 22 2010 [Bodie 2010]

We can therefore start with Eq. 5.4-2, which describes the current operating costs as a function of the ship's age using today's prices, and adapt it to also be a function of time and therefore dependent on inflation. The equation becomes:

$$OC_{N(n)} = \left(8.943M + 3601\right)\left[1 + MAX\left(1, 1.721 - 0.002n\right) I_n\right]^n \tag{5.4-5}$$

Where: N: Month at which operating costs are evaluated

n: Months from today

M: Ship's age in months at the time when the operating costs are evaluated

$OC_{N(n)}$: Nominal Operating costs in $/day at "N" months from today

I_n: Average US monthly inflation until month "n" – as predicted by current TIPS and T-Bill prices with a tenure of "n" months

In real terms (2010 dollars), the operating costs will be:

$$OC_{Nr} = \left(8.943M + 3601\right)\left[1 + MAX\left(0, 0.721 - 0.002n\right) I_n\right]^n \tag{5.4-6}$$

Where: $OC_{N(r)}$: Real Operating costs in $/day at "N" months from today

5.5 Valuation Methods

5.5.1 Introduction

There are two main approaches to valuation. The first is to say that the value of an asset is what you can sell it for in the current market. For this to hold true, we must assume high market efficiency, information distribution, liquidity etc. The second is an attempt to quantify the "intrinsic value" of an asset which can be though of as the present value of all the cash flows it is expected to generate in the future. The semi-strong form market efficiency says that assets may not always be priced at their intrinsic value but they gravitate towards it (at various speeds). This creates investment opportunities for those able to identify mispriced assets.

Valuation methods in general fall under three categories, DCF (Discounted Cash Flow), relative valuation (based on multiples or comparables) and contingent claim valuation (option pricing based). Each method has its strength and weaknesses and one may be more relevant than the other depending on the application. DCF valuations require an estimation of the projected revenues as well as the risk-adjusted discount rate. Relative valuation assumes that the chosen comparables are very similar in many ways which is often unrealistic. Option based valuation requires a mature and liquid enough market from which parameters can be drawn or estimated with reasonable accuracy and it is limited in long term valuations since an assumption has to be made about constant variance and dividend yields.

In this section we will review the methods currently used in the valuation of ships. We will also briefly look at shipping company valuation since that has implications for the values of its assets (mainly ships) which one can theoretically extract. According to [Clarksons 2009b], 6 uses for ship valuations are:

1. Establishing a fair value for buying or selling a ship
2. Establishing the collateral value for a bank loan
3. Monitoring covenants depending on asset value

4. Appraising the borrower's net worth
5. Asset valuation for prospectuses
6. Appraising the hull insurance value

Another important reason should be for public companies to check if asset value impairments are necessary on their books.

5.5.2 Ship Valuation Methods

5.5.2.1 Adjusted Comparables Pricing Method

This method is by far the most popular and falls under the category of relative valuation. Brokers use it to carry out ship valuations for their clients based on the most recent comparable transactions. Their clients, namely potential sellers, buyers and banks then use these estimates and often update them with their own views to make their decisions. The main assumptions of the valuation are "willing buyer, willing seller" and the good condition of the ship (broker will not inspect but if a survey is due, he should account for it as the market would) [Clarksons 2009b].

Much like in the real estate market, the closing price of the most recent similar transaction is used as a base line and then adjustments are made for differences in key characteristics. These include the ship's type, size, age, condition, yard of build, specification (coatings, gear, and speed), main engine, fuel consumption and survey status. The first three are the most important while others are accounted for more crudely e.g. by having 3 tiers of shipbuilding yards. The broker may also consider other influencing factors such as freight rates, investor liquidity, newbuilding prices and expectations [Clarksons 2009b].

Often, a number of recent transactions are used to form a baseline. Due to the high market volatility, brokers also incorporate their views on market changes since the last

transaction into the valuation. Slight variations of this method also exist in which new transactions are input into a statistical model which updates the baseline values.

The value of an asset is defined as the present value of the profits it is expected to generate throughout its life. This expectation changes continuously and is affected by many factors that are extremely hard to keep track of and quantify. Examples include the future supply of ships, cost of oil, demand for transportation, interest rates, political issues etc. One can assume that the market views on all these parameters have been incorporated into the closing prices of previous transactions. Assuming that the market has it right is reasonable as long as people generally have the same information. By using previous closing prices as a baseline, one is directly incorporating all the relevant parameters without having to go through the tedious and uncertain calculations and forecasts. This makes the method extremely convenient and transparent, explaining why it has been the predominant method used by brokers for many decades.

Unfortunately, changes in the world financial markets and in the shipping industry have limited the applicability of this method. There has been a tremendous increase in the volatility of the shipping market over the past decade. This is partly due to the introduction of shipping derivatives and also due to other market forces. Fluctuations in daily earnings of Capes by $10,000/day over night were not uncommon in the past few years. This precludes the use of many transactions that have occurred more than a few days ago. A relevant baseline price can only be formed using very recent transactions, which are often not available. One option brokers have is using less similar comparables, which reduces the accuracy of price adjustments. Their other option is to go back further in time to find more similar comparables. This places more weight on the broker's perception of how market changes should impact ship values over time, making the valuation more subjective.

The credit crunch impacted shipping directly in 2008, leading to minimal transactions over a period of extreme volatility in freight rates. This was followed by a limited number of transactions which were deemed by brokers as not applicable for valuation purposes. Average daily earnings of capesize bulk carriers decreased from $233,988 per day in June-5th 2008 to $2,316/day in December-2nd 2008. Over those six months, there were steep daily declines in average daily earnings of up to $32,939/day, so people were reluctant to make investments. Using the pre-decline quoted price of $154M (for a new vessel with prompt

delivery) as a baseline would be unreasonable since people would not invest anything near that in the declining market.

As a result, valuation using the above procedure became a complete guessing game. Some transactions that occurred around the decline were deemed inapplicable because they were distressed sales i.e. by companies needing immediate cash to stay in operation. Brokers thought they were not reflecting fair market values, which require a willing buyer and seller, so they could not be used to predict the fair value of another ship. The need for more rigorous valuation methods quickly became obvious to the shipping industry including banks, brokers, analysts, shipowners etc.

The research department of Clarksons shipbrokers had been keeping time series of ships with different specifications (size and age), that were often provided to clients. They also provided an online service where one could enter some key parameters and obtain an estimated ship valuation based on a simple model. The website is no longer available and they were forced to discontinue their valuation series in October 2008 until early 2010 due to the problems discussed above. According to Clarksons head of research, Dr Stopford "*It was reasonable to have halted them for a while because there were reasonable concerns that people may not have understood quite how subjective the market was... Often parts of the sale and purchase market are not very liquid and that is part and parcel of the valuation process and we rely on brokers to make their best judgment*" [McCarthy 2010].

Even when the relevant data is available, the comparables based method has serious weaknesses in a volatile or a changing market. Up until the beginning of the market boom which started in 2003, valuations were very simple using the method. The market was relatively stable and linear depreciation was a good approximation which allowed brokers to estimate the value of a ship fairly accurately based on a standard adjustment to the price of a similar ship of a significantly different age. When the market went to record levels, nobody expected it to stay high. They valued the earnings of a ship over the immediate future much more than those over the later years because they expected rates to return to "normal". The implications of this phenomenon are analyzed in great detail in Section 2.5.

The value of old ships increased disproportionately relative to that of newer ships, linear depreciation became completely inappropriate, and other factors such as delivery time suddenly became crucial. As a result, valuations using the comparables method became much

more difficult and inaccurate and it took significant time for them to adjust. On the other hand, people's expectations of the market were clear from the levels at which futures were trading for each of the following years. Therefore, a valuation procedure that took this explicitly into account would be far more adaptive to this kind of changes.

5.5.2.2 Shadow Pricing

As discussed in Section 5.5.2.1, the traditional methods based on comparables became impossible to apply when there were not enough transactions considered to be between a willing buyer and a willing seller. A new valuation method was proposed by [Levine 2009] as an attempt to overcome this problem. It is based on the high historic correlation between charter rates and ship prices and on the premise that charter rates measure the earning power of a ship and thereby its value.

By using a large database of fixtures and transactions (20 years worth), time series are formed for 6-12 month rates and ship prices (in current dollars) for various types and ages of bulk carriers and tankers. To apply the method, we first look at the prevailing charter rates for the ship we want to value. Then we go to the historic data at times when the charter rates were the same, and pull out all the transaction prices of similar ships (same age and size). Then we form a distribution, we look at the mean, median, range and inter-quartile range, and decided the "shadow price".

As the traditional method described in Section 5.5.2.1, this method also falls under the comparables based valuation category. It is in fact a multiples based valuation using the Price-to-Earnings (P/E) ratio. The shares of firms that are preparing for an Initial Public Offering (IPO) are usually valued by assuming a P/E ratio similar to that of comparable firms in the same industry. [Levine 2009] applies the same concept but to historical data of equivalent ships. The key assumption is that P/E ratios remain within a reasonable range over time.

As an example, [Levine 2009] presents the valuation procedure of a 15 year old 70,000dwt PMX bulker in February 2009. This is shortly after the steep market decline when shadow pricing would come in handy. The short term charter rates for these ships were

approximately $14,500/day so the database was searched for 15-year old PMX sales that occurred at periods when 6 to 12 month charter rates were in the range of $14,000/day to $14,999/day between January 1st, 1990 and February 1st, 2009. Since this is a very popular example, 803 rate/value pairs were found. The price range was $8.9M to $58.8M, the inter-quartile range (50% of data) was $11.3M to $13.2M, the median was $12M and the mean was $13M.

Based on the above results, the shadow price of a 1994-built (15 years old), 70,000dwt bulk carrier in February 2009 earning $14,000/day to $15,000/day is between $12M and $13M [Levine 2009]. Comparable transactions that occurred around that time are summarized in Table 5.5-1 along with average short term time charter rates at the time of the transaction.

Early 2009 ~15 year old PMX Transactions (Shadow Price ~ $12.5M)						
Date (2009)	PMX Rates ($/day)	Ship Name	DWT	Built	Yard	Price ($M)
Jan-1st	4,326	Cumbria	69,000	1994	Imabari	6.5
Feb-10th	12,182	Glorious Wind	72,119	1997	Hitachi	18.4
Mar-30th	11,481	Energy	69,255	1993	Imabari	15.1
Apr-7th	13,500	Island Globe	73,119	1995	Samsung	18.7
Apr-27	15,750	Brave NY	69,993	1997	Sasebo	20.2
Apr-28th	15,625	Trinity	69,607	1993	Hashihama	16.0
Apr-28th	15,625	Prem Proova	69,286	1994	Hashihama	16.0

Table 5.5-1: Transactions of ~70,000dwt, 15-year-old Bulkers Near February 2009

Data from [Clarksons 2010, Tradewinds 2010]

As shown by the actual transactions, noting the differences in ship age and daily earnings, the shadow price gives a rough estimate that falls in the ballpark of actual closing prices. The big advantage is that charter rates are almost always observable because unlike the S&P market, the charter market usually operates efficiently without interruptions. An estimate of ship values can thereby be inferred from observable data during periods of low transaction liquidity during which traditional valuation methods are impossible to apply. The

method gained some traction and Shadow Prices were regularly referred to throughout 2009 for valuing ships [Martin 2009a] [Martin 2009b] or whole fleets [Martin 2009c].

It is important, however, to realize that it only gives a rough alternate estimate and is not intended as a primary valuation method. First, the range of values obtained from historical data is often very large ($8.9M to $58.9M in the previous example) and it may not be clustered around a certain point. This introduces a lot of inaccuracy in interpreting the data. Another limitation is that for less popular time charter rate/ship combinations than the previous example, the process is much more difficult and there are often not enough historical data to derive reliable shadow prices. Most importantly, current earnings may be a convenient metric but the fundamental asset value depends on the expected future cash flows. This is better represented by the term structure of charter rates or the futures curve.

In Section 2.5.7, we saw that even though prices and earnings of Capes are highly correlated, the prices in March 2007 were much higher than in the peaks of February 2004 and December 2004 while charter rates were significantly lower. That was because the longer the high rates lasted, the more people believed that they were not just temporary. In other words, their expectations for futures earnings (which can easily be inferred from futures curves), were relatively higher. This, obviously, had a big impact on ship values, which is not captured by the shadow valuation method.

The same is true when freight rates drop from high levels. The longer they remain low, the more people believe they will not recover, and the more ship values decline. Such a metric could be captured by taking an integral over the recent historic earnings, rather than looking at the current value, but a much more direct and reliable approach would be to look at the term structure of the forward curve.

5.5.2.3 Proposed "Modified Shadow Price"

As suggested in Section 5.5.2.4, I believe it is more relevant to look at the current expectations of charter rates through the forward curve instead of taking a snapshot of current rates. However, the beauty of this method is its simplicity which would be compromised by

doing so. Instead, I recommend a slight modification which makes it even simpler and more transparent. This will also incorporate elements of the comparables method from historic periods when it was applicable.

The first step is to look at the prevailing charter rates and identify historic periods during which the charter rates were at the same levels. After doing that, instead of forming a distribution of the transactions that occurred within these periods, one can simply take the mean of the published ship value indices (which were derived using comparables at that time). This gives less information about our confidence in the result but has 3 advantages. First, you don't need a 20-year database of fixtures and transactions. Second, the price adjustments for ships that are not quite the same (most) is left to the experts, namely the panelists who submit quotes to the Baltic Exchange or other brokers. This, of course is only an advantage if you have more confidence in them doing that. Lastly, it gives an equal weight to each period during which the charter rates were the same rather than giving an equal weight to each ship. This is important because if many ships happen to be sold at a specific period then that period dominates the others. The dominating period may be one of adjustment during which people's expectations have not yet stabilized and therefore, transaction prices reflect earnings in a different way.

5.5.2.4 Hamburg Valuation Standard

The Hamburg Valuation Formula, developed by the Hamburg Shipbrokers Association, is arguably the state of the art in ship valuations. [VHSS 2009] describes its details and purpose along with a few examples. The very few transactions concluded during the global financial crisis can not be used as representative for valuation purposes because they were forced sales. Therefore, the new ship valuation standard was introduced to prevent a downward spiral of prices [Hagen 2009].

[VHSS 2009] also argue that charter rates are unsuitable as a basis for a projected earnings analysis because they are in some cases at the level of operating expenses. Therefore, they developed a "conservative" method to calculate the Long Term Asset Value

(LTAV) based on the long term earnings potential. They define a dysfunctional market, in which traditional valuations are impossible, when at least two of the following conditions apply:

1. Few ships for sale relative to world fleet (of same type) for 3+ months
2. Few market participants relative to total number of parties for 3+ months
3. The buyer or seller is knowingly under time pressure / distress etc.
4. Absence of essential regular market conditions (e.g. financing) for many
5. Difference between prices and LTAV exceeds 30% for 3+ months

Before going into the details of the valuation, it is important to explain the incentives behind it. This will help understand several of its elements. The standard ship loan covenant of banks stipulates that the outstanding loan should remain below 70% of the asset value. When the market was high, banks had a policy of accelerating principal repayments (as described in Section 2.9), as a precaution to avoid breaching these covenants. Due to the market volatility, this proved inadequate. Following the rapid market decline, fair market values and conventional valuation methods indicate that covenants are violated for many ships acquired in the last few years.

Under normal circumstances, additional equity would be required from shipowners to bring the debt to 70% of the ship value. However, during a low market they may find that difficult. Banks have a choice between turning a blind eye and repossessing the vessels. They want to avoid owning ships while selling them in the low market would require steep discounts. They are also are reluctant to impair the asset values on their books in order to maintain healthy ratios and the ability to issue new loans. Therefore, they grant 12-month covenant waivers hoping that a market recovery will improve asset values to satisfy the covenants.

In order to facilitate this policy, particularly in containerships which have been struck the most by the current crisis, banks have required an alternative method that avoids the use of recent transactions. The Hamburg Valuation Scheme was thereby developed which calculates a LTAV for the ships, based on "potential earnings" as opposed to current market conditions. It was developed by 4 auditing companies and around 10 shipping finance banks

excluding Deutsche Bank, the only bank in Germany that refused to participate [Garfield 2010c], and which maintains its opposition a year later [Garfield 2010d].

The Hamburg valuation Formula for the long term asset value is [VHSS 2009]:

$$LTAV = \sum_{t=1}^{T} \frac{(C_t - B)}{(1+i)^t} + \frac{RW}{(1+i)^T} \qquad (5.5.1)$$

Where:

LTAV:	Long Term Asset Value
t:	Time in years
T:	Remaining life in years
C_t:	Annual net charter rate of year "t"
B:	Annual operating costs (constant)
i:	Discount rate (constant)
RW:	Residual value of ship

To calculate "C_t", prevailing charter rates are assumed for year 1 and the 10-year historic average for the remaining years. If the ship is chartered, the charter rates apply until it expires and then the current 10-year historic average applies. 6% commissions are deducted to get the net rate. When a 25 year horizon is used, charter rates are reduced for the last 5 years by 30% for bulkers, and 15% for containerships and tankers. 360 earning days per year are assumed except for years of class renewal (every 5 years) when the number is reduced to 345. "B" is equal to the 10-year average operating costs and is held constant throughout the ship's life.

The discount rate is held at 6.6% throughout the ship's life, justified as follows. A bank margin of 1.375% over the 10-year average LIBOR (4.036%) sets the cost of debt at 5.411%. A risk premium of 3% over the 10-year average US 10-year T-Bill rates (4.63%) sets the cost of equity at 7.63%. A weighted average is then calculated assuming 70% debt and 30% equity, and a 0.5% risk premium is added for conservativeness, bringing the discount rate to 6.6%.

For ships over 15 years old, "T" is calculated assuming a 25 year life and "RW" is based on 10-year average scrap values. For ships up to 15 years old, a 20 year life is assumed and "RW" is equal to the 10-year average scrap value multiplied by 4.45 for bulkers, 3.7 for containerships and 2 for tankers. As examples, a Supramax (57,000dwt) and a Cape were valued at $57.5M and $100.1M respectively using this method in March 31st, 2009 [VHSS 2009].

This method was introduced during a time when traditional valuations had been halted, so it quickly gained high acceptance and publicity. Clause Brandt, partner at PricewaterhouseCoopers in Hamburg, says that auditors are widely applying the Hamburg Ship Evaluation Standards [Bockmann 2010] while Hamburg-based ship valuator Ingenierburo Weselmann has used it to value over 180 vessels [Macqueen 2009]. According to Koopman and Rehder, current and previous chairmen of the Hamburg Shipbroker's association, banks in Germany are using the formula on their existing lending books to demonstrate to their central bank that they are not overstretched [Garfield 2010a, Garfield 2010b].

Some major German banks have decided not to apply the Hamburg formula, but instead agree to defer payments until 2011 or 2012 when a charter rate recovery is forecast [Bockmann 2010]. According to a leading Hamburg maritime lawyer, some auditors had sympathy for it but others did not. He says, "*It seems to be a question of whether you are engaging somebody who likes it and gives a different result, which means you have to do a bit of auditor shopping*". In an environment without viable alternatives, one can predict the incentives and consequences which are confirmed by the fact that *"MOST accounting firms in Germany are using a controversial ship valuation formula to determine vessel prices for crisis-stricken KG funds and companies, as statutory deadlines to finalize 2009 financial statements loom"* [Bockmann 2010].

Inevitably, the method has received high criticism from several senior industry figures. According to some, *"It's a fudge – intellectually it does not stack up"* and many are surprised at those who support and use it. According to Karsen Wetwitschka of Deuche Bank, *"Basically, it would relieve bank's balance sheets which would help banks and eventually shipowners, but the question is whether it makes sense ...We believe market values*

– as little as we like them - just reflect markets and we have to live with that" [Hagen and Porter 2009].

A London broker openly accuses it of being the result of a collaboration between stakeholders who avoid facing reality, to make the numbers appear more appealing [Garfield 2010b], while others have directly accused the banks who use it claiming that *"Banks should not act as pawnbrokers giving 60% to 80% of a necklace's value because that is what it can be sold at tomorrow"* [Garfield 2010c].

I personally realize the merits of a stable valuation and the benefits to the banks and ultimately to their clients. However, I personally tend to agree with those criticizing the Hamburg valuation method. Many crucial parts of the valuation are questionable starting from the conditions describing a dysfunctional market, to the use of constant 10-year average charter rates, operating costs and earning days throughout the ship's life, and the 7.63% cost of equity based on a premium over historic US T-Bill rates. Given the circumstances, the underlying interests and the outcome, one can't help but question the incentives behind such choices.

Besides these obvious uncertainties, the core idea of ignoring the market is against my principles. First, people often jump too quickly to the conclusion that a "distressed" sale is at the "wrong" price. It is important to understand that distress on one side of the transaction on its own is not enough to distort values. During a "forced sale", buyers often compete and inevitably drive the price to "the maximum one is willing to pay for it" i.e. its true value. Acquisition demand has in fact been such as to prompt several IPOs and spin-offs to raise equity for that specific purpose over the past several months. Furthermore, the fact that charter rates are at operating costs is not an excuse to ignore them (or "almost" ignore them), it actually indicates important information about the ship's value. Rates below operating costs or even close to zero are not unheard of in the volatile shipping industry. I am not advocating that rates will remain at these levels throughout the ship's life but they should certainly be taken into account more heavily than by the Hamburg Valuation Formula.

A better approach would be to look at futures rates which indicate market expectations for future earnings. These reflect changes that occur in the world that should impact ship values. It seems strange that the Hamburg Valuation formula would yield similar

results today as it would if applied before the crisis. This is particularly true if a ship has a charter longer than one year.

One can evidently find many excuses to ignore the market both in terms of charter rates and transaction prices but the ship value is inevitably defined by the market. The Hamburg Valuation was introduced to cover a need when there were not enough transactions to observe market values. When S&P activity recovered, however, the disparity between the two became very clear. According to [Porter 2009], *"The revival of the secondhand activity also casts a spotlight on the Hamburg valuation formula, which throws up hugely different figures from the actual prices now being achieved in the real world"*

The Hamburg valuation method has been criticized by many for its biases and inaccuracies and primarily the fact that it essentially ignores the current market and looks at the previous 10 booming years instead. Nevertheless, it is the most sophisticated method available and is being widely used by auditors and, at least internally, by several major banks.

5.5.2.5 Short-Term Forecast Valuation

In Chapter 2, we examined the method used by Marsoft to forecast ship earnings based on projected fleet utilization. Marsoft also has a procedure involving a combination of methods to produce valuation forecasts for its clients [Marsoft 2010a]. Similar to its earnings forecasts, its valuation forecasts span out to several years but they also produce them for the immediate future. That will be our primary focus because at the limit, a very short term valuation forecast can essentially be treated as a current valuation.

The first step of the process is to obtain an "earnings-based" valuation for a 5-year old vessel of the ship type to our interest. A two parameter linear regression model is calibrated against historic data relating the 5-year-old ship value to the newbuilding price and the 1-year charter rate. Note that the two regression parameters are in fact highly correlated, which may be an issue.

To obtain the forecast of the 5-year old ship value for a certain future date, current newbuilding price forecasts and 1-year charter rate forecasts for the same future date are applied to the regression formula. The charter rate forecast is based on projected fleet utilization (described in Chapter 2), while the newbuilding price is forecasted by a model that combines projected 1 year charter rates, Chinese Won – US Dollar exchange rates, steel prices and shipyard utilization.

Next, adjustments are made to convert the 5-year-old ship valuation to 10-year-old and 15-year-old ship valuations. These results are published in Marsoft's quarterly reports. To obtain a valuation for an older ship or of a different age, simple interpolations are used between the above valuations and the scrap value.

To produce a customized valuation, as discussed earlier, they use a combination of five methods including the above. The five methods are:

1. The above earnings-based valuation
2. Comparables-based valuation (Section 5.5.2.1)
3. DCF valuation using their own charter rate forecasts for the first 5 years and a 10 to 20-year historic average beyond that (typically without an age related discount)
4. Linear depreciation between the newbuilding and scrap prices to obtain an estimate assuming a scrapping age of 25 years
5. Historic mean of values for an equivalent ship

By assigning different weights to the results of each of the above methods, a customized valuation is obtained.

5.5.2.6 Other Valuation Methods

Ship valuations can be obtained using Monte Carlo Simulations as done by [Adland 2000] at MIT. This involves identifying the factors that affect ship values and their distribution parameters, performing thousands of simulations in which they are allowed to

evolve randomly, and then form a distribution of the resulting ship values (one from each simulation) based on which one can decide the valuation or a range with some confidence.

Alternatively, valuations can be based on freight rate forecasts that can be obtained by a wide range of methods. Examples include the use of projected fleet utilization as done by Marsoft or Monte Carlo Simulations on freight rates which are used by Sydney Levine. [Adland 2003] proposes a nonparametric one-factor model and extends it to a nonparametric non-Markovian discrete-time model for freight rates. He tests the models and shows that freight rate volatility should be modeled as a function of freight rate levels (time charter equivalent). The work of [Voudris 2006] at MIT, demonstrates the accuracy of Artificial Neural Networks along with genetic algorithms in predicting bulk freight rates up to 18 months in advanced, and uses the method to forecast the Cape market.

People often make crude estimates using methods similar to those incorporated in the weighted average valuation of [Marsoft 2010a]. Using linear interpolation between the current newbuilding and scrap prices gives a rough estimate which can be very misleading in some cases as discussed in Chapter 2. The inter-quartile range of all historic transactions prices can be referenced but is only valid if the current market is not at extremes.

People often apply selected weights to various valuations or they simply update their prior views after seeing a new one. As the Black-Litterman model uses Bayesian Updating to allow investors to incorporate their private views in optimum portfolio allocations based on the CAPM, I believe it won't be long until this concept is applied to ship valuations.

5.5.2.7 Summary and Comparison of Ship Valuation Methods

A simple way to summarize the essence of the predominant ship valuation methods would be to say that the comparables method looks at what similar ships are selling for, shadow pricing looks at what similar ships were selling for when they were earning as much as your ship is earning today, the Hamburg valuation method looks at what your ship was earning yesterday (as a proxy for tomorrow) and [Marsoft 2010a] combines elements of everything with its market forecasts in a single valuation.

An important aspect to consider about the valuation is its volatility. The volatility of the comparables based valuation will depend on the frequency of transactions. If there are frequent transactions, the valuation can be updated frequently to reflect changes in the market. The Hamburg valuation uses 10-year historic average rates, which means that any current changes in the current market will have an insignificant impact on the valuation, making it very stable. Short term charter rates, on which shadow pricing is based, are very volatile. This makes the volatility of shadow prices higher but the impact is dampened due to the way the method works. In fact, if we assume that freight rates and ship values are perfectly correlated, then the volatility of the Shadow Valuation is just about right.

We will now compare the methods by considering valuations for a 5-year old 172,000dwt Cape as of March 2009. Many brokers, including Clarksons, had discontinued valuations but others including Cotzias Shipping Group and Intermodal had not. The ship value indices produced by the Baltic Exchange from a panel of brokers were highly questioned last year but they were also not discontinued. These are summarized along with the Shadow Price, the Hamburg Valuation and Marsoft Valuations (forecasts for the second quarter of 2009) in Table 5.5-2.

Valuation Method / Broker	**March 2009 Value of 172,000dwt 5-Year Cape**	**Source**
Baltic Exchange	$48.3M	[Martin 2009b]
Cotzias Shipping Group	$47.0M	[Cotzias 2009c]
Intermodal	$42.0M	[Intermodal 2009]
Shadow Pricing	$41.7M	[Martin 2009b]
Hamburg Valuation	**$94.5M**	Based on [VHSS 2009]
Short Term Forecast	$40.8M	[Marsoft 2009]

Table 5.5-2: Valuation Method Comparison for a 5-Year-Old 172,000dwt Cape as of March 31st, 2009

The disparity between the first three valuations of Table 5.5-2, which are based on comparables, indicate the amount of subjectivity involved due to the lack of transactions. Their average is $45.7M. The shadow price and Marsoft's valuation are in the ballpark but

lower than all three, while the Hamburg Valuation is the only one not in the forty's and is higher than twice the average of the comparables based values.

5.5.3 Company Value Based Estimations

5.5.3.1 General Company Valuation Methods

The value of a firm is equal to the value of its assets or equivalently the value of its equity plus the value of its debt. As for direct asset valuation, there are again various approaches to valuation. One of the most widely accepted methods is the Discounted Cash Flow valuation which has various versions that will be discussed in Section 5.5.3.3. A less popular method is valuation from an accounting perspective, using financial statements. This is presented in Section 5.5.3.4. Both approaches rely on the projection of future performance and the discount factor.

Another common valuation approach is based on multiples. This is very often used when valuing a company that is preparing for an IPO or for a merger. A set of comparable companies are selected from the same industry and certain ratios (multiples) are calculated. Typical examples include price over sales, price over EBITDA, price over book value (of assets) etc.

For price, people look at the values at which the company's shares are trading i.e. the price of its equity (averaged over a time period to account for fluctuations). The underlying assumption is that comparable companies within a given industry should have roughly the same chosen multiples as well as other parameters such as leverage, working capital etc. Therefore, the average is calculated across the comparables for each multiple and that is applied to the company being valued. The average industry multiples are combined with the company's observable metrics (Sales, EBITDA, Book Value etc) to yield estimates of its equity value.

Nobel Laureate Robert Merton has introduced a very powerful valuation framework under which the debt and equity of a company can be treated as options on the company's assets. Options are securities that allow you to buy (if a "call" option) or sell (if a "put" option) the underlying asset in the future at a pre-specified price (the strike price). They will be discussed in more detail in Section 5.6. Since the prices of options are directly observable in the securities market, by replicating the company's debt and equity using combinations of options, one can directly obtain the value of the company's debt, equity and assets.

By examining the payoff to the equity holders as a function of the asset value, we see that they are equivalent to the payoffs of a call option with a strike price equal to the amount of the debt. Both the equity and the call option have a zero payoff unless asset value exceeds the debt amount, beyond which the payoff increases linearly with the asset value. Similarly, we can replicate the debt's payoffs by going long on a bond and shorting a put with a strike price equal to the outstanding debt (the put replicates the expected default loss). As for the debt holder, the payoff to this replicating portfolio increases linearly with the asset value from zero up until the point where the assets are worth as much as the outstanding debt, and remains constant beyond that. The method can also be used to value the debt depending on its seniority (again by replicating payoffs), and thereby break down the company's value further into components.

5.5.3.2 Shipping Company Valuations and Extracting Asset Values

The general company valuation methods discussed in Section 5.5.3.1 are commonly used across many industries. Some analysts, however, use variations or different approaches across the board or within specific industries. Due to the fact that asset values are extremely volatile in the shipping industry, valuations are very often based on some kind of forecasting of asset values. Much like the Shadow price looks at historical price-to-earnings multiples for ships, one can also look at other multiples for shipping companies historically and use them for current valuations.

[Shahrim & Webb 2009] describe the methods that were used by HSBC Global Research to carry out valuations of shipping companies in the interesting period of January 2009. Their valuations of container shipping companies were based on asset values partly because of the low visibility of earnings. However, many companies were not disclosed the market value of fleets so asset values had to be obtained otherwise. This was done by assuming that the price over book value ratio will drop within one year to the bottom value it reached in the down cycle of 1998.

Their valuations of dry bulk companies were based on replacement value per share considering the adjusted fleet value, the net cash and the earnings per share during the 2nd half of 2008 (the period since the market decline). The adjusted fleet value is calculated assuming a zero value for all ships on order and all purchase options and a decline of more than 75% for the existing dry bulk fleet relative to the first half of 2008 (before the market decline).

In theory, if you know the value of a shipping company, you can then extract the value of its assets which include ships. The value of the shipping company can be obtained by one of the many methods discussed, or simply by looking at its market capitalization if it is publicly traded. That is the value at which its stock is currently trading at multiplied by the outstanding shares. One can also use an average share price across a meaningful period to net out stock market fluctuations. This is attractive because as with the comparables based ship valuation, it directly gives you the value that the market thinks the company (and assets) is worth, factoring in all relevant parameters.

In practice, however, this is not practical for various reasons. First, most company valuations require the asset values as an input or they need the projected ship earnings which could be used directly in a ship valuation if they are known in advance. If we use the stock price instead, there will be other factors significantly distorting our valuation such as the stock market sentiment, company announcements about the strategic plans etc.

Even with an accurate company valuation, the task of allocating the value between tangible and intangible assets is non-trivial to say the least. First one would have to account for the value of intangible assets such as goodwill, the competence of the management team, company reputation, industry relations etc. Even after one gets to the point where they have stripped out the value of the ships, they are left with the task of allocating that value to each

ship. This would be a nightmare in most cases since the fleet would typically include ships of various types, sizes, ages specifications, surveys due etc.

5.5.3.3 DCF Valuation

Discounted cash flow analysis will form the basis for the new ship valuation method developed in Section 5.6. Therefore, we will not go into great depth in this section. The idea is that the value of a company is equal to the present value of all the cash flows it is expected to generate in the future. The free cash flows can be defined in terms of many different parameters. [Koller et al 2005] demonstrate the equivalence between discounted cash flows and discounted economic profit starting with the following definitions.

$$V = \sum_{t=1}^{\infty} \frac{FCF_t}{(1+r_{WACC})^t} \tag{5.5-2}$$

$$FCF_t = NOPLAT_t - NetIC_t \tag{5.5-3}$$

$$NetIC_t = IC_t - IC_{t-1} \tag{5.5-4}$$

Where:

V: Present value of the company (Assets)

t: Time period (year)

FCF_t: Free Cash Flow (Unlevered) in year "t"

r_{WACC}: Weighted Average Cost of Capital (discount rate for company)

$NOPLAT_t$: Net Operating Profit Less Adjusted Taxes (profit from core operations minus income taxes related to core operations) for year "t"

$NetIC_t$: Net Invested Capital

IC_t: Invested Capital in year "t"

In practice, free cash flows are predicted until a certain time in the future and then a terminal value is calculated at that point by assuming a constant growth rate beyond that in perpetuity.

$$V = \sum_{t=1}^{T} \frac{FCF_t}{(1+r_{WACC})^t} + \frac{TV}{(1+r_{WACC})^T} \tag{5.5-5}$$

$$TV = \frac{FCF_T}{r_{WACC} - g} \tag{5.5-6}$$

Where: TV: Terminal value of company at year "T" (Present value of a growing perpetuity)

g: Assumed annual growth of future cash flows

Starting from Eq. 5.5-2, [Koller et al 2005] go on to show that the enterprise value of a company is equal to the book value of its invested capital plus the present value of future economic profits. Note that if the current book value is different from the true economic value, this will show up in the future economic profits (through impairments). Since the summation goes to infinity, any disparity will be captured.

$$
\begin{aligned}
V &= \sum_{t=1}^{\infty} \frac{FCF_t}{(1+r_{WACC})^t} \\
&= \sum_{t=1}^{\infty} \frac{NOPLAT_t - NetIC_t}{(1+r_{WACC})^t} + \sum_{t=0}^{\infty} \frac{IC_t}{(1+r_{WACC})^t} - \sum_{t=0}^{\infty} \frac{IC_t}{(1+r_{WACC})^t} \\
&= \sum_{t=1}^{\infty} \frac{NOPLAT_t - (IC_t - IC_{t-1})}{(1+r_{WACC})^t} + IC_0 + \sum_{t=1}^{\infty} \frac{IC_t}{(1+r_{WACC})^t} - \sum_{t=1}^{\infty} \frac{(1+r_{WACC})IC_{t-1}}{(1+r_{WACC})^t} \\
&= IC_0 + \sum_{t=1}^{\infty} \frac{NOPLAT_t - r_{WACC}IC_{t-1}}{(1+r_{WACC})^t} \\
&= IC_0 + \sum_{t=1}^{\infty} \frac{Economic\,\mathrm{Pr}ofit_t}{(1+r_{WACC})^t}
\end{aligned}
\qquad (5.5\text{-}7)
$$

The weighted average cost of capital is derived from the cost of equity, the cost of capital, the company's debt to equity ratio and the tax rate if that is relevant. The cost of capital is essentially the cost at which a firm can borrow money to finance its projects. The cost of equity is the fair amount by which the equity holders should expect to be compensated, and is much more intricate. There are several methods used to estimate it but the most widely adopted is by far the CAPM. The CAPM is based on the premise that diversification is costless, so investors need to be compensated only for bearing systematic (un-diversifiable) risk. Adjustments are often made to CAPM as will be shown in Section 5.6.

There are three common methods for applying discounted cash flow valuation. These are the Weighted Average Cost of Capital method, the Flow to Equity (FTE) method, and the Adjusted Present Value (APV) method.

WACC: $$\boldsymbol{V = D + E = \sum_{t=1}^{\infty} \frac{FCF_t}{(1+r_{WACC})^t}} \qquad (5.5\text{-}8)$$

FTE:
$$E = \sum_{t=1}^{\infty} \frac{ECF_t}{(1+r_E)^t} \tag{5.5-9}$$

APV:
$$\begin{aligned} V &= \sum_{t=1}^{\infty} \frac{FCF_t}{(1+r_u)^t} + PV(TS) \\ &= \sum_{t=1}^{\infty} \frac{FCF_t}{(1+r_u)^t} + \sum_{t=1}^{\infty} \frac{\tau D_{t-1} r_u}{(1+r_u)^t} = \sum_{t=1}^{\infty} \frac{FCF_t + \tau D_{t-1} r_u}{(1+r_u)^t} \end{aligned} \tag{5.5-10}$$

Where:

D:	Debt
E:	Equity
r_E:	Cost of levered equity
r_u:	Cost of unlevered equity
r_D:	Cost of debt
τ:	Tax rate
ECF:	Levered cash flow to equity holders
$PV(TS)$:	Present value of tax shields (from tax deductibility of interest payments)

If applied correctly the three methods should yield the same results. Solving them simultaneously gives the following two conditions that must be true for the methods to be equivalent.

$$ECF = FCF - (1-\tau) r_D D \tag{5.5-11}$$

$$r_{WACC} = \frac{E}{A} r_E + \frac{D}{A}(1-\tau) r_D \tag{5.5-12}$$

$$PV(TS) = \tau D \tag{5.5-13}$$

Depending on the conditions, one method may be more useful than the others. For example, if the leverage of the company is kept constant, it is usually more convenient to use the WACC method. Otherwise, we calculate the present value of the tax shields and the unlevered firm value and add them to get the value of the levered firm. The FTE method can be used to value the equity directly if the amount that equity holders will receive in each period is known in advance.

Note that the difference between the weighted average cost of capital and the unlevered cost of equity arises from tax shields (only). Shipping companies typically do not pay corporate taxes. By setting the tax rate to zero, the value of the tax shields disappears and the APV method becomes redundant to the WACC method. Therefore, in valuing shipping companies one typically has a choice between using the WACC method and the FTE method.

5.5.3.4 Valuation Using Financial Statements

Valuation from an accounting perspective is similar to conventional DCF. A key difference is that more emphasis is given to the accounting ratios of a firm. Again, there are several interlinked models, namely discounted dividends, abnormal returns and abnormal earnings. There are inter-linked and should yield the same results if applied correctly. We start by presenting the dividend discount model which is the simplest. It states that the value of the equity (the value of the shares), is equal to the sum of the discounted dividends (cash distributed to the shares):

$$E = \sum_{t=1}^{\infty} \frac{d_t}{(1+r_E)^t} \qquad (5.5\text{-}14)$$

t: time

E: Value of Equity

d_t : Dividends at time "t"

r_E : Cost of Equity

The problem with applying this method is that a very big percentage of firms (particularly new and growing ones) do not pay dividends. Note that it makes no difference to the value of the firm if dividends are paid out or reinvested in the same business. However, dividends are hard to forecast because they depend on the company's growth policy which may be unclear or on future opportunities which are not known in advance.

The second method is essentially the same as the flow to equity DCF model, with a different way to derive the cash flows. The value of the equity and equity cash flows are given by:

$$E = \sum_{t=1}^{\infty} \frac{ECF_t}{(1+r_E)^t} \tag{5.5-15}$$

$$ECF = NI - CAPEX + DEP - \Delta NWC - \Delta BVND \tag{5.5-16}$$

Where:

$CAPEX$: Capital Expenditures

DEP : Depreciation

$\Delta BVND$: Change in Value of Net Debt

The importance is to capture all the cash flows in forecasting. In order to do that, one must adjust the financials under GAAP for unrealized gains and losses, changes in asset values, accounting rule changes, foreign currency translation gains and losses etc. Once that is done for previous years, one can proceed to forecast the future financials and equity cash flows and then apply the valuation formula.

The third method is more important, while the first two are often used for verification. It is based on the same principle as the equivalence between cash flows and economic profits by [Koller et al 2005] derived in Eq. 5.6-7. We will present its derivation starting from the

discount model. We start by relating this year's Book Value of Equity (BVE) to that of the previous year, through net income and dividends:

$$BVE_t = BVE_{t-1} + NI_t - d_t \tag{5.5-17}$$

We define "abnormal earnings" as the difference between actual earnings and those expected by shareholders (return on equity multiplied by last year's equity):

$$\tilde{\varepsilon}_t = NI_t - r_E BVE_{t-1} \tag{5.5-18}$$

By combining Eq. 5.5-17 and Eq. 5.5-18, we can solve for the dividends as follows:

$$d_t = \varepsilon_t + (1 + r_E) BVE_{t-1} - BVE_t \tag{5.5-19}$$

By substituting this definition of dividends into the dividend discount model (Eq. 5.5-14) and through further manipulation, we arrive at the abnormal earnings model:

$$\begin{aligned} E &= \sum_{t=1}^{\infty} \frac{\varepsilon_t + (1 + r_E) BVE_{t-1} - BVE_t}{(1 + r_E)^t} \\ &= \sum_{t=1}^{\infty} \frac{\varepsilon_t}{(1 + r_E)^t} + \sum_{t=1}^{\infty} \frac{BVE_{t-1}}{(1 + r_E)^{t-1}} - \sum_{t=1}^{\infty} \frac{BVE_t}{(1 + r_E)^t} \\ &= \sum_{t=1}^{\infty} \frac{\varepsilon_t}{(1 + r_E)^t} + \sum_{t=0}^{\infty} \frac{BVE_t}{(1 + r_E)^t} - \sum_{t=1}^{\infty} \frac{BVE_t}{(1 + r_E)^t} \\ &= BVE_0 + \sum_{t=1}^{\infty} \frac{\varepsilon_t}{(1 + r_E)^t} \end{aligned} \tag{5.5-20}$$

This tells us that the value of equity is equal to the current book value of equity plus the present value of the expected future abnormal earnings (above expected earnings i.e.

wealth creation). Before applying the method, one must make sure to adjust for any asset impairments in order to get a starting book value that reflects the true economic value. Alternatively, disparities can be factored into the projections of future earnings. An asset value impairment, for example, will result in negative abnormal earnings when it occurs. Since the summation term extends to infinity, if applied correctly, the valuation will reflect the true economic value.

Abnormal earnings arise from some sort of advantage like competitiveness or relative efficiency which allows the company to outperform its competitors and investor expectations. In the long term, abnormal earnings will be forced to zero by competition. In other words, the Return on Equity (ROE) converges over time to the cost of equity. Note that abnormal earnings can be negative as well as positive. Below is a summary of how one would apply the method.

1. Analyze industry, key trends, competition, performance metrics & outlook
2. Analyze company, strategy, accounting decisions and financial statements
3. Choose a relevant time horizon after which there will be a terminal value
4. First look for accounting procedures and adjust to reflect changes in equity
5. Restate historical financial statements
6. Project the financial statements considering all the above data
7. Get the same valuation using abnormal earnings/returns & discounted dividends

The major advantage over the conventional DCF methods is that the terminal value (which is often inaccurate) is a much smaller fraction of the total value. That is because the terminal value in this case only includes a forecast of abnormal earnings (not the whole cash flows). The Book value of Equity captures a lot of what is in the terminal value of a DCF model. This is a powerful approach but is much less popular than conventional DCF methods. Therefore, we present an example using a US listed shipping company. The valuation will be done for Dec 2009, so the Dec 2008 financials will be used 2008 (the last available annual statements). Note that this is an intrinsic valuation, meaning that it should not fluctuate significantly.

5.5.3.5 Valuation Example – Diana Shipping (DSX) in December

5.5.3.5.1 Industry Analysis

5.5.3.5.1.1 Overview & Trends

DSX specializes in Panamaxes (60,000 to 80,000 dwt) and Capes. The industry has been examined in detail in Chapter 2. One of the key trends is that following the financial crisis, average capesize daily earnings decreased by about 99% and ship prices soon followed.

5.5.3.5.1.2 Industry Structure/Key Players

The market is highly fragmented and closely resembles perfect competition with high cyclicality (Section 2.1). Several big players are also involved in other sectors such as tankers or containerships. Most companies are privately owned but several have been listed in the US in recent years. In terms of dry bulk tons moved, the 5 major US listed companies account for 4.29% of Market Share (MS). Table 5.5-3 shows how they compare across various measures sourced from published data, primarily their 10K forms (20-F).

	MS (%)	*TOT DWT*	*AVG AGE*	*REV ($M)*	*NI ($M)*	*M.CAP (10/28)*	*NET DEBT*	*DEBT/ EQUITY*	*ROA (%)*	*ROE (%)*
DRYS	1.21	4.2	10.6	248	56.7	$3.32B	$2.58B	1.21	13.71	64.42
GNK	1.02	3.5	6.37	107	107	$446M	$734M	1.5	5.83	21.89
NM	0.84	2.9	4.5	206	21.1	$302M	$420M	0.80	6.19	51.95
EGLE	0.84	2.9	6	125	52	$329M	$602M	1.16	4.36	12.49
DSX	**0.66**	**2.3**	**3.4**	**190**	**134**	**$1.06B**	**$167M**	**0.12**	**9.99**	**21.10**

Table 5.5-3: Comparison of 5 major US-listed Dry Bulk Companies

5.5.3.5.1.3 Performance Metrics

Due to the high cyclicality of the market, success primarily lies on the timing of investment and chartering decisions. Stock prices, however, are governed by earnings per share and growth rates, so listed companies have a pressure to stay on the spot market and keep making acquisitions even at high prices. Their ability to raise finance through equity markets is critical in order to finance acquisitions without high leverage and the associated risk. Listed companies publish metrics such as fleet utilization i.e. operating days over available days (available days are ownership days less days at repair). This shows how quickly a company can employ its vessels and is typically close to 100%. Unlike containerships, which have impacted more by the financial crisis, bulk carriers do not lay up in the current market. As such, these metrics are less important.

5.5.3.5.1.4 Market Outlook

As of Dec 2008, the dry bulk orderbook was above 72% of the fleet with delivery in the following 36 months. A huge oversupply is anticipated as these orders keep coming in. Scrapping (removals) has increased since the market crash but the average fleet age has decreased, thereby limiting future scrapping potential. Order cancellations are expensive and have limited impact since supply is ultimately governed by the shipyard building capacity which has increased dramatically. Any cancelled ship will still be delivered, only to another buyer at a lower price, until market prices drop below the variable costs of shipyards. Delaying deliveries only delays the market recovery, while converting the orders to tankers or containerships is unlikely as they also have high orderbooks. In fact, the tanker and containership markets are worse so their orders are being changed to bulk carriers, further increasing the dry bulk orderbook. Besides anticipated oversupply, the market outlook is bad due a weakening demand for raw materials by China and the bad financial situation resulting in low consumption and demand for finished products in the west.

5.5.3.5.2 Company Analysis

5.5.3.5.2.1 Company Overview

DSX completed an IPO on the New York Stock Exchange (NYSE) in March 2005. Its fleet grew from 7 ships in 2004 to 19 ships in 2009 (plus one newbuilding with March 2010 delivery) over a series of acquisitions financed primarily through subsequent equity offerings. Under Code Section 883, the company pays no income taxes to the US (or elsewhere). As of Dec 2008, the company had $337M in revenues, $221M in net income, $1,057M in asset book value and a ROE of 27.6%. Over 90% of its assets are ships. It has been very profitable with a high ROE primarily because of the market boom. Growth in daily earnings has been tremendous while operating costs remain fairly constant, giving rise to these results. The low leverage results from the company's low debt policy and frequent equity issuances to finance. The company recently entered the low part of the cycle, so these metrics are almost certainly going to worsen in the next few years.

5.5.3.5.2.2 Strategy

1. Reputation for performance, reliability and safety

This enables strong relationships with charterers, shipping members and financial institutions, thereby achieving better contracts, avoiding renegotiations or disputes, and allowing access to finance and possible covenant waivers if needed. The company achieves this by maintaining a modern, high quality fleet. Its average age of ~4 years is below all key competitors and ~10 years lower than the industry average [UNCTAD 2007]. Its experienced management team (CEO with over 40 years experience in shipping) manages vessels internally for full control. It has credit facilities from 2 major banks and its 3 largest charterers consistently account for approximately half the revenues.

2. Expand fleet in a manner that creates value for shareholders

DSX continuously buys and sells ships to keep the average age low and finances them through equity to maintain a strong balance sheet (lowest leverage amongst key competitors). It acquires ships in a booming market and locks them in long term charters at high rates to bring down the debt and boost revenues. It balances these with short term charters that allow for higher earnings in a good market and regularly hedges its exposure via the futures market (though less than its competitors).

3. Low cost efficient operations

DSX operates only two ship types (PMX and Capes) and 4 groups of sister-ships allowing for operational efficiency. This policy is complemented by internal management of vessels which allows full control of costs by a very experienced management team with technical expertise

4. Success Factors / Sustainability

The company relies on its few big charterers to keep paying the agreed rates which are significantly above market levels. Though Diana Shipping has not experienced any problems yet, there have been many recent renegotiations and bankruptcies. Two of its three biggest charterers, Australian Wheat Board and Cargill rely heavily on wheat prices. If the price of wheat declines, that will have a big impact on their ability to keep paying Diana Shipping the high contracted charter rates.

The company relies on the recovery of the market to avoid asset impairments. Though leverage is low, a high fraction of asset value is tied in the charter contracts which are not recognized by banks. If assets keep declining, there may be a danger of breaching loan

covenants. This will remove the option of drawing down on the company's credit facilities to finance future growth.

The high operating efficiency - low cost strategy with over 99% fleet utilization has been achieved with an extremely young fleet. As the fleet ages, off-hire time and maintenance costs will increase while managing older ships requires different capabilities. To sustain its operating performance, the company has to demonstrate the ability to operate older ships efficiently or keep investing in new ones which may become more difficult (raising finance might be a challenge).

Finally, the company's growth till now was facilitated by a growing industry. If the industry begins shrinking, sustaining the growth strategy may be difficult.

5.5.3.5.2.3 Accounting Analysis

Most of the major dry bulk shipping companies invested heavily at very high prices last year and asset values dropped dramatically after the market crash. Some managed to lock in high charter rates through long term contracts but many of these are being renegotiated by charterers and several charterers are now operating under Chapter 11. As a result, these shipping companies have an incentive to overstate their assets in order to avoid recording expenses due to asset value impairments but also to avoid breaching bank loan covenants.

Diana Shipping reports its assets at book value and discounts them assuming a 25 year lifetime and a scrap value of $150/ltd (residual value of steel per ton of lightship). These assumptions are reasonable when considering historical averages. An impairment test is carried out by summing the undiscounted future cash flows which are determined using its charter contracts and 10-year average values of daily rates for the non-contracted periods. These assumptions are less reasonable because of the time value of money, the risk associated with the expected cash flows, and because the previous 10 years were phenomenal. I therefore find it necessary to conduct a more relevant impairment test.

I projected the book value of assets from Dec 2008 to Dec 2009 using the company's depreciation method after accounting for yard installments for ships on order, the prepaid

installments and the ship delivered etc. I then calculated the fair value of assets including their charters as of Dec 2009. This shows if impairment would be necessary in Dec 2009. The impairment amount is then discounted back to Dec 2008. The 10-year T-bill is assumed for the risk free rate to account for a blended average of the discounting periods. The equity beta of 1.6 is quite high and somewhat unreliable but the resulting discount rate of 9.7% seems reasonable and close to what is being used in the industry. Earning days per year are assumed to be 350 going forward (higher than utilization so far) because ships are getting older and will have to undergo major repairs more frequently. This is more in line with the industry average.

Since December 2009, no contracts seem to have been renegotiated. Therefore, I assumed that they will be paid in full. To calculate the value of these charters, I compare the contracted rates to the current market rates of a charter for a similar ship and for a period equal to the remaining contract period. I then calculate the difference and discount the resulting "above market" future cash flows to Dec 2009 using the cost of equity as per the CAPM model. The market value of the "charter-free" ship is observed from recent transactions of similar vessels and from data published by the Baltic exchange and brokers.

The vessel redelivery period typically ranges a few months. In cases where the contract is above market rates, charterers will try to deliver the ship at the start of the window whereas if the contract rate is lower than the market, they will keep the ship as long as possible. This assumption is applied in deciding the delivery date. The charter value is the present value of an annuity of the difference between contract and market values. The outstanding payment of $14.7M is deducted from the fair market value of the ship on order because it has not been paid yet. The ship was ordered for $60.2M in 2006 and the final payment of 25% is due upon delivery in March 2010. It is discounted 3 months to December resulting in $14.7M. Table 5.5-4 shows the summary of the results while Table 5.5-5 shows the detailed analysis ship by ship.

ITEM	*VALUE*
Dec 2008 Vessel Net Book Value	960,431,000
Dec 2008 Vessel Advances	27,199,000
Dec 2009 Vessel Net Book Value	**1,023,107,000**
Dec 2009 Charters Market Value	158,596,741
Dec 2009 Charter-Free Ships Market Value	824,309,141
Dec 2009 Vessel Fair Market Value	**982,905,882**
Asset Impairment In December 2008	**-36,646,416 (-3.82%)**

Table 5.5-4: Summary of Impairment Test Results

An impairment of ship values would be immaterial. If this analysis was carried out in Dec 2008, using charter-free market values of that period, it would be substantially more significant. Given the information available in Dec 2008 (ship values and the possibility of renegotiating contracts), the company should have probably carried out an impairment. Perhaps the decision not to, was in line with its strategy of maintaining big accounts with major clients and thereby good relationships, avoiding the risk of contract cancellations/renegotiations. On the other hand, a bankruptcy of any of these clients would result in a big decrease in fair market values.

The above analysis also highlights the risk of a future impairment since $159M of the asset value lies in contracts above market rates. As the market declines, more of the charter-free market value ($824M) is shifted to the $159M, increasing the risk of future impairments.

As for the remaining balance sheet, it is in line with the company's strategy. The company rents its office under a 3 year renewable lease from its wholly owned subsidiary to which it also pays management fees per vessel. The accounts between the two companies don't appear on the balance sheet and the building book value is depreciated over 20 years. Its PP&E is insignificant and no intangible assets or goodwill are recorded while vessels including (vessel construction advances) account for 93.4% of total assets.

IMPAIRMENT TEST CALCULATION								
Ship	**Dwt**	**BLT**	**Delivery**	**Rate**	**Dec-09 Rate**	**Charter Val**	**Ship Val ($m)**	**Tot Fair Val**
Coronis	74381	2006	Apr-10	14000	26000	-1,708,350	34,000,000	32,291,650
Erato	74444	2004	Feb-10	15000	28000	-1,119,355	32,000,000	30,880,645
Naias	73546	2006	Sep-10	19000	23000	-1,116,433	34,000,000	32,883,567
Clio	73691	2005	Mar-10	11000	27000	-1,829,546	33,000,000	31,170,454
Calipso	73691	2005	Mar-10	9400	27000	-2,012,500	33,000,000	30,987,500
Protefs	73630	2004	Aug-11	59000	20000	19,960,105	32,000,000	51,960,105
Thetis	73585	2004	Mar-10	10500	27000	-1,886,719	32,000,000	30,113,281
Dioni	75172	2001	Sep-10	12000	23000	-3,070,190	29,000,000	25,929,810
Danae	75106	2001	Apr-11	12000	21000	-4,153,824	29,000,000	24,846,176
Oceanis	75211	2001	Sep-10	18000	23000	-1,395,541	29,000,000	27,604,459
Triton	75336	2001	Nov-10	17000	22500	-1,827,560	29,000,000	27,172,440
Alcyon	75247	2001	Nov-12	34500	19000	14,071,966	29,000,000	43,071,966
Nirefs	75311	2001	Feb-10	60500	28000	2,798,388	29,000,000	31,798,388
Norfolk	164,218	2002	Jan-13	74750	30000	42,557,305	43,000,000	85,557,305
Aliki	180235	2005	Mar-11	45000	38000	3,052,700	54,000,000	57,052,700
Salt Lake City	171810	2005	Aug-12	55800	32000	20,036,121	52,000,000	72,036,121
Sideris GS	174186	2006	Oct-10	36000	41000	-1,529,015	54,000,000	52,470,985
Semirio	174261	2007	Apr-11	31000	37500	-2,999,984	56,000,000	53,000,016
Boston	177828	2007	Sep-11	52000	35000	9,956,708	56,000,000	65,956,708
Houston	177729	2009	Oct-14	55000	27000	38,201,269	60,000,000	98,201,269
New York (Mar2010)	177000	2010	Jan-15	48000	25000	32,611,194	60,000,000	77,920,335
25% payment due March 2010 for "New York"							-14,690,859	
Total:						**158,596,741**	**824,309,141**	**982,905,882**

Table 5.5-5: Impairment Test Calculation

The long term debt of $238M is $214.7M on a $300M revolving credit facility by RBS and $24.1M on a $60.2M loan facility by Fortis Bank. This accounts for 84.5% of total liabilities. The company reports deferred revenue of unearned charter payments that have been received and when acquiring ships with charters attached at rates significantly different from market levels. This resulted in negative Net working capital last year.

5.5.3.5.2.4 Financial Analysis

The company has a very high ROE, equal to 19% for 2006, 37% for 2007 and 28% for 2008. The standard DuPont breakdown and the DuPont alternative breakdown for 2008 are shown in Eq 5.5-10 & 5.5-11 respectively while Table 5.5-6 shows a summary of 10 key ratios calculated for years 2006, 2007 and 2008.

$$\boldsymbol{ROE} = \frac{\boldsymbol{NI}}{\boldsymbol{Sales}} \times \frac{\boldsymbol{Sales}}{\boldsymbol{Assets}} \times \frac{\boldsymbol{Assets}}{\boldsymbol{Equity}} = 65\% \times 32\% \times 136\% = 28\% \qquad 5.5\text{-}21$$

$$\begin{aligned} ROE &= \left(\frac{NOPAT}{Sales} \times \frac{Sales}{NetAssets} \right) + \left(Spread \times NetFinLev \right) \\ &= \left(67.3\% \times 0.38 \right) + \left(18.1\% \times 0.1 \right) \\ &= 28\% \end{aligned} \qquad 5.5\text{-}22$$

The alternative DuPont ratio shows a big spread but low leverage, which is consistent with the company's strategy. ROE is heavily accounted for by profit margins which have been extremely high due to the record high market levels. The collapse in daily rates occurred in September 2008 and this impacted operating ROA bringing it down from 2007 levels since some vessels were trading on the spot market. Net financial leverage was also lower for 2008 bringing down ROE. Going forward, daily earnings are unlikely to recover any time soon so ROE is expected to decline significantly and remain low over the next few years even though some of the vessels have long term contracts at high rates.

	2006	2007	2008
ROE	18.8%	37.0%	27.6%
Operating ROA	20.6%	29.0%	25.8%
Revenue Growth	12.6%	64.1%	77.1%
Gross Margin	68.7%	73.9%	79.6%
Net Income Margin	52.6%	70.5%	65.5%
Current ratio	5.70	2.05	1.03
Debt to Equity	0.04	0.38	0.12
Net Long Term Assets / Revenues	271.4%	257.2%	266.1%
Interest Coverage	16.19	20.01	36.01
Dividend Payout Ratio	120.5%	97.6%	111.8%

Table 5.5-6: Calculation of Ten Key ratios for DSX from 2008 to 2009

Growth rates were significant due to the increase in the number of vessels from 7 in 2004 to 18 in 2008 but also due to the increase in daily earnings. The company took delivery of a Cape in November 2009 and is expecting one in March 2010. Both were ordered in 2006 and no other orders have been placed since. Due to the market outlook, it is questionable whether the company will keep adding ships to its fleet. Its margins have been very high because operating expenses are relatively stable whereas the revenues are much more volatile. In a market boom, margins go through the roof whereas in a bust, even though expenses also typically come down (as they have, slightly since 2008), margins decrease dramatically. Net long term assets over revenues are low during a market boom because revenues are more volatile than asset values. This is expected to increase going forward.

The current ratio of 3.43 is high, showing that the company has no problem paying its short term dues. The 0.31 debt to equity ratio is low, in line with the low-debt strategy. Its interest coverage ratio of 36.01 is also very high, again in line with the low debt strategy. Going forward these may decrease as earnings and net income decline. The company has a high dividend policy, resulting in a very low or negative sustainable growth rate. However it recently decided to suspend dividends due to the market situation. An inconsistency with its

strategy worth noting is that its operating expenses per vessel are higher than those of its key competitors even though it operates the youngest fleet (Fig 5.5-1).

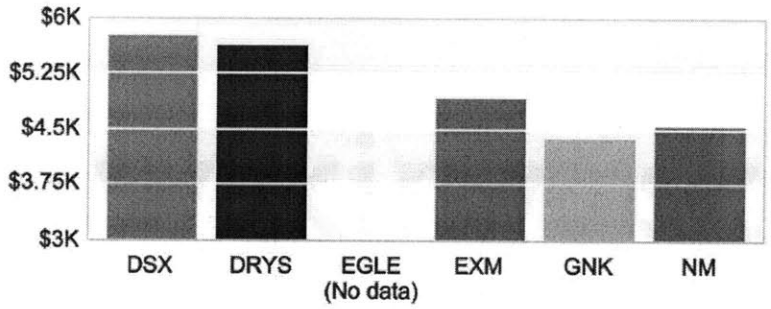


Fig. 5.5-1: Operating expenses per vessel compared to key competitors [http://www.wikinvest.com]

5.5.3.5.3 Valuation

5.5.3.5.3.1 Adjustments and Horizon Choice

No asset impairment or other adjustments were deemed necessary following the accounting analysis. A horizon of 9 years was chosen because the company's charter contracts span until 2015 and it is reasonable to expect the current market crisis to have finished, thereby enabling us to make steady long term assumptions beyond that point.

5.5.3.5.3.2 Revenue Projections

Revenues were projected using current charters and futures on the Cape and Panamax Baltic indices for the non-contracted periods. We also know from quarterly reports that revenues for first three quarters of 2009 were $180,700,000. Table 5.5-7 shows the revenue projections for each ship and Table 5.5-8 shows the total revenue projections along with year on year growth.

REVENUE PROJECTIONS							
Ship	**Q42009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Coronis	1,225,000	6,300,000	5,950,000	5,600,000	5,250,000	4,900,000	4,900,000
Erato	1,312,500	6,941,667	5,950,000	5,600,000	5,250,000	4,900,000	4,900,000
Naias	1,662,500	6,562,500	5,950,000	5,600,000	5,250,000	4,900,000	4,900,000
Clio	962,500	6,300,000	5,950,000	5,600,000	5,250,000	4,900,000	4,900,000
Calipso	822,500	6,160,000	5,950,000	5,600,000	5,250,000	4,900,000	4,900,000
Protefs	5,162,500	20,650,000	13,300,000	5,600,000	5,250,000	4,900,000	4,900,000
Thetis	918,750	6,256,250	5,950,000	5,600,000	5,250,000	4,900,000	4,900,000
Dioni	1,050,000	4,725,000	5,950,000	5,600,000	5,250,000	4,900,000	4,900,000
Danae	1,050,000	4,200,000	6,066,667	5,600,000	5,250,000	4,900,000	4,900,000
Oceanis	1,575,000	6,300,000	5,950,000	5,600,000	5,250,000	4,900,000	4,900,000
Triton	1,487,500	5,979,167	5,950,000	5,600,000	5,250,000	4,900,000	4,900,000
Alcyon	3,018,750	12,075,000	12,075,000	11,506,250	5,250,000	4,900,000	4,900,000
Nirefs	5,293,750	9,595,833	5,950,000	5,600,000	5,250,000	4,900,000	4,900,000
Norfolk	6,540,625	26,162,500	26,162,500	26,162,500	9,238,542	7,000,000	7,000,000
Aliki	3,937,500	9,450,000	11,025,000	8,400,000	7,700,000	7,000,000	7,000,000
Salt Lake City	4,882,500	19,530,000	19,530,000	15,703,333	7,700,000	7,000,000	7,000,000
Sideris GS	3,325,000	12,250,000	9,450,000	8,400,000	7,700,000	7,000,000	7,000,000
Semirio	2,712,500	10,850,000	9,916,667	8,400,000	7,700,000	7,000,000	7,000,000
Boston	4,550,000	18,200,000	12,937,838	8,400,000	7,700,000	7,000,000	7,000,000
Houston	3,208,333	19,250,000	9,450,000	8,400,000	7,700,000	7,000,000	7,000,000
New York (Mar2010)	0	13,300,000	16,800,000	16,800,000	16,800,000	16,800,000	7,816,667

Table 5.5-7: Revenue Projections by Ship

	2009	2010	2011	2012	2013	2014	2015
Revenues ($M)	**235.4**	**231.0**	**206.2**	**179.4**	**140.5**	**123.0**	**120.5**
Growth	**-30.23%**	**-1.85%**	**-10.74%**	**-13.02%**	**-21.68%**	**-7.82%**	**-6.94%**

Table 5.5-8: Aggregate Revenue and Revenue Growth Projections for DSX

A revenue growth of 5% was assumed thereafter in perpetuity. This is relatively high but is in line with industry expectations since the market is directly linked to that of developing countries (major cargos are iron ore and coal) such as China and India. Delivery of a new ship takes about 2 years in the current market. This assumes no secondhand ships or "resales" will be bought and that newbuildings will be ordered again in about 3 to 4 years after the older ships in the market have been scrapped and the market begins to recover.

5.5.3.5.3.3 Remaining Projections

The bulk of costs varies with ship ownership days. Over the past 3 years the average for DSX was ~$8800/day. Costs decreased after the market crash so I assume a constant rate of $8000/day going forward. Ownership days are based on the company not increasing its fleet size until 2015, after which point they grow with revenues (daily rates are assumed constant). Table 5.5-9 shows the cost projections.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Ownership Days	5,813	4,897	6,913	6,996	7,239	7,300	7,300	7,300	7,300	7,300	7,665	8,048	8,451
COGS ($/ ShipDay)	6,245	10,169	9,938	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000
COGS ($M)	36.3	49.8	68.7	56.0	57.9	58.4	58.4	58.4	58.4	58	61	64	68

Table 5.5-9: Cos projections for DSX

To project the book value of assets, depreciation was projected using the company's method. That is linearly depreciating ships to 25 years of age at which point they are worth their scrap value at a price of $150/ltd (lightship ton). The total residual value of the fleet was estimated at $50M. Other assets are very low but they were projected to increase with revenues. This ignores economies of scale for conservativeness because the company has indicated that it is reaching capacity and approaching the point of diseconomies of scale (it has expanded greatly over the past few years). The cash on its balance sheet was reduced going forward because it is preparing to make its final shipyard installment in March 2010. Cash was then also projected to grow with revenues in line with the company's policy of maintaining $400,000 per vessel in liquid assets. The financial projections are summarized in Table 5.5-10.

Financial Projections										
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Ships	18	18	20	20	20	20	20	20	21	22.05
Revenue	337.4	235.4	231.0	206.2	179.4	140.5	129.5	120.5	126.5	132.9
Ships B. Val	960.4	995.9	964.5	927.9	892.8	859.1	826.7	795.6	765.8	737.2
Depreciation		42.7	46.5	36.6	35.1	33.7	32.4	31.1	29.8	28.6
Other Assets	69.0	60.0	30.0	40.0	50.0	50.0	50.0	50.0	50.0	52.5
Total Assets	1,029.4	1,055.9	994.5	967.9	942.8	909.1	876.7	845.6	815.8	789.7
COGS	68.7	56.0	57.9	58.4	58.4	58.4	58.4	58.4	61.3	64.4
NOPAT	225.4	136.8	126.6	111.2	85.9	48.4	38.7	31.0	35.4	39.9

Table 5.5-10: Financial Projections for DSX

Net working Capital over revenues has been highly volatile and occasionally negative. That is highly attributable to deferred revenues which include received but unearned charter payments and the value of charters attached to vessels that are being acquired (when the rate is different from market rates). Going forward, most charters will be under period contracts which are paid periodically throughout the charter so this item will decrease making NWC positive. A value of 2% was chosen for the long term and projections

over the next few years beginning from zero and gradually approaching that value. The resulting projections are shown in Table 5.5-11.

KEY ASSUMPTIONS									
	2009	2010	2011	2012	2013	2014	2015	2016	2017
REVENUES g	30.23%	-1.85%	-10.74%	-13.02%	-21.68%	-7.82%	-6.94%	5.00%	5.00%
NOPAT M.	58.10%	54.81%	53.94%	47.87%	34.44%	29.91%	25.76%	27.97%	29.99%
NWC/Revenues		0.00%	0.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%
Assets/Revenues		417.4%	450.0%	497.8%	611.5%	638.4%	660.2%	605.2%	554.8%

Table 5.5-11. Key Assumptions for DSX Valuation

5.5.3.5.3.4 Long Term Projections

Long term assumptions are based on long term historical averages while it is assumed that the company will maintain a ratio of approximately 2 Panamaxes per Cape in the long term. Tables 5.5-12 and 5.5-13 show the analysis and results.

LONG TERM ASSUMPTIONS					
	Value	**Earnings/day**	**Expenses/day**	**NOPAT M.**	**Assets/Revenues**
Cape	40,000,000	25,000	9,000	0.64	4.57
PMX	25,000,000	12,500	6,000	0.52	5.71
Weighted Average	**30,000,000**	**16,667**	**7,000**	**0.56**	**5.33**

Table 5.5-12: Long Term Assumption Analysis for DSX

TERMINAL VALUE ASSUMPTIONS	
	Terminal Value
Revenues Growth	5%
Nopat Margin	56%
NWC/Revenues	2%
Assets/Revenues	533%

Table 5.5-13: Long Term Assumption Results

5.5.3.5.4 Results & Sensitivity Analysis

5.5.3.5.4.1 Expected Results

Applying the valuation models, using the above assumptions, we get a share value of **$12.38**. The share is currently trading at $15.88. Perhaps that is because the market expects the company to take advantage of the low market prices and grow through the crisis. That is indeed the intention of the management (as of many other shipping companies). I assumed no fleet expansion until 2015 because of the current difficulty of raising finance, the market conditions and future outlook, and the fact that the company has expanded rapidly and will need some time to digest this growth and bring down its expenses to cope with new market levels. This is compensated for by assuming a relatively high 5% growth in perpetuity beyond 2015. We will also carry out a "best case" and "worst case" scenario by modifying our assumptions.

5.5.3.5.4.2 Worst Case (Charter Contract Cancellation Scenario)

It is assumed that the company is forced to renegotiate all its contracts down to market rates. This is somewhat extreme but no asset impairments are made. The consequence is a worse decline in Earnings and NOPAT margins while Assets/Revenues are forced up (no

asset impairment). NWC/Revenues is left the same, earning days are kept at 350/year and long term assumptions are adjusted to 4% growth and 50% NOPAT/Revenues. The resulting projections are in Table 5.5-14. The Share value under these assumptions becomes **$9.81**

KEY ASSUMPTIONS									
	2009	2010	2011	2012	2013	2014	2015	2016	2017
REVENUES g	35.79%	-15.33%	-12.30%	-7.76%	-6.37%	-6.80%	6.94%	0.00%	5.00%
NOPAT M.	54.47%	43.08%	40.96%	36.98%	33.71%	29.91%	25.76%	27.97%	29.99%
NWC/Revenues		0.00%	0.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%
Assets/Revenues		525.7%	576.7%	601.6%	618.2%	638.4%	660.2%	605.2%	554.8%

Table 5.5-14: Worst Case Key Assumptions

5.5.3.5.4.3 Best Case (Fleet Expansion Scenario)

Under the best case scenario, no charter renegotiations are made. The fleet grows by an additional Cape and two Panamaxes every year from 2010 onwards. The price at which these assets are acquired is assumed to vary with the futures value for average daily earnings of the given calendar year. These new additions are chartered at rates given by futures for each period. This pushes revenues and assets up and NOPAT margins down. That is because market charter rates are lower than the average contract rates of the company since its high rate charters are not renegotiated.

Earning days per year are increased from 350 in the base scenario to 360. This is assisted by the new additions which help keep the average age low. Costs per ship day are adjusted down to 6,000 which is close to the industry average, assuming some EOS with the fleet expansion. Long term growth is kept at 5%, while NOPAT/Revenues is increased to 65%. The resulting projections are in Table 5.5-15. These assumptions bring the share value up to **$14.34**

KEY ASSUMPTIONS									
	2009	2010	2011	2012	2013	2014	2015	2016	2017
REVENUES g	29.8%	12.4%	-12.2%	-12.6%	-20.2%	-7.8%	6.1%	5.00%	5.00%
NOPAT M.	64.3%	64.6%	60.6%	52.0%	36.6%	27.9%	19.7%	20.3%	21.0%
NWC/Revenues		0.00%	0.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%
Assets/Revenues		395.8%	462.6%	539.7%	686.7%	752.3%	809.1%	777.5%	746.4%

Table 5.5-15. Worst Case Key Assumptions

5.5.3.5.5 Summary of Valuation

In order to predict a share value equal to the $15.88 at which the share is trading, some aggressive assumptions are necessary. This can be done by assuming the best case scenario and adjusting the long term annual revenues growth to 6.5%. To conclude, even though the company compares very favorably to its major competitors, and while analysts currently suggest buying the share at $15.88, my assumptions and forecasts indicate that it is currently overvalued.

Its key advantages are low leverage and probability of breaching loan covenants, the fact that assets currently don't have to be impaired, that it might be in a position to take advantage of low market prices for growth, and that a big portion of future revenues is secured under long term charters. Its key disadvantages are the bad prospects of the market, that it must rely on a few big charterers to keep paying above-market rates, and that potential contract renegotiations may necessitate asset value impairments.

5.5.3.5.6 Asset Value Extraction

While ship values were assumed to carry out the impairment test, they were not part of the valuation. We made assumptions about future earnings, which could have been used

directly in a ship valuation. Nevertheless, we can still make some crude assumptions to extract ship values from our valuation and the share price.

Our base case scenario values the equity at $929.4M ($12.38/share). The company's total liabilities stand at $281.7M. For simplicity, we take the debt at face value instead of deducting the value of a put option to account for expected default losses following Merton's model. This brings the asset value to $1.21Bn. In its Dec 2008 report, non-ship assets (including intangibles) amounted to $98M. Assuming this is still true, we get a total value for the fleet equal to $1.1Bn.

The next step is to distribute the total fleet value to the individual ships. We will do that by assigning points to each ship, that are roughly proportional to its value. A new Cape is equivalent to 1 point. Using the company's straight line depreciation approach a 25 year old Cape is worth its scrap value, which we can assume is approximately 10% of the value of a new ship. Therefore, a 25-year old Cape is equivalent to 0.1 points, and each year of age decreases the ship's points by 0.036. Based on the industry rules of thumb, we multiply the points of a Cape by 2/3 for a Panamax. The fleet list and the points per ship are summarized in Table 5.5-16.

The total number of points of the fleet were 13.46. This is the equivalent of new Capes. Dividing the fleet value ($1.1Bn) by the number of points brings the value of a new Cape to $82.8M. We can use the point ratio to value Capes of different ages and we can repeat the analysis with the trading value of the stock ($15.88/share) to repeat the valuation. The results are summarized in Table 5.5-17. both sets of results are slightly higher than actual values, perhaps because the company underestimates its non-ship assets, which we have used to arrive at the fleet value.

SHIP	DWT	BLT	POINTS
Coronis	74381	2006	0.570667
Erato	74444	2004	0.522667
Naias	73546	2006	0.570667
Clio	73691	2005	0.546667
Calipso	73691	2005	0.546667
Protefs	73630	2004	0.522667
Thetis	73585	2004	0.522667
Dioni	75172	2001	0.450667
Danae	75106	2001	0.450667
Oceanis	75211	2001	0.450667
Triton	75336	2001	0.450667
Alcyon	75247	2001	0.450667
Nirefs	75311	2001	0.450667
Norfolk	164,218	2002	0.712
Aliki	180235	2005	0.82
Salt Lake City	171810	2005	0.82
Sideris GS	174186	2006	0.856
Semirio	174261	2007	0.892
Boston	177828	2007	0.892
Houston	177729	2009	0.964
New York (Mar2010)	177000	2010	1

Table 5.5-16: Point Allocation to DSX Fleet for Asset Value Allocation

Ship Age	Points	Valuation	Trading Value
0	1	$82.77	$102.29
5	0.82	$67.87	$83.88
10	0.64	$52.98	$65.47
15	0.46	$38.08	$47.05
20	0.28	$23.18	$28.64

Table 5.5-17: Extracted Cape Values based on Equity Valuation and Equity Trading Price

5.6 New Valuation Model

5.6.1 Critique and Choice of Valuation Approach

One approach would be to do company valuations and extract the asset values from the results. The advantage of this approach is that company valuations can be referenced from other analyses for verifications, many companies exist so averaging out the results may eliminate errors, and we have several methods such as multiples based, DCF, the accounting approach etc. There are however two major problems with this method. First, the company valuation relies on a valuation of the assets, which we are trying to extract, or on a projection of future earnings which relies on forecasting the asset earnings. This defeats the purpose of the exercise.

We can get around this by using the market cap of the company, averaged over a period of time, as our valuation. The value at which a company is traded implies a value of its assets as viewed by the investors. We can extract that value by considering the firm's assets, its share price and the number of outstanding shares. For a liquid share, this should give a reliable estimate of the total asset value. However, this does not overcome the second limitation which is that the assets of most publicly traded companies consists of other types and sizes of ships as well as non-ship assets. Furthermore, the capes in the fleet will be of various sizes and ages and with various time charters attached. In order to extract the value of a particular cape, we will have to make an assumption about the value of the remaining assets. This will obviously introduce unacceptable errors in our valuation.

The comparables based approach has been applied by brokers using rules of thumb coupled with intuition and experience. Though comparables based models have not been published, this approach is by far been the most widely used in the industry. Its major limitation is that it relies on similar sales that have been conducted very recently and that qualify as willing-buyer willing-seller. These are often not available, particularly during a sudden downturn of the market as the one that was experienced after the credit crunch at the

end of 2008. This limitation led to the development of other approaches such as the Shadow-Pricing approach and the Hamburg Valuation.

Another major limitation of this approach, which holds even when there are qualifying comparables, is that it takes the view that the market has it right. This means that the sale on which the valuation will be based was at the "right" price. This approximation is becoming less valid as the mix of owners is becoming more complex. Publicly traded companies, for instance, value newer ships and immediate earnings disproportionately compared to private companies. They also finance their acquisitions through equity and often even pay in stock as opposed to having to raise debt which can be difficult for private companies at times. The relevant differences between private and public companies have been analyzed in great detail in Section 5.3. As a result, it would not be appropriate for a private owner to base a valuation on a comparable acquisition or disposal by a public company. This explains why most of the prompt-delivery resale acquisitions, that involved a very significant premium over newbuilding orders, have been conducted by listed companies over the past several years, whereas most of the newbuilding orders were placed primarily by private companies.

Shadow pricing was developed to overcome the problem of limited comparables. It provides a good rough estimate relative to historical multiples but no more than that. Future expectations of the market are the main driver or ship values. By valuing ships based on multiples of current earnings that have been derived from historic data, shadow pricing implicitly assumes that future market expectations are related to current market levels in the same way they have been in the past. This is clearly a bad approximation since the shape of the forward curve is not constant over time. Forward curves have been examined in Section 2.8. The forward curve today is much flatter than in was in 2008 when the market was multiple times higher. That means that people were then expecting a much bigger decline in daily earnings than they are today. This should surely impact ship values but is not captured by the shadow pricing model. Furthermore other parameters such as operating costs and interest rates also change over time and have to be accounted for.

Hamburg Valuation is a more scientific approach but the motives in its development were questionable and that explains several of its crude assumptions. One of those is the cost of equity, which is based on US bond returns (plus a spread) and is only 7.63%. Another one

is the use of 10-year average earnings to project future revenues at a time when the market outlook and futures point to significantly lower rates over a long period of time. A third example is the approximation of the residual value as 3.45 times the scrap value for 20 year old bulk carriers. Besides these crude approximations that point to a higher valuation, the main limitation of the Hamburg Valuation is the use of recent historical average data as opposed to forward looking data.

We will use DCF. If applied correctly, the 3 approaches should yield exactly the same result. Of the 3 approaches, since we assume no income taxes, the APV is essentially the same as WACC. To apply FTE, we have to determine the bank installments which means that we have to know the initial amount borrowed. This requires our knowledge of the ship value which is what we are set to find. In order to avoid having to take this iterative approach, we can use the WACC method.

Another choice would be to use forward views on ship values and carry out a valuation taking a no-arbitrage approach. In Section 2.6.3, we derived a forward curve on ship values based on newbuilding prices. The limitations of this approach are that the forward curve goes out only up to 5 years, and it only applies to new ships. Options on ship values were at some point introduced but the liquidity was too low and they were discontinued. This approach could potentially be combined with the model that we will develop if in the future these options become liquid enough.

5.6.2 Proposed Valuation Model

Having decided that the WACC method is the most relevant valuation approach, we will make use of the findings in the thesis so far to develop and apply a model for the valuation of capes. Using futures, determined probabilities of crack failure, repair costs and operating expenses, we can predict the expected monthly unlevered free cash flows throughout the ship's life. Discounting them to the present with an adjusted Weighted Average Cost of Capital (WACC) should yield the ship's value as per the WACC method. Under the WACC method, the net present value of a project or a company is as follows:

$$NPV = \sum_{t=1}^{\infty} \frac{UCF_t}{(1+r_{WACC})^t} - InitialInvestment \qquad (5.6\text{-}1)$$

Where: t = Measure of time (typically years)

UCF_t = Unlevered cash flows at time "t"

NPV = Net present value of the project or company

r_{WACC} = Weighted Average Cost of Capital

Initial Investment = Cost invested at t =0

The unlevered cash flows of a company are conventionally defined as follows

$$UCF = EBITDA - CAPEX - \Delta NWC \qquad (5.6\text{-}2)$$

Where: EBITDA: Earnings Before Interest Depreciation and Amortization

CAPEX: Capital Expenses

ΔNWC: Changes in Net Working Capital

Note that in Eq. 5.6-1, the initial investment, which occurs at the beginning (t=0), has been pulled out of the summation and that is why the summation begins with t=1 as opposed to t=0. We can pull this back in and start the summation at t=0. Furthermore, we will switch the parameter "t" for time with "n" which indicates the number of months from the investment date. Also, note that to get a valuation, we must assume that the net present value of the project is zero, meaning that an investor would be indifferent between undertaking the project or not. In place of WACC, we will be using an adjusted discount rate which will be a function of time (function of "n"). Making these adjustments and substituting Eq. 5.6-2 in Eq. 5.6-1, we get:

$$\sum_{n=0}^{\infty} \frac{EBITDA_n - CAPEX_n - \Delta NWC_n}{(1+i_n)^n} = 0 \qquad (5.6\text{-}3)$$

When we are dealing with the unlevered free cash flows of a ship, our expected EBITDA is essentially equal to the expected revenues minus the expected operating costs. In our model, we will quantify the expected revenue losses and expected additional costs due to crack failures as a separate term which is equal to the probability of failure times the failure cost.

The net working capital is the amount of liquidity required to run the business on a daily basis (current assets minus current liabilities). This is cash that is not available to the extract, so any changes in net working capital should be deducted from the free cash flows. Changes in net working capital usually result from factors that require an increase in the cash held by a company. This may be due to an increase in volatility, or an expansion of the company. Since we are dealing with a single ship, the changes in net working capital from one period to the next will be small. In our model, the small changes in net working capital are captured under management fees that are paid by the ship owner to the managing company. These are included under operating expenses. Therefore, we have:

$$EBITDA_n - \Delta NWC_n = \mathrm{Re}v_n - OpEx_n - P(fail)_n FailCost \qquad (5.6\text{-}4)$$

The capital expenses in a ship include the investment cost i.e. the ship value at n=0 which we are trying to identify, plus the repair costs throughout the ship's life. Therefore, we have:

$$CAPEX_{n=0} = ShipValue \qquad (5.6\text{-}5)$$

$$CAPEX_{n>0} = \mathrm{Re}\,pCost_n \qquad (5.6\text{-}6)$$

We will use the convention that all cash flows occur at the end of the time interval i.e. the end of each month. For "n=0" the only cash flow is the ship value (part of CAPEX). All other revenues and costs are equal to zero since they correspond to the month before the ship is acquired. Therefore, we have:

$$\mathrm{Re}v_0 = OpEx_0 = P(fail)_0 FailCost = 0 \tag{5.6-7}$$

We have a assumed a life of 27.5 years meaning that a ship will be scrapped just before the intermediate survey after the 5th special survey. This assumption has been discussed in the previous chapters and seems to be close to what the market has historically assumed. Due to the discounting this will have an insignificant impact on the valuation. Using 27.5 years as the ship's lifetime means that "n" will start from zero and increase until 330 months minus the ship's age today in months. Pulling everything together and substituting into Eq. 5.6-3, we get our valuation model as follows:

$$ShipValue = \sum_{n=1}^{Life-Age_0} \frac{\mathrm{Rev}_n - OpEx_n - \mathrm{Rep}Cost_n - P(fail)_n FailCost}{(1+i_n)^n} \tag{5.6-8}$$

Where:

$ShipValue$:	Ship Value Today
n:	Month of ship's life
Rev_0:	Ship's age today (in months)
Life:	Number of months in ship's life (27.5 years = 330 months)
Rev_n:	Revenues during month "n"
$OpExp_n$:	Operating expenses during month "n"
$\mathrm{Rep}Costs_n$:	Repair costs during month "n"
$P(fail)_n$:	Probability of failure due to cracks during month "n"
$FailCost$:	Cost of failure due to cracks
i_n:	Discount rate for month "n"

An important aspect of the proposed valuation model is that we will be using forward looking data wherever possible to quantify the required parameters. This applies to both numerator and denominator terms. Traditional valuation approaches, including the Hamburg Valuation Method, which is the current state of the art in ship valuation, are based on

historical data. As Nobel Laureate Robert C. Merton would put it, this is equivalent to driving on the highway at 60mph while looking at the rear view mirror. The analogy is particularly true for the volatile shipping industry where the previous decade has been completely different from the one before, and completely different from the current market outlook for the next one.

The great advantage of using forward looking data when possible is that they can simply be hedged through derivatives markets. In other words, if one disagrees about the projections, they can simply bet on their beliefs and make money. So there is nothing to argue about regarding the relevance of forward looking projections. On the other hand, traditional models that are based on historical data or market forecasts, can be manipulated to produce distorted results and can be easily disputed. Put in other words, there is nothing to assure you that the previous ten years will repeat themselves or that some analyst's forecasts (on which a valuation is based) will materialize. If on the other hand you want insurance on the forward looking projections, you can simply get it by trading derivatives accordingly.

In the valuation formula (5.6-6), the parameter "n" is in months meaning that we will assume a monthly time period as opposed to annual. This avoids the approximation that all earnings and costs are incurred at the end of each year. Note that "n" contains information simultaneously about the time we are in and about the ship's age at that time. The parameters in the numerator are functions time or ship age or both, so for a given ship valuation, they are defined by the month "n".

One could make the argument that each of the parameters of the numerator should be discounted at a different discount rate. That is because different risks are associated with each of them. For example, operating expenses and repair costs are more certain than revenues and therefore should be discounted at a lower discount rate. However, the widely adopted convention is to calculate the expected net profits or cash flows for each period and discount those at a discount rate related to the riskiness of the overall profits. Furthermore, note that at the extreme, the alternative could lead to a negative net present value even for an expected positive net profit in each of the future time periods.

Note that it would also be convenient to apply a discount factor using continuous compounding. We choose monthly discounting to keep the model simple and accessible to a wider audience. We will need continuous compounding to incorporate the hazard function

(risk due to crack failures) into the discount rate before converting back to monthly discounting. This will be carried out in the final stage of determining the discount rate.

5.6.3 The Discount Rate

5.6.3.1 Cost of Equity

5.6.3.1.1 Introduction

The cost of equity is the minimum expected return which an investor requires in order to carry out an investment. This is quite ambiguous and varies across investors so analysts use rules of thumb and great judgment with some guidance from approximate models. In general, the higher the risk in an investment, the higher the required return. Risk can be systematic, meaning that it is due to market fluctuations, or idiosyncratic to the specific investment.

Though there is big room for speculation, the cost of equity will have a significant influence on valuations so it is worthwhile spending time and effort to get a reasonable estimate. There are several types of investors in the cape industry who probably have different required returns. One reason for this is that some are well diversified, while others have a limited ability to diversify the idiosyncratic risk away, and therefore have to be compensated for it. Therefore, the industry ownership structure is of great relevance in our valuation.

As of March 2010, there are 994 Capes in the world fleet. 671 of these are owned by 50 companies. Fig. 5.6-1 shows the number of capes in each of these 50 fleets. The remaining one third of the world fleet (323 Capes) is owned by 175 owners (an average of 1.85 Capes per owner). For convenience, we will define 4 categories of owners. These are large public companies, small public companies, large rivate companies and small private companies.

Examples of large private companies from the top 50 list in Fig. 5.6-21 include Angelicoussis (22), Cardiff Marine (20), Enterprises Shipping (13), Polembros (12), Alpha Tankers (11), Carras Hellas (7), Marmaras (6) and Neda Maritime (6). They are privately held companies with estimated annual revenues measured in $100Ms. The brackets indicate the number of capes in each company's fleet.

Small private companies are not present in the top 50 list. They are companies with annual revenues below $100M. The average company of this group would own approximately 2 Capes, 7 Panamaxes and 3 Handies or Handymaxes, with total annual revenues of ~$75M for 2009.

Large public companies include Mitsui (45), COSCO (43), NYK (42), Zodiac (37), K Line (14) etc. They are companies with various operations in and out of shipping, various kinds of fleets including capes, and whose annual revenues are in the billions. This group also includes cargo owners such as Vale (13).

Small Public include Genmar (9), Navios (8), Diana (8) and Excel (6) from the top 50 list. They are comparable in size to the average large private company, with revenues in $100Ms.

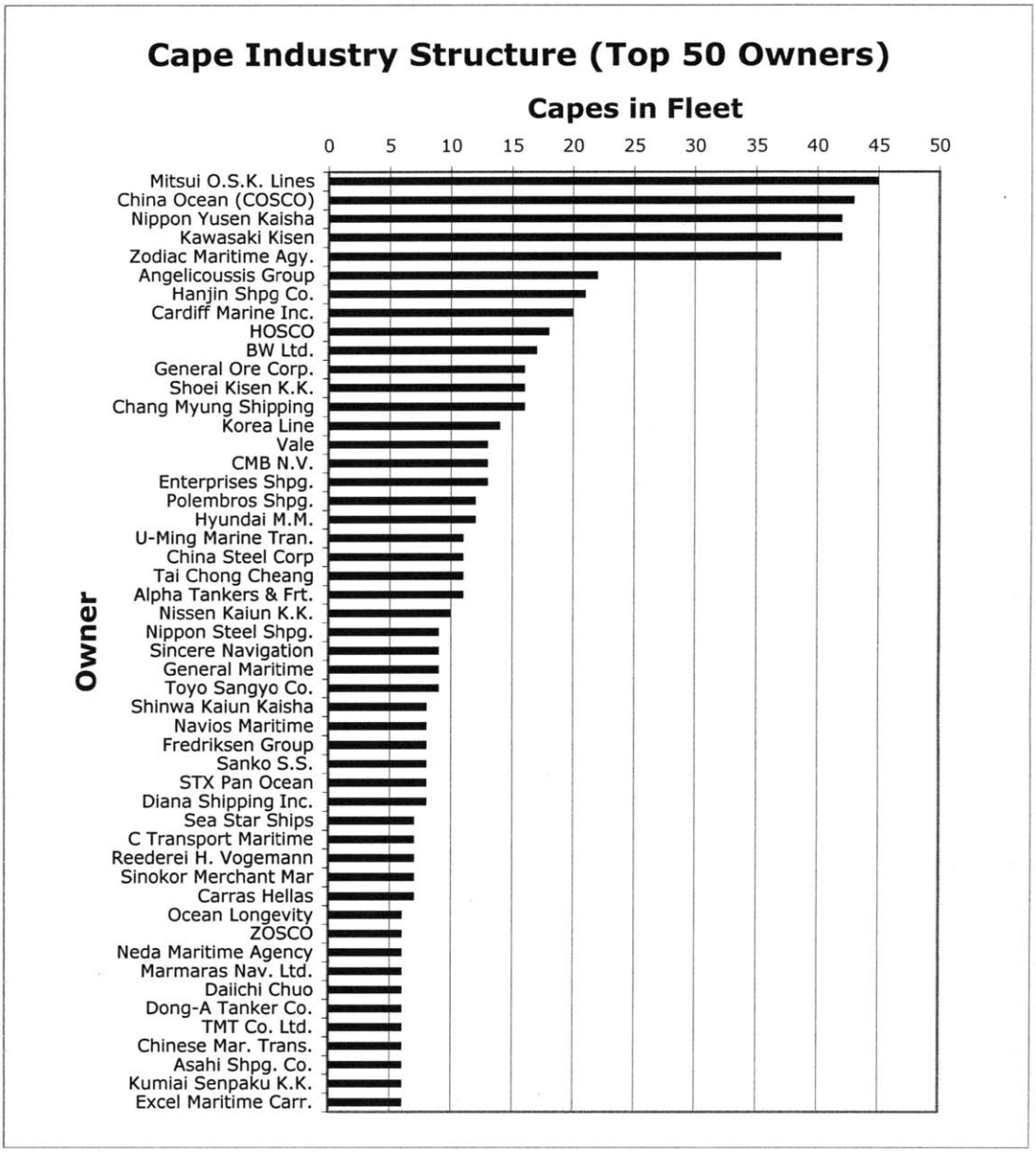


Fig. 5.6-1: March-2010 Top 50 Cape Fleets (671 capes out of 994 in World Fleet)

Table 5.6-1 attempts to quantify the individual market share the 4 groups. The first column refers to the top 50 owners in Fig. 5.6-1. The remaining third of the world fleet (323 ships) is treated separately before aggregating the results in the last two columns. The estimated public versus private ownership split is approximately 55 to 45.

INVESTOR TYPE	Ships from Top 50 List	% of Remaining Fleet	Ships from Remaining Fleet	Total Number of Ships	**% of World Fleet**
PUBLIC LARGE	373	10%	32	405	**41%**
PUBLIC SMALL	95	15%	48	143	**14%**
PRIVATE LARGE	203	25%	81	284	**29%**
PRIVATE SMALL	0	50%	162	162	**16%**
Total	**671**	**100%**	**323**	**994**	**100%**

Table 5.6-1: % of World Fleet Owned by the 4 Defined Investor Groups

The reason for developing Table 5.6-1, was to determine the weights that we will apply on the cost of capital of each investor group to determine a weighted average that we will use in the valuation. One could argue that the investor with the cost of capital that yields the highest valuation will be the ultimate buyer, so only the lowest cost of capital is relevant. However, there are three major counterarguments to this.

First, the valuation depends on the discount rate but also on financial projections, which will vary between investors. As a result, acquisitions are made by all investor groups. Otherwise, we would only have one investor group, which is clearly not the case. Second, even if everyone has similar needs and projections, as the investor with the lowest cots of capital buys enough, they stop competing for acquisitions, so the cost of capital of the other investors, who are now the buyers, becomes relevant. Third, the transaction price does not only depend on the valuation of the buyer but also on the valuation of the seller, who most likely will be from a different investor group. Lastly it is reasonable to assume that as owners renew their fleets, setting relative fleet growth rates aside, future transactions will be carried out in a roughly equal proportion between investor groups as the current ownership structure of the world fleet. Therefore, it is a good approximation to use a weighted average cost of capital, based on the weights determined in Table 5.6-1.

5.6.3.1.2 Short Overview of Build-Up Method

We will employ the build-up method to compute the cost of capital for each of the 4 classes of investors. This method is based on the principle that higher returns are required for riskier investments. We start from the risk free asset, and add risk premiums for various classes of risk to get to the cost of capital.

Starting from the risk-free rate, we employ the Capital Asset Pricing Model (CAPM) which accounts for systematic risk (market risk). This will require a list of comparable companies whose operations are primarily dry bulk shipping (preferably capes). CAPM assumes that the investors are well diversified so that idiosyncratic risk is eliminated. This is a reasonable approximation for listed companies, but significant adjustments will be required for private companies.

An alternative framework will be discussed for determining the parameters required for the CAPM, using a completely forward looking approach. This will be based on the Black-Scholes option pricing formula and will not require comparables. Unfortunately, the approach cannot yet be applied in its complete form because the shipping derivatives markets have not matured to an adequate level. However, some of its elements can be applied and will be used to verify the results from the comparables based approach. The method may become more useful as the required prices become observable in the market. This is likely as the derivatives market is expanding and more instruments are being introduced. A SWAP on container rates was recently introduced by Clarksons, while tanker FFAs have now started being traded in terms of $/day as opposed to World Scale.

The first adjustment on CAPM is to account for the risk due to leverage. Adding debt increases the riskiness of the firm and that affects our calculation of the required returns. Adjusting for this requires "un-levering" the betas of the comparable firms using their debt to equity ratio. This yields the unlevered beta or asset beta. Next, we have to account for excess cash on the balance sheets of our comparables to strip out its effect on the beta. This will leave us with the operating asset betas. We will then take an average across our comparables to net out company-specific errors. That will yield the unlevered beta, which is applicable to well diversified investors.

For the case of private investors, we will employ a method described by [Damodaran 2002] in order to add back idiosyncratic risk to the unlevered beta and remove it from a well diversified portfolio perspective. This will give us the "total beta", which is applicable to private companies.

Having the applicable unlevered betas for public and private companies, we will re-lever them using our debt to equity ratio which will be a function of time. Multiplying the resulting equity betas by the historic market risk premium will give us the adjusted CAPM premium over the risk free rate. Note that the risk free rate also varies with time. The next step will be to add risk premiums based on company-size, industry/company-specific risks, illiquidity, control and patient capital. These will be determined separately for each type of investor based on estimates and methodologies developed by earlier studies. Finally, a weighed average of the resulting returns on equity will be determined.

Note that the build up method does not end here. Some identical adjustments have to be made to the cost of equity and to the cost of debt. These include inflation and the risk premium due to potential crack failures, and will be incorporated directly to the WACC after accounting for the cost of debt. Table 5.6-2 shows an outline of the procedure to get to the cost of equity and to the final discount rate which will be a function of time.

Risk / Adjustment Type	Method	Result
Start with Risk Free Rate (τ = time)		
+ Systematic Risk	CAPM	
- Leverage Risk	Un-lever Betas	Unlevered Betas
- Excess Cash Effect	Asset-Weighted Beta	Operating Asset Betas
- Company Specific Errors	Take Average	Operating Asset Beta
+ Idiosyncratic Risk (Private Comp)	"Total Beta"	Total Beta
+ Leverage Risk: D/E (τ)	Re-Lever Betas	Levered Beta (τ)
+ Size/Company/Industry Risks + Illiquidity / Control and Patient Capital Premiums	Previous Studies	Cost of Equity (τ) for each investor type
Combine Costs of Equity	Weighted Average	**Cost of Equity (τ)**
Account for Debt/Equity time (τ)	Weighed Average	WACC (τ)
Account for Inflation (τ)	Subtract Inflation (τ)	Inf. Adjusted WACC (τ)
Account for Risk due to Cracks	Incorporate Hazard Function	**Hazard-Adjusted WACC (Discount Rate)**

Table 5.6-2: Build-Up Method to Calculate the Discount Rate

5.6.3.1.3 The Risk Free Rate

The risk free rate is the highest rate of return to which an investor has access with zero risk. The return on US T-Bills is typically used as a proxy to the risk free rate. Ship owners often keep cash in bank deposits on which they earn LIBID minus a spread. As a rule of thumb, LIBID is ~0.125% below LIBOR. Fig. 5.6-2 shows the yield curves for both Treasuries and Libor as of March 19, 2010.

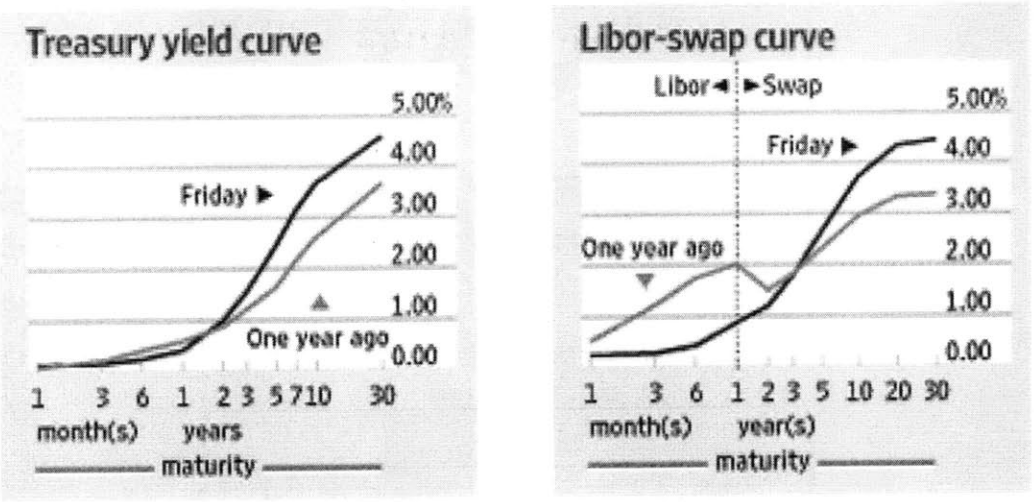


Fig. 5.6-2: Treasury Yield and Libor Swap Curves as of March 19, 2010 [WSJ 2010a]

Since the current yield curves are very similar, it really does not matter which we choose. However, T-Bills are a better proxy for various reasons. First, they are publicly traded, accessible to anyone and liquid so their prices are well documented. Bank deposits are guaranteed by the government up to a maximum of $100,000 per account while several banks have been bailed out by governments both in the US and in Europe. Therefore, one could argue that T-Bills are just as safe if not safer than bank deposits. Finally, the published betas which will form the basis of our return on equity calculations are determined using T-bills as a proxy for the risk free rate.

T-Bill rates are published daily for various tenures. Average values were taken between the 28 of February and the 18 of March and are summarized in Table 5.6-3.

TENURE	YIELD ON T-BILLS
1 Months	0.11%
3 Months	0.15%
6 Months	0.22%
1 Year	0.38%
2 Years	0.91%
3 Years	1.44%
5 Years	2.37%
7 Years	3.11%
10 Years	3.68%
20 Years	4.46%
30 Years	4.61%

Table 5.6-3: Inflation as a Function of Tenure Based on TIPS/T-Bill Yield Spreads

By interpolating between the values of Table 5.6-3, we can construct the term structure of the risk free rate. This is shown in Fig. 5.6-3.

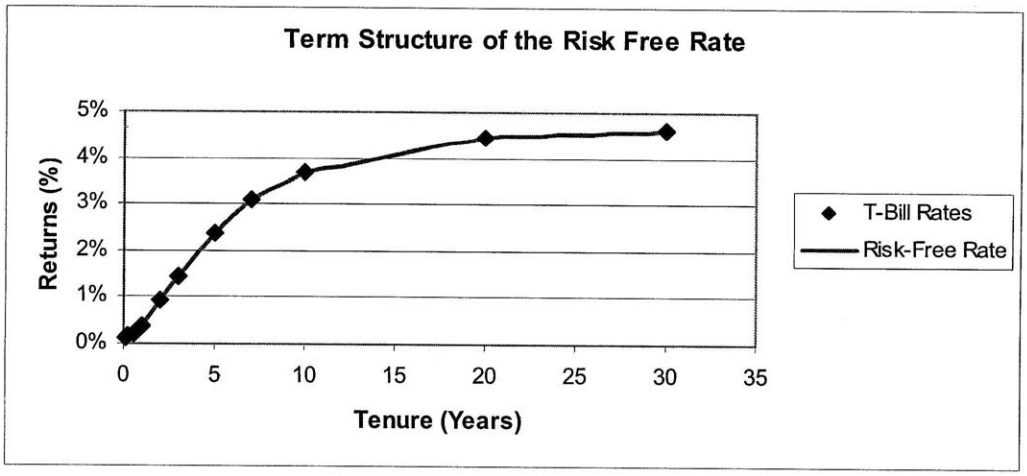


Fig. 5.6-3: Term Structure of Risk Free Rate Based on T-Bill Yields

Fig. 5.6-3 gives us the risk free rate as a function of time, $r_f(\tau)$. This will be the starting point for determining the cost of equity.

5.6.3.1.4 Capital Asset Pricing Model (CAPM)

The CAPM estimates the returns on a publicly traded stock as follows:

$$r_j = r_f + \beta_{j,m}\left(r_M - r_f\right) + \alpha_j \tag{5.6-9}$$

The beta of the stock is calculated by regressing the historical returns on the market returns using the following formula:

$$\beta_j = \frac{Cov\left(r_j, r_m\right)}{Var\left(r_m\right)} = \rho_{j,m}\frac{\sigma_j}{\sigma_m} \tag{5.6-10}$$

A beta value equal to 1 implies that the stock is as volatile as the market. A higher beta indicates a higher volatility which indicates a higher risk and therefore results in a higher required return. Note, that we are only concerned with the portion of the risk that is correlated with the market, systematic risk which cannot be diversified. We are not concerned with the remaining risk because it can be diversified away at negligible cost without sacrificing expected returns.

A low beta may result from a less volatile stock (i.e. with low stand-alone risk), but it could also be due to a low correlation with the market. In that case, the stand alone risk of the stock may be high, but the low calculated required return is justified by the diversification that the stock offers, which in turn improves the Sharpe Ratio of an investor's portfolio (slope of the maximum achievable return vs. volatility curve).

The Jensen's alpha term denotes the ability to consistently generate returns higher than the "fair" value given its risk and is almost always zero due to market efficiency. Since assets are equal to debt plus equity, we have the following equations:

$$r_e = r_f + \beta_e\left(r_M - r_f\right) \tag{5.6-11}$$

$$r_D = r_f + \beta_D \left(r_M - r_f \right) \tag{5.6-12}$$

$$r_A = r_f + \beta_A \left(r_M - r_f \right) \tag{5.6-13}$$

$$\beta_A = \left(\frac{D}{D+E} \right) \beta_D + \left(\frac{E}{D+E} \right) \beta_e \tag{5.6-14}$$

In fact, Eq. 5.6-7 neglects the effect of interest tax shields or assumes a tax rate of zero. This is true in our case, since earnings from shipping are typically not taxed. However, in the general case, since interest is tax deductible, in fact we have:

$$\beta_L = \left(1 + \frac{D}{E}(1-\tau) \right) \beta_U - \left(\frac{D(1-\tau)}{E} \right) \beta_D \tag{5.6-15}$$

By assuming a zero tax rate, we get Eq. 5.6-7. By assuming a zero debt beta, we get the Hamada Formula:

$$\beta_L = \left(1 + \frac{D}{E}(1-\tau) \right) \beta_U \tag{5.6-16}$$

The beta of debt is proportional to the correlation of the return on debt with the return on the market. It is close to zero but 0.2 is typically used for accuracy. Fig. 5.6-4 shows an estimate of the beta of debt as a function of credit rating of the company.

[A] Rating	[B] Default Spread (Over RFR)	[C] Cost of Debt	[D] Beta of Debt
AAA	0.53%	5.44%	0.05
AA	0.73	5.64	0.07
A+	0.81	5.72	0.08
A	0.88	5.79	0.09
A−	0.95	5.86	0.10
BBB	1.36	6.27	0.14
BB	2.80	7.71	0.28
B+	3.15	8.06	0.32
B	3.95	8.86	0.40
B−	4.55	9.46	0.46
CCC	9.90	14.81	0.99

[C] = [B] + R_f of 4.91%

To estimate the beta of debt, we used the default spread at each level of debt, and assumed that *half the risk is market risk*

[D] = ([B]/5.0%) × 0.5, where ERP = 5.0%

Note: This is an update of beta estimates that appear in Aswath Damodaran, *Investment Valuation: Tools and Techniques for Determining the Value of Any Asset*, 2nd ed. (Hoboken, NJ: John Wiley & Sons, 2002), 413.

Source: BondsOnline; FT Interactive Data; Bloomberg; calculations by Duff & Phelps LLC. Used with permission. All rights reserved.

Fig. 5.6-4: Beta of Debt vs. Credit Rating [Pratt & Grabowsky 2008]

It has been observed that the beta of companies gravitates to the industry average beta over time and that companies with the biggest errors gravitate faster. Bloomberg automatically adjusts historical betas to forward looking betas by shifting them towards their peer group average beta.

The CAPM uses a single factor beta to relate excess returns of a portfolio with excess returns of the market. However, small stocks (growth stocks) and those with higher book value of equity to market price ratio (value stocks) significantly outperform the market on average. Fama and French therefore introduced the Fama-French 3-Factor model to estimates returns as follows:

$$r = r_f + \beta_3\left(r_M - r_f\right) + b_S SMB + b_V HML + \alpha \qquad (5.6\text{-}17)$$

β_3 in this model is analogous to the beta from CAPM but not equal to it since we also have other factors. SMB stands for "Small (market cap) Minus Big" and HML stands for "High (book value of equity to price ratio) Minus Low". These parameters measure historic

returns of growth stocks in excess of large firms and of value stocks in excess of stocks with lower market price to book ratio. Table 5.6-3 shows values for applying the model as of March 2010.

	January	Last 3	Last 12
	2010	Months	Months
Rm-Rf	-3.51	4.79	35.25
SMB	0.43	3.04	18.07
HML	3.51	3.63	40.22

Table 5.6-4: Fama-French Model Data on March 2010 [French 2010]

The Fama-French is a more complete and slightly more accurate model. However, data for CAPM are better documented and more widely accessible. Furthermore, the build up method allows us to make adjustments to the CAPM returns in order to account for the additional factors considered in the Fama-French Model as well as others. The return on equity is given by:

$$r_e(t) = r_f(t) + \beta_e(t) MRP + \sum RP \qquad (5.6\text{-}18)$$

Where: t: Time

$r_e(t)$: Cost of Equity

$r_f(t)$: Risk Free Rate

$\beta_e(t)$: Beta of Equity

MRP: Market Risk Premium

$\sum RP$: Sum of Risk Premiums over CAPM

5.6.3.1.5 Cost of Equity for Small Public Firms

To apply the CAPM, we have to create a list of comparable firms. These are chosen so that their operations are predominantly focused on dry bulk carriers and preferably Capes. To avoid the need for major adjustments, it is important for the chosen not to be involved in unrelated operations or have significant unrelated assets on their balance sheets. Furthermore, our list should be limited to companies with adequate trading history (over 5 years) in order to obtain reasonable beta estimates. The list of six comparables is summarized in Table 7.

Equity betas of publicly traded companies are published in various sources. These are the "levered betas" since they take into account the leverage of the firm. To un-lever those betas, we must use the following formula:

$$\beta_A = \left(\frac{D}{D+E}\right)\beta_D + \left(\frac{E}{D+E}\right)\beta_e = w_D\beta_D + w_e\beta_e \qquad (5.6\text{-}19)$$

By assuming a typical value of 0.2 for the debt beta, we calculate the "asset beta" or "unlevered beta". The data on comparables was sourced from their 10-K forms, [Bloomberg 2010], [Googlefinance 2010], [Yahoofinance 2010] and [Trade-Ideas 2010]. Table 5.6-5 lists the comparables along with their (published) equity betas, their debt structure and the unlevered betas. Fig. 5.6-5 shows their market share in the global dry bulk industry.

	Equity Beta	Debt (M)	Equity (M)	Assets (M)	**Asset Beta**
DRYSHIPS	3.63	2,994	2,805	5,799	**1.86**
EXCEL	3.09	1,827	1,401	3,228	**1.45**
DIANA	1.60	307	971	1,278	**1.26**
NAVIOS	2.98	1,908	894	2,801	**1.09**
GENCO	2.40	1,408	929	2,337	**1.07**
EGLE	2.52	988	620	1,608	**1.09**

Table 5.6-5: Beta Un-levering of Comparables

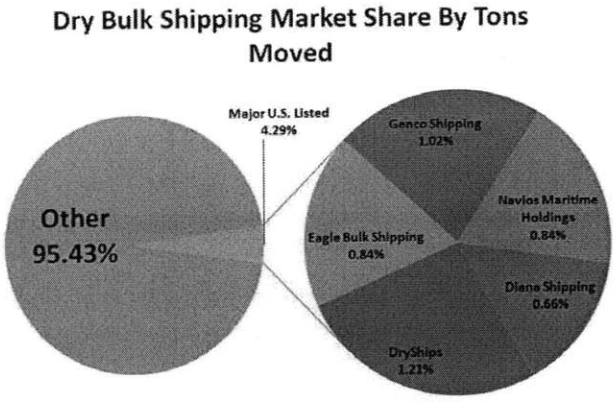


Fig. 5.6-5: Dry Bulk Market Share of Comparables [wikinvest 2009a]

It is important to have a complete understanding of the full set of assets of a company when applying this model. This includes assets both on and off the accounting balance sheet. [Jin et al 2006] demonstrated the importance of considering the "true balance sheet" particularly for company with large pension funds. They showed examples where operating asset betas are overstated by between 32% and 139%, which result in huge errors in the cost of capital and valuations. That is because only the net assets of pension funds are recorded in a company's balance sheet, so the beta of the full assets and debt in the pension funds is wrongfully omitted. Constructing a "Risk Balance Sheet" is often helpful when faced with complicated situations.

In our case, we don't have pension funds but extra care is needed in choosing comparables without hidden assets that are irrelevant to Capes. Along those lines, an important adjustment is that for excess cash on the balance sheet. Excess cash typically has a beta of zero. The right amount of cash required to run a company depends on the industry and can be quoted as a percentage of revenues or a percentage of Assets. Not much guidance is available on this but we can take the average of our listed companies as an estimate of the right amount of cash. Due to the rapidly changing environment in the shipping industry, we will replace annual revenues with 4 times the quarterly revenues of the quarter during which we have the cash held on the balance sheet.

We calculate the average percentage cash of total assets and the average percentage cash over 4 times quarterly revenues. This yields two estimates of the "right" amount of cash. By subtracting this value from each firm's cash, we get two values of excess cash, from

which we take the average. Only positive values are recorded and the rest are set to zero. Table 5.6-6 shows the results of this analysis.

	Cash ($M)	Cash/ 4*QRev	Cash/ Assets	Implied Excess Cash ($M)			Excess Cash ($M)
				Rev. Implied	Asset Implied	Average	
DRYS	693.2	89.6%	12.0%	247	143	195	**195**
EXCEL	94.6	13.6%	2.9%	-308	-212	-260	**0**
DIANA	251.6	108.1%	19.7%	117	130	124	**124**
NAVIOS	275.1	42.8%	9.8%	-95	9	-43	**0**
GENCO	188.3	48.9%	8.1%	-34	-34	-34	**0**
EGLE	72.3	43.0%	4.5%	-25	-80	-52	**0**
Average		**57.7%**	**9.5%**				

Table 5.6-6: Excess Cash Calculation

To be more accurate, we would have to go back and perform this calculation over time in order to calculate the average amount of excess cash that was held by the company throughout the period over which the betas were calculated. In this case, however, we have a very small percentage of excess cash in our comparables to justify that analysis. To remove the effect of excess cash and determine the beta of operating assets, we use the weighted average formulae:

$$\beta_{TA} = \left(\frac{OpA}{TA}\right)\beta_{OpA} + \left(\frac{ExA}{TA}\right)\beta_{ExA} \qquad (5.6\text{-}20)$$

Where: $$TA = OpA + ExA \qquad (5.6\text{-}21)$$

i.e. total assets are equal to operating assets plus excess assets (mainly excess cash), for which the beta is taken to be zero. It follows that the company's operating asset beta is:

$$\beta_{OpA} = \left(\frac{TA}{OpA}\right)\left[\beta_{TA} - \left(\frac{ExA}{TA}\right)\beta_{ExC}\right] \approx \beta_{TA}\left(\frac{TA}{OpA}\right) \qquad (5.6\text{-}22)$$

Table 5.6-7 shows the comparables' beta adjustments for excess cash.

	Excess Cash ($M)	Total Asset Beta	Operating Asset Beta
DRYS	194.9	1.86	1.92
EXCEL	0	1.45	1.45
DIANA	123.8	1.26	1.40
NAVIOS	0	1.09	1.09
GENCO	0	1.07	1.07
EGLE	0	1.09	1.09
Average		1.31	**1.34**

Table 5.6-7: Beta Adjustment for Excess Cash

The average unlevered beta increased from 1.31 to 1.34. The influence was small since our comparables did not have significant excess cash, but carrying out the procedure may be important under different circumstances. We will call this the market beta to distinguish it from the total beta which we will calculate later. We have:

$$\beta_m = \beta_{OpA} = 1.34 \qquad (5.6\text{-}23)$$

This value of beta is applicable to our second group of investors (small public firms), since the data used so far came from comparables of that group. If we were valuing a company, the next step would typically be to re-lever the beta using a target debt to equity ratio, or an industry average debt to equity ratio. Using the average debt to equity ratio of our comparables (54%), we get an equity beta of 2.7. However, in our case, the debt to equity ratio of a cape varies with time as the principal is paid down. This means that our equity beta will be a function of time.

Returning to Eq. (5.6-11), for the case of small public companies, all the risk premiums in the summation term are set to zero. That is because the return on equity will be applied to companies of the same size and risk profile and ownership structure as the comparables on which the betas where based. The CAPM is often applied by analysts to calculate the cost of equity of these small public firms without any adjustments. We assume that the CAPM yields the true cost of equity for these firms from which we have also obtained the betas in order to avoid introducing any bias. Premiums over CAPM for the other investor groups are then calculated relative to those of small public firms. Solving Eq. (5.6-12) for the bet of equity, we get:

$$\beta_e(t) = \frac{\beta_U - w_D(t)\beta_D}{w_E(t)} \tag{5.6-24}$$

Combining this with Eq. 5.6-11, and setting the sum of the risk premiums to zero yield:

$$r_{e,SmallPublic} = r_f(t) + \left[\frac{\beta_U - w_D(t)\beta_D}{w_E(t)}\right] MRP \tag{5.6-25}$$

The debt to equity weight will be determined as a function of time in a later part of the analysis. The unleveraged market beta was calculated to be 1.34, and the beta of debt is taken to be 0.2. The Market Risk Premium (MRP) varies depending on which period you look at and whether you start measuring during a crisis or a boom. Between 1926 and 2005, MRP was 5.22% [Pratt & Grabowsky 2006], and the most commonly used and relevant value according to latest research is: **MRP = 5.2%** Plugging these values into Eq. 5.6-18, we get the cost of equity for small public firms as follows:

$$r_{e,SmallPublic} = r_f(t) + \left[\frac{1.34 - 0.2w_D(t)}{w_E(t)}\right] 5.2\% \tag{5.6-26}$$

5.6.3.1.6 Cost of Equity for Large Public Firms

For large public firms, as for small public firms, we need not be concerned with the diversifiable idiosyncratic risks and other premiums due to illiquidity, control and patient capital that are relevant to private companies. The applicable operating asset beta is the same as for small public companies. The main difference that we need to account for is the size premium. This is one of the most important adjustments, which is explicitly accounted for in the Fama-French model described earlier.

To adjust for size premium, we can use the famous studies carried out by Morningstar (Ibbotson) since 1926 and by Duff & Phelps since 1963. Fig. 5.6-6 shows the excess returns over CAPM based on company market capitalization according to the Morningstar's (Ibbotson) studies between 1926 and 2005, using the MRP of 5.22%. Fig. 5.6-7 defines the company size groups used in Fig. 5.6-6.

Term Returns in Excess of CAPM Estimation for Decile Portfolios of the NYSE/AMEX/NASDAQ, 1926–2005

Decile	Beta*	Arithmetic Mean Return	Realized Return in Excess of Riskless Rate†	Estimated Return in Excess of Riskless Rate‡	Size Premium (Return in Excess of CAPM)
1-Largest	0.91	11.29%	6.07%	6.45%	−0.37%
2	1.04	13.22%	8.00%	7.33%	0.67%
3	1.10	13.84%	8.62%	7.77%	0.85%
4	1.13	14.31%	9.09%	7.98%	1.10%
5	1.16	14.91%	9.69%	8.20%	1.49%
6	1.18	15.33%	10.11%	8.38%	1.73%
7	1.23	15.62%	10.40%	8.73%	1.67%
8	1.28	16.60%	11.38%	9.05%	2.33%
9	1.34	17.48%	12.26%	9.50%	2.76%
10-Smallest	1.41	21.59%	16.37%	10.01%	6.36%
Mid-Cap, 3–5	1.12	14.15%	8.94%	7.91%	1.02%
Low-Cap, 6–8	1.22	15.66%	10.44%	8.63%	1.81%
Micro-Cap, 9–10	1.36	18.77%	13.55%	9.61%	3.95%

*Betas are estimated from monthly portfolio total returns in excess of the 30-day U.S. Treasury bill total return versus the S&P 500 total returns in excess of the 30-day U.S. Treasury bill, January 1926-December 2005.

†Historical riskless rate is measured by the 80-year arithmetic mean income return component of 20-year government bonds (5.22 percent).

‡Calculated in the context of the CAPM by multiplying the equity risk premium by beta. The equity risk premium is estimated by the arithmetic mean total return of the S&P 500 (12.30 percent) minus the arithmetic mean income return component of 20-year government bonds (5.22 percent) from 1926–2005.

Fig. 5.6-6: Size Risk Premium over CAPM from Ibottson Study 1926 – 2005 [Pratt & Grabowsky 2008]

Decile	Market Capitalization of Largest Company (in thousands)	Company Name
1-Largest	$367,495,144	General Electric Co.
2	16,016,450	Entergy Corp.
3	7,187,244	Chesapeake Energy
4	3,961,425	Ball Corp.
5	2,519,280	Celenese Corp.
6	1,728,888	AGCO Corp.
7	1,280,966	ESCO Technologies inc.
8	872,103	West Pharmaceutical Services, Inc.
9	596,393	General Cable Corp.
10-Smallest	264,981	4 Kids Entertainment

Source: Stocks, Bonds, Bills, and Inflation® Valuation Edition 2006 Yearbook. Copyright © 2006 Morningstar, Inc. All rights reserved. Used with permission. (Morningstar, Inc. acquired Ibbotson in 2006.) To purchase copies of the *Valuation Edition Yearbook*, or for more information on other Morningstar publications, please visit global.morningstar.com/DataPublications. Calculated (or derived) based on CRSP® data, © 2006 Center for Research in Security Prices (CRSP®), Graduate School of Business, The University of Chicago.

Fig. 5.6-7: Largest Company Market Cap for each Decile Group in Fig. 5.6-6 [Pratt & Grabowsky 2008]

Duff & Phelps publish risk premiums over CAPM using 8 different measures for company size including market cap, revenues, number of employees, book value of equity etc. They produce regression relations that are very convenient to apply such as the following [Pratt & Grabowsky 2008]:

$$\text{Size Premium (Over CAPM)} = 12.594 - 2.865\log(\text{Market Cap}) \quad (5.6\text{-}27)$$

$$\text{Size Premium (Over CAPM)} = 9.253 - 2.052\log(\text{Book Value of Equity}) \quad (5.6\text{-}28)$$

$$\text{Size Premium (Over CAPM)} = 8.817 - 1.550\log(\text{Revenues}) \quad (5.6\text{-}29)$$

These give the premium in the discount rate in excess of CAPM. The third relation (Eq. 5.6-22) is particularly useful when valuing private companies for which there is no market cap. Fig. 5.6-8 shows the regression plot for that equation.

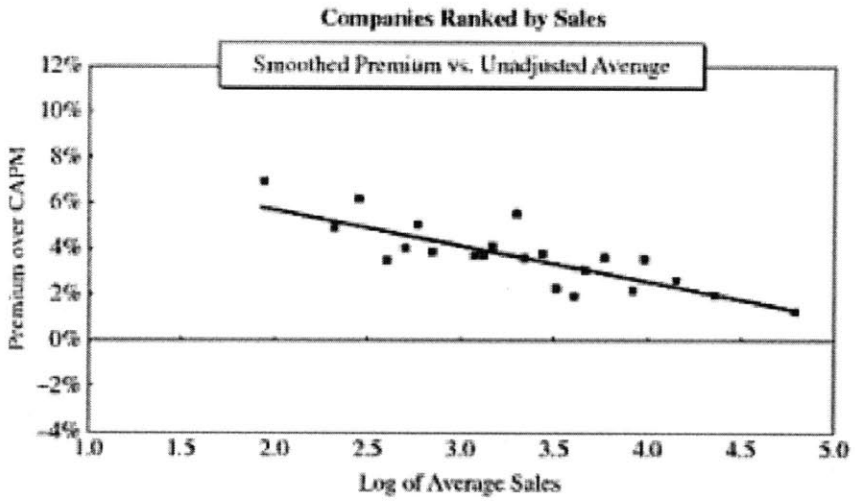


Fig. 5.6-8: Duff & Phelps Study CAPM Premium vs. Revenues Regression [Pratt & Grabowsky 2008]

A size premium is normally added on the discount rate for smaller companies. That is because smaller companies are inherently more risky and perform better on average than larger ones. Our calculated CAPM returns are based on the betas of small public companies. These betas have been derived from the returns of small public companies and therefore include the inherent size premium for small public companies. Therefore, to adjust these returns for large public companies, we need to subtract the size premium of small public companies and add the size premium of large public companies. Therefore, we have:

$$r_{e,LargePublic} = r_{e,SmallPublic} - SP_{SmallPublic} + SP_{LargePublic}$$

$$r_{e,LargePublic} = r_f(t) + \left[\frac{\beta_U - w_D(t)\beta_D}{w_E(t)}\right] MRP - SP_{SmallPublic} + SP_{LargePublic} \quad (5.6\text{-}30)$$

Table 5.6-8 gives the size premium over CAPM returns for our comparables based on the Morningstar (Ibbotson) studies (Fig. 5.6-6 & 5.6-7).

	Market Capitalization ($M)	Decile	SP over CAPM
DRYS	1440	6	1.73
EXCEL	463	9	2.76
DIANA	1050	7	1.67
NAVIOS	604	8	2.33
GENCO	657	8	2.33
EGLE	322	9	2.76
Average	756	**8**	**2.26**

Table 5.6-8: Average Size Premium for Comparables using the Morningstar Studies

Table 5.6-9 shows the results after applying the three formulae of Duff & Phelps (Eq. 5.6-20-22) to our comparables. After doing that, we take an average of the results for each comparable and then take the average across the comparables.

	MCap ($M)	Equity ($M)	Assets ($M)	4xQ.Rev ($M)	SP (Rev) Eq.5.6-20	SP (MCap) Eq.5.6-21	SP (Equity) Eq5.6-22	Average
DRYS	1,440	2,805	5,799	773.84	4.34	3.55	2.18	3.35
EXCEL	463	1,401	3,228	697.6	4.41	4.96	2.80	4.05
DIANA	1,050	971	1,278	232.88	5.15	3.94	3.12	4.07
NAVIOS	604	894	2,801	642.28	4.47	4.63	3.20	4.10
GENCO	657	929	2,337	384.92	4.81	4.52	3.16	4.16
EGLE	322	620	1,608	168.08	5.37	5.41	3.52	4.77
Average	**756**	**1,270**	**2,842**	**483**	**4.76**	**4.50**	**3.00**	**4.08**

Table 5.6-9: Average Size Premium for Comparables using the Duff & Phelps Studies

The average size premium over CAPM for our comparables is 2.26% using the Morningstar (Ibbotson) studies and 4.08% based on the Duff & Phelps studies. Taking the

average of those two, we get 3.17%. This is the size premium relevant to small public companies.

$$SP_{SmallPublic} = 3.17\% \tag{5.6-31}$$

By definition, we neglect the size premium of the large public companies. So we have:

$$SP_{LargePublic} = 0\% \tag{5.6-32}$$

Combining Eq. 5.6-23 and 5.6-26, we get the cost of equity for large public companies as follows:

$$r_{e,LargePublic} = r_f(t) + \left[\frac{1.34 - 0.2w_D(t)}{w_E(t)}\right] 5.2\% - 3.17\% \tag{5.6-33}$$

5.6.3.1.7 Cost of Equity for Large Private Firms

The value of 1.34 is the unlevered beta which is applicable to public firms. It assumes a fully diversified investor, since the CAPM only accounts for idiosyncratic risk. We need to add back idiosyncratic risk in order to remove the stock from a well diversified portfolio perspective. That is because owners of private companies are heavily invested in their companies and lack the resources to fully diversify, so they bear additional idiosyncratic risk and therefore require additional compensation.

One approach in estimating the additional returns for a private firm relative to a public one is to use the difference between the returns of private equity or venture capital firms and publicly traded stocks. Between 1990 and 2000, the difference was (24-15) = 9%. However, errors in this approach are large for several reasons including the fact that no adjustments for company size are made [Damodaran 2002].

[Feldman 2005] describes several methods to calculate a return on equity for private stocks. First we can following research indications that all betas drift toward the riskiness of the market and therefore assume a beta of 1. We can also assume a beta for an aggregate industry or develop a model to estimate the beta for a disaggregate sector using the operating earnings of the sector and the overall economy. We can also regress the accounting earnings of a private company with the stock market, or try to create a tracking portfolio and make the relevant adjustments.

The most neat and accurate method for our purposes is described by [Damodaran 2002]. He describes a method to calculate the "Total Beta" which is simply a volatility ratio, for the case of private investors. The total beta sets the correlation between firm returns and market returns to one, and is therefore essentially a volatility ratio. Thereby, the "total" risk is captured in the beta. We have:

$$\beta_{TOTi,m} = \frac{\beta_{i,m}}{\rho_{i,m}} = \frac{\sigma_i}{\sigma_m} \tag{5.6-34}$$

The advantages of using Total Beta and its effectiveness in solving several of the CAPM problems, are discussed by [Butler & Pinkerton 2009]. Note that by using the total beta, the CAPM becomes:

$$r_j = r_f + \sigma_j \frac{MRP}{\sigma_M} \tag{5.6-35}$$

In other words, the investor is compensated by an equal amount per unit of volatility as if investing in the market portfolio. This leaves the stock uncorrelated with anything which is exactly how we want to look at it from a private firm's perspective. However, in doing so, it measures the total risk meaning that it also captures risk premiums due to size and company specific factors. This is important to understand in order to avoid double counting when calculating risk premiums for the private companies. In other words, for private

companies, we only have to apply the excess risk premiums relative to the investor group from which we calculated the total betas (small public companies).

According to the procedure described by [Damodaran 2002], to get from the average unlevered beta to the average total beta, we simply divide by the average correlation of returns on our comparables to returns on the market. Table 5.6-10 shows the Total Beta calculation for our comparables.

	R Squared	Correlation	Operating Asset Beta	Total Beta
DRYS	0.288	0.537	1.92	3.58
EXCEL	0.267	0.517	1.45	2.81
DIANA	0.336	0.579	1.40	2.41
NAVIOS	0.308	0.555	1.09	1.96
GENCO	0.323	0.568	1.07	1.89
EGLE	0.256	0.506	1.09	2.16
Average		**0.544**	**1.34**	**2.46**

Table 5.6-10: Total Beta Calculation for Comparables

The average total beta is 2.46. Dividing the average unlevered beta by the average correlation also yields approximately the same result. So we take:

$$\beta_{Tot} = 2.46 \tag{5.6-36}$$

We will re-lever the total beta using the debt to equity ratio which is a function of time. Then we will apply this to our model and include the additional relevant risk premiums to get the cost of equity for large private companies. Therefore, we have:

$$r_{e,LargePrivate} = r_f(t) + \left[\frac{\beta_{Tot} - w_D(t)\beta_D}{w_E(t)}\right] MRP + \sum RP_{LargePrivate} \tag{5.6-37}$$

From Eq. 5.6-16 & 5.6-29, the total beta (2.46) is significantly larger than the market beta (1.34) because the earnings of the comparables are significantly correlated with the market. Therefore, private company investors are severely penalized relative to public company investors because of their limited ability for diversification. The total beta essentially adds one of the risk premiums that we are concerned about. That is the industry or Company Specific Risk Premium (CSRP), which can be diversified at negligible cost by public investors, but which has to be born by private investors.

The lower cost of capital due to the market beta being lower than the total beta is one of the big advantages of going public. Others include access to capital, liquidity and potential employee incentives using stock options. A big disadvantage of public firms is related to agency cost and will be captured in some of the other risk premiums that will favor private companies. The owners of a public firm (the shareholders) have very limited control over the management, other than electing the board of directors. This does not insure that the right incentives are in place as efficiently as in a private company where the manager is typically the sole owner.

When there is a company buy-out, a premium is paid over the stock price for "control". The buy out in fact eliminates agency costs, so the premium paid gives some guidance for their magnitude. Activist funds essentially try to capture this value (of control) without paying for it. In our case, part of the agency cost will be captured under the control premium and part of it under patient capital. This will favor private companies and will tend to offset the effect of limited diversification.

Having captured the industry or company specific risk premium under the total beta, the summation of risk premiums will include the size premium relative to small public firms, the illiquidity premium, the patient capital (family effect) premium and the control premium. Therefore, we have:

$$\sum RP_{LargePrivate} = SP_{LargePrivate} - SP_{SmallPublic} + \left[IP + FE + CP\right]_{LargePrivate} \tag{5.6-38}$$

We have defined the large private companies to be of a similar size as the small public companies. This means that the size premiums cancel out, so the relative size premium is equal to zero. We have:

$$SP_{Large\,Private} - SP_{SmallPublic} = 0 \qquad (5.6\text{-}39)$$

Before moving on, to consider the other risk premiums, lets assess the company/industry specific risk premium that we have implicitly added through the total beta. The Butler Pinkerton Model gives an estimate for the company specific risk premium of publicly traded companies based on the total beta, which can then be used as a benchmark for private companies [Butler & Pinkerton 2009]:

$$CSRP = \left(r_e - r_f\right)\left(\beta_{Tot} - \beta_U\right) - SP \qquad (5.6\text{-}40)$$

In our case, the relative size premium is equal to zero (Eq. 5.6-31). Applying this in the Butler Pinkerton Model (Eq. 5.6-33), we get the company (industry) specific risks, as follows:

$$CSRP = \left(\beta_{Tot} - \beta_U\right) * MRP = \left(2.46 - 1.34\right) * 5.2\% = 5.84\% \qquad (5.6\text{-}41)$$

It is worthwhile comparing this result to that of estimation procedures used by valuation analysts. [Feldman 2005] provides the guidelines shown in Table 5.6-11.

	Measurement	CSRP (%)	Applicable
A	Profitable only for the last 3 years or less	0.50	YES
B	No audited statement is produced for each year	0.50	Private
C	Receive over 30% of revenues from 5 customers	1.25	YES
D	Cannot change suppliers without sacrificing quality or cost	0.50	Varies
E	Personnel critical to the firm's success	1.00	YES
F	Highly competitive industry	1.25	YES
Total		5	>4

Table 5.6-11: Valuation analyst guidelines for CSRP [Feldman 2005]

Most if not all these risks in Table 5.6-11 would apply to the shipping industry but the maximum of this measure is 5%. However, several studies have indicated values of 8% over CAPM over 25 years, or even up to 40% [Feldman 2005]. It is also important to note that approximation systems such as the one in Table 5.6-5 have been developed based on typical industries for which analysts carry out valuations. The volatility and risks inherent in the shipping industry are profound compared to most of these industries. Therefore, our estimate of 5.84% for CSRP seems very reasonable.

The next step is to calculate the illiquidity, patient capital and control premiums. Value discounts due to lack of marketability have been examined by restricted stock studies and pre-IPO studies. These indicate discounts of 30-35% relative to fair market value while combined lack of control and illiquidity can add up to significantly more in family held firms. That is because a minority share holder has no voice while the shares may also be callable at a low price.

Illiquidity or marketability discount relates to the fact that shareholders will have to sell at a discount if they want to exit. For them to be properly compensated, this corresponds to a premium that has to be added on expected returns (the IP).

The "patient capital" of private firms has a counter acting effect, meaning that it is an advantage which they have over public firms, and therefore corresponds to a negative premium on the discount rate. Private firms have the ability to take a long term view on

profitability and adjust the timing of their investments to take advantage of opportunities very effectively. This is crucial, particularly in the shipping industry which is very cyclical and volatile. Public firms are under pressure to keep low cash on their balance sheets and invest their resources to boost earnings per share (which drive stock prices) for the next quarter. Therefore, they take a short term perspective relative to private companies. The value of patient capital has been studied in various papers and is very significant, particularly in volatile industries.

As Feldman's procedure with industry specific risks, [Clinger & Morin 2006] use a buildup method to estimate the equity premium due to patient capital, as summarized in Table 5.6-12. The last column refers to the typical case in private shipping companies based on my view.

	Measurement	**If Applies**	**Score**
Vision	Clear, developed vision	-1	YES
Management	Includes outside professionals & advisors	-1	~50%
Ownership	Regular family meetings	-1	YES
Communication	Clear communication & annual reports	-1	~50%
Governance	Transparent governance	-1	YES
Succession	Buy-sell agreements in place	-1	YES
Strategy	Strong strategic plan & accountability	-1	YES
Total			**-6**

Table 5.6-12: Family Business Attributes Risk Analysis [Clinger & Morin 2006]

[De Visscher 2010] provides a framework for thinking about the combined effect of illiquidity and patient capital in private firms. The adjustment on equity returns for a privately held firm is:

$$\left[r_f + \beta\left(r_m - r_f\right)\right] * \left[1 + IP'\right] * \left[1 - FE'\right] \qquad (5.6\text{-}42)$$

Where IP' and FE' are the illiquidity factor and family effect and both range from 0 to 1. Due to the structure of this formula, we see that an equal family effect and illiquidity

factor result in an overall decrease in the cost of equity. We already have an estimate of -4% for the Patient Capital risk premium, so we can focus on a separate estimate of the illiquidity premium. We will assume a typical value of 20% for the illiquidity discount. This, however, is applied on the total value (of equity shares) so we need to convert it into a premium over the discount rate. To do that, we have to assume an initial cost of equity and the weighted average time over which the cash flows are received. This is a form of duration like the one we use for bonds but not quite the same. To get the effective "Duration" denoted as D, we can solve the following Eq. assuming a new ship which has a 28 year life:

$$NPV = \sum_{y=0}^{28} \frac{CF_y}{(1+r_e)^y} = \frac{\sum_{y=0}^{28} CF_y}{(1+r_e)^D} \qquad (5.6\text{-}43)$$

Where
- y: year in the ship's life
- CF_y: Cash flow in year "y"
- D: Effective duration of cash flows
- NPV: Net present value of all cash flows
- r_e: Cost of equity

To get the duration, we use the above formula with a preliminary estimate of an unadjusted cost of equity by using the total beta of 2.46 (unlevered), a risk free rate of 2%, a debt to equity ratio of 54% (the average of our comparables), a debt beta of 0.2 and a market risk premium of 5.2%. For the cash flows (equivalent to bond coupon payments), we will assume a linear decrease from the initial value to 60% of the initial at the end of the ship's life and a residual value (equivalent to the bond dace value) equal to twice the first years earnings. These estimates are based on the current market. The cash flows are thereby given as a function of the year as follows:

$$CF_{1\le y\le 27} = 1 - \frac{1}{0.68} y, \; CF_{28} = 2.6 \qquad (5.6\text{-}44)$$

Solving Eq. 5.6-36 yields a duration of 7.96 which means that earning the cash flows of a new ship as they come along is equivalent to earning the total amount in eight years (as an estimate). Now to convert the illiquidity discount (ID) to an illiquidity risk premium (IP), we set up and solve the following equation:

$$NPV = \frac{1}{(1+r_e)^D}(1-ID) = \frac{1}{(1+r_e+IP)^D} \tag{5.6-45}$$

By applying the same values for the cost of equity and duration as above, and an illiquidity discount of 20%, we solve for the illiquidity premium and find a value of 3.57%. Using this and the patient capital value of 6%, we can solve the [De Visscher 2010] formula, 5.6-35 backwards to get IP' of 12.6% and FE' of 18.9%. The combined effect of illiquidity and patient capital is equal to:

$$IP_{\text{Private}} + PC_{Public} = -2.43\% \tag{5.6-46}$$

This value will also be applied to small private firms while the corresponding values for public firms (small and large) are equal to zero.

The control premium in a merger is the difference between acquisition price and the price at which the shares are traded between minority shareholders. Control Premium and Minority Discount measure the same thing and are related as follows:

$$MID = 1 - \frac{1}{1+CP} \tag{5.6-47}$$

Typical control premiums can be examined by comparing acquisition premiums over the stock price. Values between 35% and 50% are typical. However, one must also extract the value of synergies to calculate the "pure control premium", which is on average approximately half of the reported control premium [Feldman 2005]. The most obvious

control rights attached to a share are the voting rights, which can be easily quantified for companies with dual-class stock. The value of the voting rights is simply equal to the premium in the price of voting stocks over the trading price of non-voting shares. Estimates of voting premium vary widely across countries, but in the US, typical values are 5 to 10% [Lease et al 1983, 1984, Zingales 1995].

There is limited guidance in the published literature on quantifying a premium on the return on equity to account for the value of control. We are concerned with the fact that the CAPM estimates the value to shareholders of publicly traded companies. Shareholders include the founders who have control but, also many minority shareholders who don't. In a typical private firm, the sole owner has full control.

From the shipowner's perspective, full control corresponds to a lower risk on the future cash flows. It also eliminates agency costs relative to the public company, in which managers have the authority and incentive to cater to their own interests which may be conflicting with those of the owner. Therefore, control translates to a reduced cost of equity. However, we must bear in mind that the controlling managers of the public companies we are considering own a significant percentage of the stock (15% or more). In other words, agency costs can't be excessive. Furthermore, a significant portion of the value we are trying to quantify is already captured in the patient capital term of Eq. (5.6-36). Based on these considerations, a reasonable value for control premium over the cost of equity rate would be:

$$CP_{\text{Private}} = -1.5\% \qquad (5.6\text{-}48)$$

Note that the corresponding value for public companies is zero. Also, it is important to note that this premium is over the cost of equity of private firms, which will be blended with the cost of equity of public firms to get the average cost of equity. Then that value will be blended with the cost of debt using the debt to equity ratio, to arrive at the WACC, which will then be adjusted for inflation and risk of crack failures. Therefore, errors on the estimated control premium will not have a material impact on our results. Putting everything together, we have:

$$r_{e,Large\,Private} = r_f(t) + \left[\frac{2.46 - w_D(t)0.2}{w_E(t)}\right]5.2\% - 3.93\% \qquad (5.6\text{-}49)$$

5.6.3.1.8 Cost of Equity for Small Private Firms

As for large public firms, we will employ the total beta in order to incorporate idiosyncratic risks back into the cost of equity. Again, this takes care of CSRP. This leaves us with:

$$r_{e,Small\,Private} = r_f(t) + \left[\frac{\beta_{Tot} - w_D(t)\beta_D}{w_E(t)}\right]MRP + \sum RP_{Small\,Private} \qquad (5.6\text{-}50)$$

The first risk premium that we need to account for is the size premium. To do that, we have to estimate the excess size premium for small private companies, relative to small public companies. We have assumed average annual revenues of $75M for the typical small private company. Applying the Duff & Phelps formula based on revenues (Eq. 5.6-22), we get

$$\text{Size Premium (Over CAPM)} = 8.817 - 1.550\log(75) = 5.91\% \qquad (5.6\text{-}51)$$

Subtracting the average for our comparables (4.76% from Table 5.6-8), gives us 1.15%. Using the smallest group from the Morningstar (Ibbotson) studies (Fig. 5.6-6), we have 6.36%. Subtracting the average of our comparables (2.26% from Table 5.6-9), we get 4.10%. Taking the average between the results based on the two studies (1.15% and 4.10%), we get 2.63%. Note that this is in excess of what is captured in the total beta. We therefore have:

$$SP_{Small\,Private} - SP_{Small\,Public} = 2.63\% \qquad (5.6\text{-}52)$$

Regarding, illiquidity, patient capital and control premiums, the same principles apply as for large private companies. Therefore, we have:

$$IP_{\text{Private}} + PC_{\text{Private}} = -2.43\% \tag{5.6-53}$$

&

$$CP_{\text{Private}} = -1.5\% \tag{5.6-54}$$

Putting everything together, we get:

$$r_{e,\text{LargePrivate}} = r_f(t) + \left[\frac{2.46 - w_D(t)0.2}{w_E(t)}\right]5.2\% - 1.30\% \tag{5.6-55}$$

5.6.3.1.9 Summary and Weighted Average Cost of Equity

Eq. 5.6-19, 5.6-26, 5.6-39 and 5.6-45 estimate the cost of equity for each of the 4 investor groups as a function of the risk free rate and the leverage, which in turn will be a function of time. Replacing the weight of equity with one minus the weight on debt in these equations, we get the final forms:

$$r_{e,\text{LargePublic}} = r_f(t) + \left[\frac{1.34 - 0.2w_D(t)}{1 - w_D(t)}\right]5.2\% - 3.17\% \tag{5.6-56}$$

$$r_{e,\text{SmallPublic}} = r_f(t) + \left[\frac{1.34 - 0.2w_D(t)}{1 - w_D(t)}\right]5.2\% \tag{5.6-57}$$

$$r_{e,LargePrivate} = r_f(t) + \left[\frac{2.46 - w_D(t)0.2}{1 - w_D(t)}\right]5.2\% - 3.93\% \qquad (5.6\text{-}58)$$

$$r_{e,SmallPrivate} = r_f(t) + \left[\frac{2.46 - w_D(t)0.2}{1 - w_D(t)}\right]5.2\% - 1.30\% \qquad (5.6\text{-}59)$$

Table 5.6-13 provides a summary of the equity risk premiums over the risk-free rate, using the build up method. Note that the use of total beta in place of the market beta for private companies, accounts for the CSRP which is diversifiable.

Investor Group	Weight	Unlevered Beta	Size Premium (Relative to Public Small)	Net Illiquidity & Patient Capital Premium	Control Premium
Public Large	41%	1.34	-3.17%	0%	0%
Public Small	14%	1.34	0%	0%	0%
Private Large	29%	2.46	0%	-2.43%	-1.50%
Private Small	16%	2.46	2.63%	-2.43%	-1.50%
Weighted Average		**1.84**	**-0.87%**	**-1.09%**	**-0.67%**

Table 5.6-13: Equity Risk Premiums for the 4 investor groups using the Build-Up Method

Finally, using the weighted average values, we get total return on equity as follows:

$$r_e(t) = r_f(t) + \bar{\beta}_L MRP + \sum \overline{RP} \qquad (5.6\text{-}60)$$

$$r_e(t) = r_f(t) + \left[\frac{1.84 - w_D(t)0.2}{w_E(t)}\right]5.2\% - 1.76\% \qquad (5.6\text{-}61)$$

The risk free rate and the debt to equity ratio in our analysis will be a function of time. However, we can carry out a preliminary analysis by making some assumptions to keep

them constant. We will assume a constant debt to equity ratio equal to the average of our comparables (54%), a constant risk free rate of 2%, a market risk premium of 5.2% and a cost of debt equal to the risk free rate plus a 2.5% spread. Based on these assumptions, we can estimate approximate typical values for the cost of equity and weighted average cost of capital for our 4 investor categories. The results are shown in Table 15.

Note that the adjustments to account for the risk of crack failures and inflation (since we are discounting in real terms), will be applied after determining the WACC and will counteract each other. Consequently, the approximation in Table 5.6-14 is also an approximation of the discount rate.

Investor Group	Public Large	Public Small	Private Large	Private Small	Weighted Average
Cost of Equity	12.74%	15.91%	24.68%	27.31%	18.97%
~Discount Rate	8.29%	9.75%	13.78%	14.99%	11.16%

Table 5.6-14: Approximate Cost of Equity and Adjusted WACC using Typical Values

This is only a crude estimate, but typical constant values for WACC applied by analysis are about 10% for shipping companies, which is very close to our prediction. The cost of equity values are also close to the returns that investors of these categories expect on their investments.

5.6.3.1.10 Alternative Method Based on the Black-Implied Volatility

We have developed a procedure to estimate the relevant cost of equity for the valuation of capes based on a combination of historical data (from comparables) and forward looking data (the risk free rate). Option pricing theory allows us to focus more on forward looking data which is a big advantage.

Unlike futures, options involve a cash transaction today. The holder of an option has the right to buy the underlying asset (if it is a "call" option) or the right to sell it (if it is a "put" option) at the predefined strike price which defines the value of the option. The option holder has the right to exercise the option on the day it matures if it is a "European" option or at any time until maturity if it is an "American" option. The price of an option depends on the strike price, the time to maturity, the risk free rate, the current price and the volatility of the underlying asset. The Black-Scholes formula for the valuation of a call option of a non-dividend paying stock is given by:

$$C = SN(d_1) - PV(K)N(d_2) \tag{5.6-62}$$

$$d_1 = \frac{\ln\left(\frac{S}{PV(K)}\right)}{\sigma\sqrt{T}} + \frac{\sigma\sqrt{T}}{2} \tag{5.6-63}$$

$$d_2 = d_2 - \sigma\sqrt{T} \tag{5.6-64}$$

$$N(y) = \frac{1}{2\pi}\int_{-\infty}^{y} e^{-\frac{u^2}{2}} du \tag{5.6-65}$$

Where:

C:	Value of call option today
S:	Price of underlying stock option today
N:	Cumulative distribution function of the standard normal distribution
K:	Strike price
$PV(K)$:	The value of the strike price discounted from maturity $PV(K) = Ke^{-rT}$
T:	Time to maturity
σ:	Volatility of the underlying stock

Having the price of the call, we can determine the price of the put and vice versa through the put-call-parity as follows:

$$P = C - S + PV(K) = PV(K)\left[1 - N(d_2)\right] - S\left[1 - N(d_1)\right] \quad (5.6\text{-}66)$$

The most interesting thing about the Black-Scholes formula is that it does not require the probabilities of the various outcomes regarding the future value of the stock. In other words, the prices of puts and calls do not reflect any information about the value of the price tomorrow. They are not based on any such views and therefore can't be used to extract such information. They do however imply a view about the future volatility of the underlying asset. In other words, by solving Eq. 5.6-52 and 5.6-55 backwards, using the prices at which puts and calls are currently trading, we can back out what is termed the Black-Implied-Volatility.

As a side note, if the Black-Scholes formula was perfect, the strike price would have no effect on the calculated volatility. In practice however, there is a skew, often cancelled a volatility "smile" or "smirk". When the options are far out of the money or far into the money, meaning that the strike price is very different from the current price of the underlying, there is an error in the predicted volatility. In practice, several options near the money are used to back out the implied volatility and an average value is taken. The implied volatility is then published as an index, which is actually traded.

The VIX (Chicago Board Options Exchange Volatility Index) gives us the annualized implied 30-day volatility of the S&P 500. As of March 22nd 2010, VIX is trading at 16.68% [CFE 2010b]. To get the implied volatility for the next 30 days, we simply divide by the square root of twelve, which yields 4.8%. That means that the market expects the S&P 500 to be up or down by 4.8% from current levels 30 days from now. Futures are traded on the VIX, which allows us to construct the term structure that shows how the 30-day implied volatility will vary over time. The term structure of the VIX as of March 22nd 2010 is shown in Table 5.6-15.

Expiration Date	Bid Price	Ask	Mid	Implied 30-Day Vol
4/17/2010	14.97	16.56	15.79	4.56
5/22/2010	17.28	18.77	18.04	5.21
6/19/2010	18.66	20.47	19.58	5.65
7/17/2010	19.23	21.38	20.33	5.87
9/18/2010	20.39	22.41	21.43	6.19
12/18/2010	21.49	22.96	22.24	6.42
3/19/2011	21.97	23.38	22.68	6.55
6/18/2011	22.46	24.45	23.47	6.78
12/17/2011	23.6	24.97	24.29	7.01
12/22/2012	24.38	26.06	25.23	7.28

Table 5.6-15: VIX Term Structure as of March 22nd 2010 [CBOE 2010]

Besides the 30-day VIX, there are other indices for different maturities. The CBOE 12 month variance index, was trading at 26% as of March 22 2010 [CFE 2010]. This tells us that the current 12-month volatility of the S&P 500 is:

$$\sigma_{S\&P500,12M} = 26\% \qquad (5.6\text{-}67)$$

The Baltic Sale and Purchase Assessment Index (BSPA) is based on average price assessments of standard ships, reported by an international and independent panel of sale and purchase brokers. It is published bi-monthly for various ship types including the cape by the Baltic Exchange. Options traded on that index with various tenures allow a ship owner to hedge the value of a ship for various points in time in the future. By considering the prices of various options of certain tenure "T", we could extract the implied average volatility of the value of a cape.

We have seen how the volatility can be implied for various points in the future from the current prices of options. In theory, it would also be possible to get a forward view of the correlation between two assets if we had the prices of options that would allow you to

exchange one asset for the other. Such options exist for companies whose executives are compensated on the relative performance of the stock price relative to the market (the strike price is the ratio of the stock price to the level of the S&P 500). If we had the price of an option to exchange a unit of the BSPA-Cape index with a unit of the S&P 500, we could use the following formula:

$$\sigma_{S,T}^2 = \sigma_{BSPA-Cape,T}^2 + \sigma_{S\&P500,T}^2 - 2\rho_{BSPA-Cape,S\&P500,T}\sigma_{BSPA-cape,T}\sigma_{S\&P500,T} \quad (5.6\text{-}68)$$

$$S(t) = \frac{V_{BSPA-Cape}(t)}{V_{S\&P500}(t)} \quad (5.6\text{-}69)$$

Where:

T:	Tenure (time to expiration)
t:	Time variable
$V_{BSPA-Cape}(t)$:	Value of the BSPA-Cape index
$V_{S\&P500}(t)$:	Value of S&P 500 index at time "t"
$S(t)$:	The underlying asset of our exchange option
$\sigma_{S,T}$:	Black-Implied volatility of the exchange option with tenure "T"
$\sigma_{BSPA-Cape,T}$:	Black-implied volatility of BSPA Cape index for tenure "T"
$\sigma_{S\&P500,T}$:	Black-Implied volatility for S&P 500 index for tenure "T"
$\rho_{BSPA-Cape,S\&P500,T}$:	Correlation between BSPA-Cape and S&P 500 over time "T"

By using current prices of options on the S&P 500, options on the BSCA-Cape index, and options to exchange units of one for the other, we can back out the implied volatilities for each using Eq. 5.6-52 to 5.6-55. Then, by substituting those into 5.6-57, we can get the forward implied correlation between the value of a Cape and the S&P 500 for the period "T". Now, recall that we used the "market beta" for public investors and "total beta" for private investors. We can extend their definitions to use the BSPA-Cape index as opposed to the share price of companies owning capes, and to use forward implied parameters from the prices of current options as opposed to average historic values:

$$\beta_{m,T} = \rho_{BSPA-Cape,S\&P500,T} \frac{\sigma_{BSPA-Cape,T}}{\sigma_{S\&P500,T}} \tag{5.6-70}$$

$$\beta_{Tot,T} = \frac{\sigma_{BSPA-Cape,T}}{\sigma_{S\&P500,T}} \tag{5.6-71}$$

Note that these are equity betas that assume the industry average leverage for a cape of the same age. Cape prices are in fact published for ships of various ages (new building, new with prompt delivery, 5, 10, 15 and 20 years old) and there is also the Baltic Demolition Index (BDA) which indicates the price of an even older vessel. By performing the analysis using options on the relevant indices to match the age of the ship with the option tenures "T", we can obtain the forward implied market and total betas throughout as a function of time throughout the ship's life.

A more rigorous approach would be to base the betas on the volatility of the ship value as opposed to the revenues. To calculate the volatility of the ship value, we have to assume a value of beta and as we shall see later, it turns out that the value volatilities and consequently the betas are higher for older vessels. This approach would allow us to determine the betas for each ship age using an iterative approach.

We can then weight these betas using the percentage of public and private owners and proceed with the analysis as in the previous method using the comparables. A difference is that in this case, the beta also be a function of time (which is more appropriate). The

interesting part is that the industry average leverage of the cape of each age is already factored into these beta values so there is no need to un-lever and re-lever them using leverage assumptions. Performing this analysis using prices of liquid options, is just about as accurate as you can get in terms of using current market data to extract what the future discount rate must be.

The major limitation of this approach is that, at least for the time being, the liquidity of options on the BSPA-Cape index is not at a level so that we can extract reliable implied volatilities, while the described "exchange option" which is required to extract the forward correlation, has not been introduced yet.

Real options are often included as part of deals in the shipping industry. For example, a charterer may be granted the option to buy the vessel at a pre-specified price after the end of a long term charter, in exchange for an increased charter rate. The present value of the charter rate increase could be used to value the option and potentially to extract an implied volatility for ship prices. However, since ship characteristics (including age) vary significantly, and since these deals are not standardized, this method is unlikely to produce accurate results.

Futures were only introduced this past decade in the shipping industry and rapidly gained momentum, with options being introduced a couple of years ago and the volatility index on earnings being introduced last year. I believe that with continuing IPOs of shipping companies in US stock exchanges, as external investors become more involved in the shipping, and as the shipping industry investors continue to become more sophisticated, liquidity in the existing derivatives will continue to increase and more exotic instruments will be introduced. In a few years time, it is very possible that the relevant prices will be available to apply the above method and obtain a complete forward view on the discount rate as a function of time throughout the ship's life.

5.6.3.1.11 Approximate Beta Verification Using Derivatives

As we discussed, the method based on options to determine the forward discount rate cannot be applied in its entirety due to the lack of liquidity in the various instruments etc. However, we can attempt to combine some historical data with forward data on available derivatives that can be used as proxies to the required data, in order to produce a rough estimate.

Shipping freight rate options are "Asian" options meaning that they settle at the average of over a settlement period. As of March 23rd 2010, the futures for the BCI in Q2 is trading at $35,000/day. Table 5.6-16 summarizes bid/ask prices for puts and calls with different strike prices for the second quarter of 2010.

	Strike Price	Bid	Ask
CALL	40,000	2000	2500
CALL	45,000	1000	1500
33,000 PUT	33,000	2500	3250
30,000 PUT	30,000	1250	1750

Table 5.6-16 Q2 2010: Option Prices as of March 23, 2010 with Q2 Futures at $35,000/day

[Clarksons 2010]

The call options for Q2'2010 with a strike price of $40,000/day are trading for approximately $2,250/day. The value of $2,250 times the number of days in the settlement period (the second quarter) is paid by the buyer of the option. Then, at the end of each month in the settlement period, the average BCI is calculated. If the average is higher than $40,000, the call option is exercised by the holder and they get the monthly average minus the strike price ($40,000/day) times the number of days. If the month average is lower, the strike price is simply not exercised.

This is different from the futures contract in which the long position has to pay if the market level is below the strike price, but there is no cost to enter into the contract. The put option, on the other hand is exercised when the underlying (the BCI average in the settlement period) is less than the strike price. The underlying asset is the future rate for Q2 which is

trading at 35,000/day. The options of Table 5.6-16 are all out of the money, meaning that they would not make money if they were exercised today (calls are above the underlying and puts are below it).

[Levy 1997] extended the option pricing theory to Asian options. The pricing of Asian options is discussed by [Ellefsen and Sclavounos 2009] and in section 8.2.5 of [Alizadeh and Nomikos 2009]. Implied volatilities from options in the BCI are similarly backed out of option prices and a volatility index is composed by the Baltic Exchange and traded daily. Implied volatilities as of March 22nd 2010 are summarized in Table 5.6-17. These are the Baltic Option Assessments (BOA) of the implied volatility for an "at-the-money" option (strike price equal to forward rate) in the dry bulk options market submitted by brokers in London.

	Description	Average	Movement
IV_CTC_CURMON	Mar (10)	81.86	0.46
IV_CTC_CURQ	Mar (10)	81.86	0.46
IV_CTC_+1Q	Q2 (10)	84.29	0.29
IV_CTC_+2Q	Q3 (10)	71.07	-0.43
IV_CTC_+3Q	Q4 (10)	62.21	-0.49
IV_CTC_+4Q	Q1 (11)	61.00	-0.4
IV_CTC_+1CAL	**Cal 11**	**56.14**	**-0.66**
IV_CTC_+2CAL	Cal 12	51.71	-0.39
IV_CTC_+3CAL	Cal 13	49.57	-0.23

Table 5.6-17: Implied Volatilities for Baltic Capesize Earnings as of March 22nd 2010 [Baltic 2010]

The row in black indicates an annualized volatility of 56% for the next year. Due to the way shipping options work, it is important to realize that this is the volatility of a whole year's earnings. The "Cal 11" is a packet of 12 monthly settlements on the average of the BCI over the whole of 2011. The implied volatility of the daily BCI would be significantly higher. Since capes are normally chartered in period contracts that span from a few months to several years, when assessing the volatility of their earnings, it is more relevant to use the implied volatility of an option from a calendar year, as opposed to using the implied volatility

of daily earnings. We have seen in chapter 2 that ship values have historically moved with period earnings. Therefore, we will use the current volatility of the ship's earnings a year from now, as a proxy for the current annual volatility in the value of a cape. Using the implied volatility of the "Cal 11" option, we get:

$$\sigma_{BSPA-Cape,12M} \approx \sigma_{BCI,Cal-11} = 56\% \tag{5.6-72}$$

We already have the implied annual volatility of the S&P 500 from Eq. 5.6-56. Combining that with Eq. 5.6-61 and Eq. 5.6-60, we can get an implied total beta for 12 months:

$$\beta_{Tot,12M} = \frac{\sigma_{BSPA-Cape,12M}}{\sigma_{S\&P500,12M}} \approx \frac{56}{26} = 2.2 \tag{5.6-73}$$

To get the market beta, we need a forward view for the correlation between the ship values and the S&P 500. Since the "exchange option" required for that is not traded, our best estimate is the historic correlation between the two. The BCI has a relatively short history, but it has been almost perfectly correlated with the BDI and its predecessors which go back much further. Over the long term (25 years), the BDI and the S&P 500 have had a positive correlation of 0.5 [Research Reloaded 2009]. Assuming that this long term correlation holds going forward, we can apply it to Eq. 5.6-59 and Eq. 5.6-62 to get the market beta for the net 12 months:

$$\beta_{m,12M} = \rho_{BSPA-Cape,S\&P500,12M} \frac{\sigma_{BSPA-Cape,12M}}{\sigma_{S\&P500,12M}} \approx 0.5 \frac{56}{26} = 1.1 \tag{5.6-74}$$

This was a very approximate analysis using very crude assumptions, just to demonstrate how the alternative method would be applied with the appropriate data, and to

verify that the results using the comparables based approach are in the right ballpark. The alternative method would yield the betas as a function of time but in this approximation we have calculated the 1-year betas and assume they hold constant. The values were 2.2 and 1.1 for the market and total beta respectively. The earlier method based on comparables resulted in corresponding values of 2.46 and 1.34 which are very similar.

As we will derive in a later analysis, the implied volatility of the ship value is higher than the volatility of the revenues. That is because the volatility of profits is higher than the volatility of the revenues, since costs are relatively stable. The volatility of a new ship's value is currently about 67%. This is based on current option prices and a method that we develop later that combines Black-Scholes with portfolio theory and our valuation model. The volatility of 67% corresponds to a total beta of 2.6 and a market beta of 1.3 (using the historic correlation between the BCI and S&P 500 of 0.5 as a proxy). These results are even closer to the corresponding values of 2.5 and 1.3 derived by the comparables method. Note that using the volatility of old vessels will yield higher betas and the mismatch is explained by the fact that the comparables on which the betas are based are US-listed companies that own primarily new ships.

5.6.2.2 Cost of Debt

[Feldman 2005] Describes a method to estimate the cost of debt of a company based on Z-scores. The Z-score is calculated as a linear function of 5 financial ratios that can easily be determined from a company's financial statements. A table is then used to convert the Z-score into a credit rating and a corresponding yield spread over treasures as a function of maturity. The higher the Z-score, the higher the credit rating. The yield spread decreases with the Z-score and increases with maturity time.

This model, however, is not very relevant to shipping. Rather than issuing bonds, shipping companies typically borrow from banks at a spread over LIBOR. LIBOR is the inter bank rate and historical rates are shown in Fig. 5.6-9.

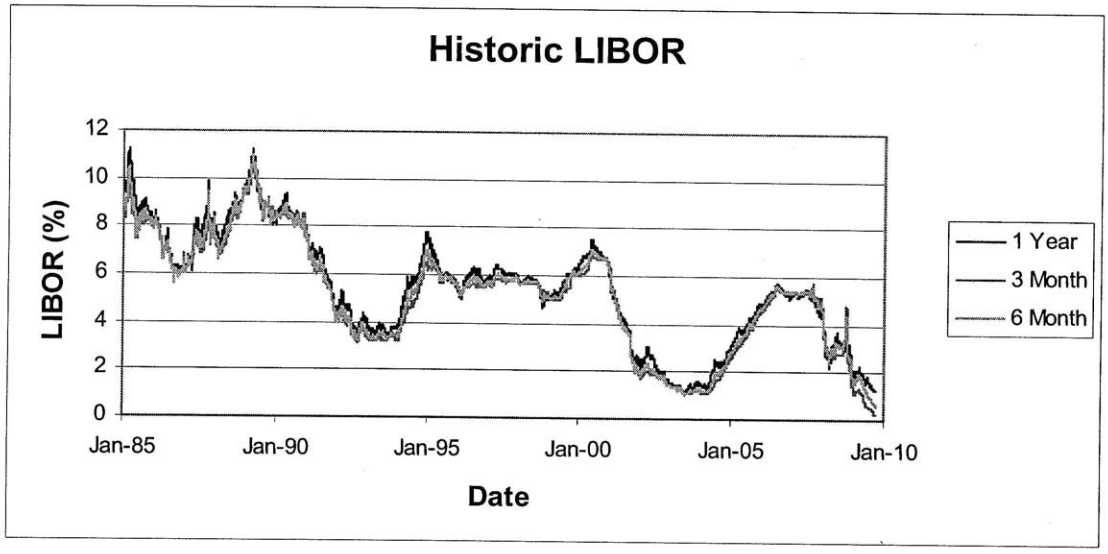


Fig. 5.6-9: Historic LIBOR Rates

The spread depends on the client and their relations with the bank but also on the credit markets. In a regular market (before the market crash), typical spreads were 90 to 150 basis points over LIBOR (perhaps 80 for exceptional clients). Today, the typical would be about 250 basis points and probably not lower than 200 basis points.

Since the spread is locked in for the whole duration of the loan, it applies until the full debt is repaid. The spread may be different if the owner chooses to refinance at a later date (after repaying the initial loan at today's spread). However, since there is no forward market for spreads, we will not attempt to make the spread a function of time. We will assume a constant spread of 2.5% over LIBOR, which will be a function of time. Therefore, we have:

$$r_D(t) = LIBOR(t) + r_{SPREAD} = LIBOR(t) + 2.5\% \qquad (5.6\text{-}75)$$

To get LIBOR as a function of time, we can look at what swaps are trading for. This will give us a forward looking estimate of interest rates, but also the interest rate at which each bank installment can be hedged by the owner, should they choose to do so. Fig. 5.6-10 shows historic Swap rates for various maturities.

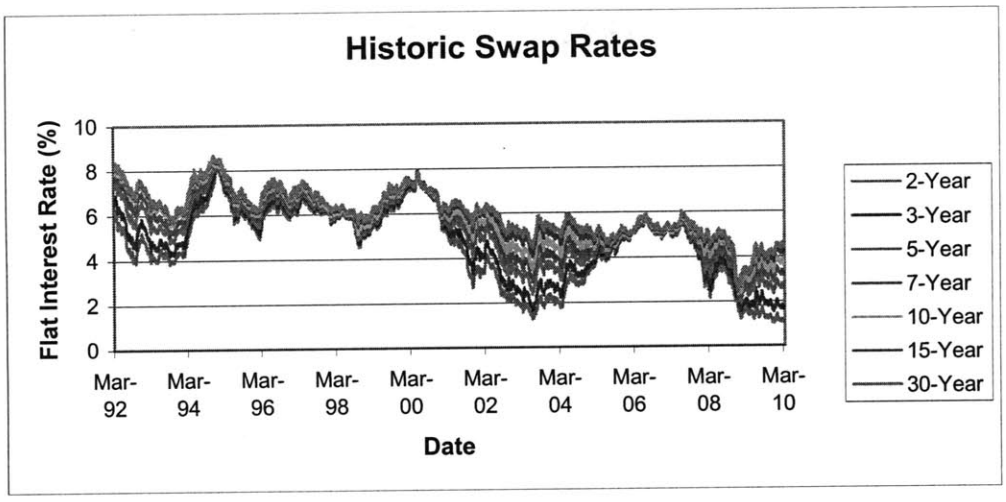


Fig. 5.6-10: Historic SWAP Rates

From Fig. 5.6-10, we see that in the most part, the forward curve on interest rates has been upward sloping. When the lines converge, it means that the forward curve was flat i.e. interest rates were relatively constant with tenure. For today's values, we will take the average between Oct-15-2009 and March-15-2010 so that the range is centered at the start of 2010. The next step is to construct the yield curve. We could use complicated smoothing functions for this purpose but given the shape of the curve and the frequency and location of the data points, simple linear interpolation is adequate. After interpolating through the swap rates, we add the 2.5% spread to get the cost of debt. The resulting cost of debt as a function of time is shown in Fig. 5.6-11, along with the corresponding swap rates.

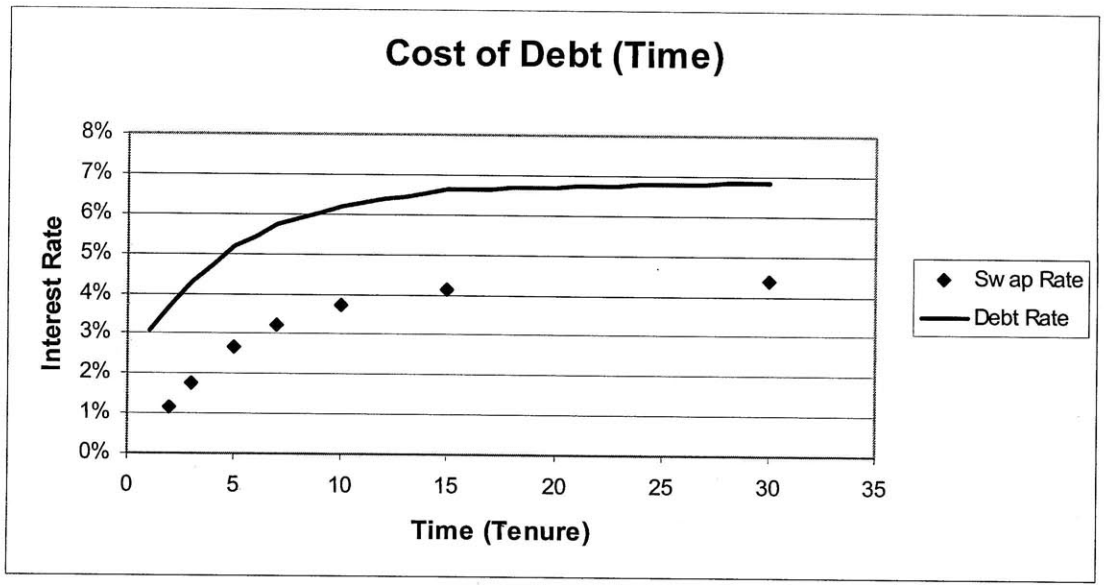


Fig. 5.6-11: Swap Rates and the cost of Debt as a function of time

5.6.2.3 Weighted Average Cost of Capital

The WACC for a ship at any point in time, is a function of the cost of equity, the cost of debt the leverage, and the tax rate. In our case, the tax rate is assumed to be zero, since shipping companies typically don't pay a tax on revenues. Having developed methods for obtaining the cost of equity and debt, the next step is to estimate the percentage of debt as a function of time.

Prior to the credit crunch, it was not uncommon for banks to finance up to 80% of the ship's value. Today, spreads are much higher but also loans are much harder to secure and cover a smaller percentage of the acquisition price. A bank will typically finance up to 70% of a new ship under a 10 year loan with a time horizon of 17 years. That means that the percent debt will begin at 70% and decline linearly with a gradient that would bring it down to zero when the ship would be 17 years old, but a balloon payment of the outstanding loan will be paid and bring the debt down to zero when the ship is 10 years old. Typically, the owner will refinance when the balloon payment is due, so the debt decrease will be gradual.

The owner may choose to refinance the ship again and again when the time comes under terms that will prevail at the time. Furthermore, the ship value will fluctuate with the market so the percent of debt will also fluctuate. Loan covenants typically apply, which require that the outstanding loan remains below 70% of the charter-free market value of the ship. As the debt is repaid, chances of that occurring decrease but many of these covenants were breached when ship values collapsed towards the end of 2009. When that happens, an owner may be called to pay down more of the principal that would normally be due. However, for valuation purposes, using the currently available data, it would be most appropriate to assume that the debt will begin at 70% and decline linearly to zero when the ship is 17 years old.

Between 2004 and 2008, when market values were very high, banks required accelerated principal repayments in order to bring down the debt levels to the historic average ship value. This was done as a precaution to minimize the chances of a covenant breach, even though evidently it was not enough. Under these circumstances, the debt to equity ratio is not a single linear function of time. The appropriate method to deal with this for a valuation has been described in Section 2.9.

For a 10-year old and a 15-year old vessel, the bank will typically finance 60% of the acquisition price with a time horizon of 20 years (ship age). The percentage debt in this case is approximated as a linear decrease from 60% at the start when the ship is 10 or 15 years old, to 0% after 10 or 5 years when the ship is 20 years old. For a 5-year old ship, the bank will probably finance 70% of the ship value, and a time horizon of 18.5 years has been assumed (average of new ship and 10 year old ship). For a 20-year old ship, we will assume 100% equity throughout the ship's life (no bank loan).

Using the above approximations, we have the percentage of debt as a function of time for a given ship. Since the value of the ship is composed of debt and equity, we also have the percent of equity as a function of time.

$$w_D(t) + w_E(t) = 1 \qquad (5.6\text{-}76)$$

Now, having the weight of debt and equity as a function of time, as well as the average cost of equity from Section 5.6.3.1 and the cost of debt from Section 5.6.3.2, we can combine them to get the weighted average cost of capital as a function of time.

$$r_{WACC}(t) = w_e(t)r_e + w_D(t)\left(1-\tau\right)r_D(t) \qquad (5.6\text{-}77)$$

The bracket including the tax rate accounts for interest tax shields since interest is tax deductible. In our case, since the tax rate is taken to be zero, we have:

$$r_{WACC}(t) = w_e(t)r_e + w_D(t)r_D(t) \qquad (5.6\text{-}78)$$

Since bank installments are typically paid annually or biannually, for simplicity we will assume the percentage of debt and equity to be constant within each year. Since LIBOR would theoretically be hedged separately for each bank installment, it follows that the cost of debt would have to be constant within each year. For consistency, we also make the cost of equity and hence the weighted average cost of capital constant within each year.

5.6.2.4 Accounting for Inflation

Two ways are generally used to account for inflation in discounted future cash flows. The first one is to account for inflation in the numerator terms, i.e. the projected revenues and costs. The second way is to account for it in the discount factor and leave the numerator terms as real projections.

Shipping freight rates and most of the terms in the numerator are not directly related to inflation. The markets are cyclical and are governed by factors such as supply demand, congestion, technological improvements etc. However, the cost of debt is directly affected by inflation because the role of interest rates is partly to offset the decline in the value of money. A lender will demand a higher return if inflation expectations are high. Similarly, the return

on equity is higher because an investor will require a higher return on the investment in periods of high inflation.

Today, inflation is low, so accounting for inflation will not have a major impact on the valuation. However, it is important to include it in the model which should be applicable regardless of chosen time period. Given the above discussion, it makes more intuitive sense to account for it in the discount factor.

Since shipping costs and revenues are denominated in dollars, ship owners have access to American debt, and companies are increasingly being listed in American stock exchanges, US inflation would be the most appropriate to use. Furthermore, that is most convenient because we can extract a forward view on inflation for each time period in the future from the TIPS / T-Bill yield differences. To adjust the discount rate, we simply subtract the inflation values from the return on debt and equity for each corresponding time period.

A forward view on US inflation can be extracted from the relative pricing of TIPS and regular US T-Bills. The difference between the two prices is not only an expectation of future inflation but also a level that can be hedged.

TIPS were introduced in 1997. The principal in TIPS is adjusted semiannually to reflect rises in the CPI, but it is NOT reduced in periods of deflation (the government guarantees the face value). They are free of fees and commissions so friction costs are very limited when hedging against inflation. As of February 22nd 2010, the yield on the new 30-year TIPS was 2.17%, while the 30-year nominal issue had a yield of 4.63% [Swedroe 2010]. This implies a US inflation rate of 2.46% over the next 30 years. We could use the yield curve of TIPS and T-Bills to determine the implied inflation for each year going forward.

Table 5.6-1 shows current rates for TIPS and T-Bills with corresponding tenures published by the United States Department of the Treasury. Average values were taken over the period Feb-28 to Mar-23 2010. The difference between corresponding values, which is also shown in Table 5.6-18, is an estimate of average inflation over the equivalent period as the tenure.

Tenure	TIPS	T-Bills	Inflation
5yr	0.48%	2.37%	1.89%
7yr	1.01%	3.11%	2.10%
10yr	1.46%	3.68%	2.22%
20yr	1.96%	4.46%	2.50%
30yr	2.14%	4.61%	2.48%

Table 5.6-18: Average Feb-28-2010 until March-23-2010 [USDT 2010a, USDT 2010b]

Based on Table 5.6-18, future projections of inflation are relatively flat. This means that we can reasonably use linear interpolation to infer values of average inflation for the years between the available tenure lengths. However, we need to make some assumptions regarding values between now and 5 years, which is our first data point. Average inflation for 2009 was -0.34% (deflation), and the corresponding values for January and February of 2010 were 2.63% and 2.14% respectively [CPS 2010]. Table 5.6-19 shows a summary of average US inflation forecasts for years 2010 (our year 1) and 2011 (our year 2) from 14 independent studies, along with the average for each year (taking the range mid point for the Federal Reserve study).

To estimate average inflation for durations less than 5 years, we can extrapolate our data backwards using the inflation levels for 5 years and 7 years (our first two data points). This results in an estimated inflation of 1.46% for year 1 and 1.57% year 2 which is remarkably close to the average forecasted values. It therefore seems an accurate enough approach for our purposes.

Using this method, we can plot the term structure of inflation which is shown in Fig. 5.6-12 along with the TIPS/T-Bill yield spreads from Table 5.6-18. Note that the values read off the ordinate indicate the average inflation from today until the time measured off the abscissa, not the inflation at that point in time.

	Inflation Forecast	
Source	**2010**	**2011**
[UMICH 2010]	1.10%	1.40%
[WFSE 2010]	1.30%	1.70%
[WSJ 2010b]	1.90%	
[Reuters 2010]	1.30%	1.60%
[Bloomberg 2010]	1.20%	
[CNBC 2010]	1.50%	1.70%
[Fed. Reserve 2010]	1.1%-1.7%	1%-1.9%
[SPF 2010]	1.30%	1.50%
[OMB 2010]	1.30%	1.70%
[CBO 2010]	1%	0.90%
[USAToday 2010]	1.80%	
[ABA 2010]	1.20%	
[MorganStanley 2010]	1.40%	1.90%
[Livingston 2010]	2.20%	1.80%
Average	**1.42%**	**1.57%**

Table 5.6-19: Inflation Forecasts from Various Sources

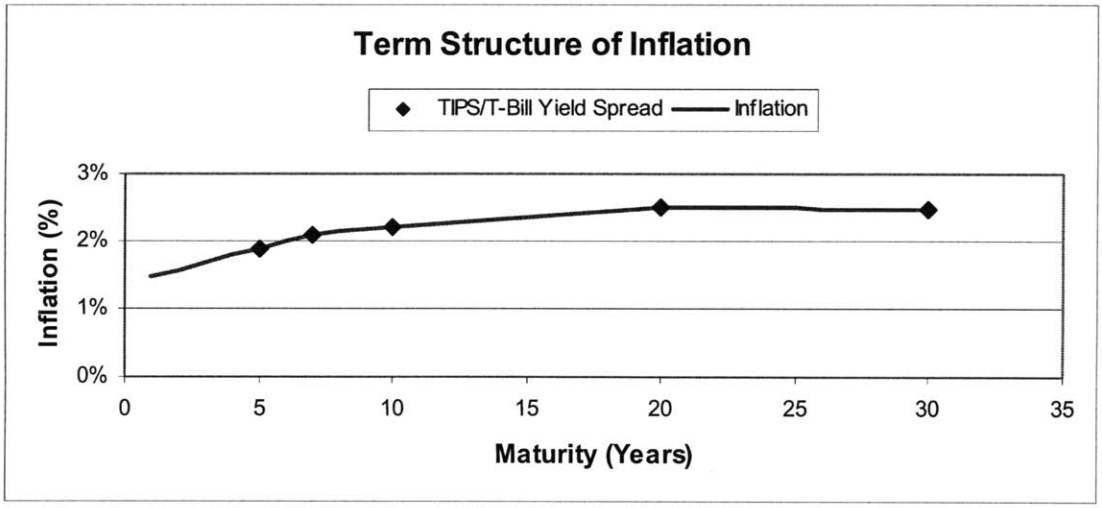


Fig. 5.6-12: Inflation as a Function of Tenure Based on TIPS/T-Bill Yield Spreads

For consistency with the weighted average cost of capital calculation, we will assume the inflation to be constant within each year. We can then obtain an inflation adjusted weighted average cost of capital for each year by subtracting the inflation (based on Fig. 5.6-11) from the initial weighted average cost of capital of the corresponding year:

$$DF = \frac{\left(1+I(t)\right)^t}{\left(1+r_{WACC}(t)\right)^t} = \frac{1}{\left(1+r'_{WACC}(t)\right)^t}$$
$$\Rightarrow r'_{WACC}(t) = \frac{r_{WACC}(t) - I(t)}{1+I(t)} \approx r_{WACC}(t) - I(t) \qquad (5.6\text{-}79)$$

Where: $r_{WACC}(t)$: Weighted average cost of capital (constant within each year)

$r'_{WACC}(t)$: Inflation-adjusted WACC (constant within each year)

$I(t)$: Inflation from yield spread of TIPS and T-Bills (constant within each year)

5.6.2.5 Incorporating the Hazard Function

In Section 4.5, we developed the hazard function due to cracks throughout the ship's life. This corresponds to a probability that the ship will undergo an emergency repair or a total loss. The purpose of this section is to account for that effect by incorporating the hazard function as a credit spread over the inflation adjusted weighted average cost of capital. This will give us the discount rate throughout the ship's life.

The hazard function has been calculated continuously as a function of the ship's age, while the inflation adjusted weighted average cost of capital is a function of time and will be constant throughout each year. Since we have chosen months as the time increment (i.e. discounting each months unlevered free cash flows to the present), after incorporating the

hazard function, we will have the discount rate for a given initial ship age, as a function of time in months.

In order to incorporate the hazard function into the discount rate, we have to use continuous compounding as opposed to monthly. Changing to continuous compounding would allow us to use a discount rate that is a function of time and to incorporate the hazard function into it. Using continuous compounding, the present value of a cash flow "x_T" at time "T" is given by:

$$PV(x_T) = \lim_{n\to\infty}\left[\frac{x_T}{\left(1+\frac{r_n}{n}\right)^{nT}}\right] = x_T e^{-r_\infty T} \qquad (5.6\text{-}80)$$

Where:

x_T:	Cash flow at time T
T:	Time in Years
$PV(x_T)$:	Present value of cash flow at time "T"
n:	Number of compounding periods per year
r_n:	Annual interest compounded "n" times per year
r_∞:	Constant continuously compounded annual interest rate

When the interest rate changes over time, we can begin by expressing the continuously compounded return as:

$$r_t = \frac{x'}{x} \qquad (5.6\text{-}81)$$

Where

r_t:	Continuously compounded interest rate (varies with time)
x:	Principal amount
x':	Return on principal over an infinitesimal time increment (its-

time derivative)

By simple integration, it follows that:

$$\int_0^T r_t dt = \int_{PV(x_T)}^{x_T} \frac{dx}{x} = \ln\left(\frac{x_T}{PV(x_T)}\right) \tag{5.6-82}$$

Hence, the present value "x_T",is given by:

$$PV(x_T) = x_T e^{-\int_0^T r_t dt} \tag{5.6-83}$$

By solving Eq. 5.6-69, we get the equivalent annual continuously compounded interest rate "r_t" is given in terms of the annual interest rate "r" and number of compounding periods per year "n" as follows:

$$r_t = n \ln\left(1+\frac{r}{n}\right) \tag{5.6-84}$$

Now, recall the survivor function which gives us the probability of survival until time "t" as a function of the hazard function:

$$S(t)e^{-\int_0^t \lambda(\tau)d\tau} \tag{5.6-85}$$

Where: $S(t)$: Survivor function (probability of survival until time "t")

$\lambda(\tau)$: Hazard function (function of time variable τ)

Assuming we want to discount a cash flow at time "t" to the present at the risk free rate, while accounting for the probability of failure (due to the hazard function). The expected present value will be determined by combining Eq. 5.6-72 and 5.6-74 as follows:

$$E\left[PV(X)\right] = S(t)PV(X) = e^{-\int_0^t \lambda(\tau)d\tau} Xe^{-\int_0^t r_f(\tau)d\tau} = Xe^{-\int_0^t \left[r_f(\tau)+\lambda(\tau)\right]d\tau} \tag{5.6-86}$$

Since we are taking the present value equal to the discounted expected returns, we are implicitly assuming a risk neutral investor with a linear utility function. Instead of calculating the present value of the expected returns, one could calculate the present value of the expected utility (in "utils") by assuming a utility function for the investor, and then convert that into $ through the inverse utility function.

A typical hazard function of a risk averse investor starts linear and diverges as more is at stake. This means that investors are approximately risk neutral when little is at stake, which is intuitive. An example often used is the exponential utility model:

$$u = 1 - e^{-cx}, c \sim 10^{-5} \tag{5.6-87}$$

Where
- x: Cash flow "x"
- u: Utility of cash flow "x"
- c: Constant that defines the risk averseness and is typically in tens of millionths

The Absolute Risk Aversion (ARA) of a utility function is equal to the second derivative of the utility function, divided by its first derivative:

$$ARA = -\frac{u''}{u'} \tag{5.6-88}$$

Note that the exponential utility model displays a constant risk aversion which is equal to "c". This is not true for all utility functions.

The expected present value model, can be modified by replacing λ with λ^* in order to account for the investor's risk-averseness. However, this can be avoided as long as the investor is adequately diversified and as long as the hazard function is not too big relative to the risk free rate. In our case, we can make these assumptions and avoid predicting the utility function of investors, particularly because the hazard function will be small relative to the discount rate.

Having discussed the basic principles and assumptions, we begin by converting the annual inflation adjusted weighted average cost of capital to an annual continuously compounded rate:

$$r'_{WACC_t} = n \ln\left(1 + \frac{r'_{WACC}(t)}{n}\right) \qquad (5.6\text{-}89)$$

Where:

$r'_{WACC}(t)$: Annual inflation adjusted weighted average cost of capital

r'_{WACC_t}: Annual continuously compounded inflation adjusted WACC

n: Number of compounding periods per year (typically equal to 1)

t: Time (in years)

Based on Eq. 5.6-72, we can then calculate the discount factor resulting from the continuously compounded inflation adjusted WACC. That is the factor by which a cash flow at time "t" is multiplied to give its present value. It is important to note that the weighted average cost of capital is calculated for "t" to start with, so it is constant and can be removed from the integral. Therefore, we have:

$$DF(t) = \frac{1}{\left(1 + r'_{WACC}(t)\right)^t} = e^{-\int_0^t r'_{WACC_t}(t)d\tau} = e^{-r'_{WACC_t}(t)t} \qquad (5.6\text{-}90)$$

Since the hazard function assumes a monthly time interval, and since the integral boundaries (t) will also measured in months instead of years, for consistency, we have to convert the continuously compounded annual rate to a continuously compounded monthly rate. To calculate that, we consider the present value of a payment "x" one year from today:

$$PV(x_{12m} = x_{1y}) = e^{-12 r^m_{WACC_t} * x_{12m}} = e^{-r_{WACC_t} * x_{1y}} \qquad (5.6\text{-}91)$$

Where: $x_{12m} = x_{1y}$: Cash flow in one year

$PV(x_{12m} = x_{1y})$:Present value of cash flow in one year

$r'^m_{WACC_t}$:Monthly inflation adjusted continuously compounded WACC

r'_{WACC_t} :Annual inflation adjusted continuously compounded WACC

It follows that:
$$r'^m_{WACC_t} = \frac{r'_{WACC_t}}{12} \qquad (5.6\text{-}92)$$

The discount rate, with "t" measured in months becomes:

$$DF(t) = e^{-\int_0^t r'^m_{WACC_t}(t)d\tau} = e^{-r'^m_{WACC_t}(t)t} \qquad (5.6\text{-}93)$$

Now, to incorporate the hazard function, we have to note that in our case, we have three possibilities; a total loss, an emergency repair lasting 6 months and an emergency repair

lasting 2 months. Given that a failure occurs, the probabilities of being in each of the three categories has been estimated as 1/18, 9/36 and 25/36 respectively. Using the theory described above, the discount factor becomes:

$$DF_t = e^{-\int_0^t \left[r'^{m}_{WACC_t}(t) + \frac{1}{18}\lambda(\tau) \right] d\tau - \frac{9}{36}\int_{t-5}^{t} \lambda(\tau) d\tau - \frac{25}{36}\int_{t-1}^{t} \lambda(\tau) d\tau} \tag{5.6-94}$$

Again, since the continuously compounded inflation adjusted WACC has been pre-defined for time "t", it is constant and can be removed from the integral. This leaves us with:

$$DF_t = e^{-\left[r'^{m}_{WACC_t}(t)t + \frac{1}{18}\int_0^t \lambda(\tau) d\tau + \frac{9}{36}\int_{t-6}^{t} \lambda(\tau) d\tau + \frac{25}{36}\int_{t-2}^{t} \lambda(\tau) d\tau \right]} \tag{5.6-95}$$

We can proceed to derive the spread on the continuously compounded inflation adjusted weighted average cost of capital as follows:

$$DF(t) = e^{-\left\{ r'^{m}_{WACC_t}(t) + \frac{1}{t}\left[\frac{1}{18}\int_0^t \lambda(\tau) d\tau + \frac{9}{36}\int_{t-6}^{t} \lambda(\tau) d\tau + \frac{25}{36}\int_{t-2}^{t} \lambda(\tau) d\tau \right] \right\} t} = e^{-\left[r'^{m}_{WACC_t}(t) + S_t(t) \right] t} \tag{5.6-96}$$

The spread on the continuously compounded inflation adjusted WACC is given by:

$$S_t(t) = \frac{1}{t}\left[\frac{1}{18}\int_0^t \lambda(\tau) d\tau + \frac{9}{36}\int_{t-6}^{t} \lambda(\tau) d\tau + \frac{25}{36}\int_{t-2}^{t} \lambda(\tau) d\tau \right] \tag{5.6-97}$$

Therefore, the monthly continuously compounded discount rate is given by:

$$i_t^m(t) = r'^{m}_{WACC_t}(t) + S_t(t) \tag{5.6-98}$$

This can be converted to an annual continuously compounded discount rate as follows:

$$i_t(t) = 12 i_t^m = 12\left(r'^m_{WACC_t}(t) + S_t(t)\right) = r'_{WACC_t}(t) + 12 S_t(t) \qquad (5.6\text{-}99)$$

Recall that we can relate the continuously compounded discount rate to a discretely compounded discount rate as follows:

$$i_t(t) = n \ln\left(1 + \frac{i(t)}{n}\right) \qquad (5.6\text{-}100)$$

By combining Eq. 5.6-88 and 5.6-89, we can compute the discretely compounded annual discount rate as follows:

$$i(t) = n\left(e^{\frac{i_t(t)}{n}} - 1\right) = n\left(e^{\frac{r'_{WACC_t}(t) + 12 S_t(t)}{n}} - 1\right)$$

$$= n\left[\left(1 + \frac{r'_{WACC}(t)}{n}\right) e^{\frac{12 S_t(t)}{n}} - 1\right] = \left(n + r'_{WACC}(t)\right) e^{\frac{12 S_t(t)}{n}} - n \qquad (5.6\text{-}101)$$

Unfortunately, it is not possible to convert the spread over the continuously compounded interest rate to a spread over the annual discount rate analytically without it being a function of the actual discount rate. However, it can be calculated in retrospect by subtracting the inflation adjusted weighted average cost of capital from the annual discount rate.

Since our values for cost of equity and debt are based on annual compounding, we have n=1, so Eq. 5.6-91 simplifies to:

$$i(t) = \left(1 + r'_{WACC}(t)\right) e^{12 S_t(t)} - 1 \qquad (5.6\text{-}102)$$

Where: $r'_{WACC}(t) = w_e(t) r_e + w_D(t) r_D(t) - I(t)$

$$S_t(t) = \frac{1}{t}\left[\frac{1}{18}\int_0^t \lambda(\tau)\,d\tau + \frac{9}{36}\int_{t-5}^t \lambda(\tau)\,d\tau + \frac{25}{36}\int_{t-1}^t \lambda(\tau)\,d\tau\right]$$

We have thereby developed a formula that combines the hazard function with the inflation adjusted WACC to give a hazard and inflation adjusted WACC or in other words the discount rate as a function of time. Note that this will vary from month to month even though the inflation adjusted WACC is taken to be constant throughout the year. The hazard function adds a credit spread on the discount rate due to the possibility of off-hire time from crack failures.

Now, we can proceed to get a preliminary estimate of this spread as a function of the inflation adjusted WACC. We will assume that the inflation adjusted WACC is constant throughout the ship's life. Then we calculate the average difference of the final discount rate from the inflation adjusted WACC over the ship's life. The analysis is performed for various ship ages and inflation adjusted WACC levels and the results are presented in Table 5.6-20.

	Inflation Adjusted WACC					
Age (years)	**0%**	**5%**	**10%**	**15%**	**20%**	**Average**
0	0.10%	0.11%	**0.11%**	0.12%	0.12%	**0.11%**
5	0.12%	0.12%	**0.13%**	0.13%	0.14%	**0.13%**
10	0.13%	0.14%	**0.15%**	0.15%	0.16%	**0.15%**
15	0.15%	0.16%	**0.16%**	0.17%	0.18%	**0.16%**
20	0.15%	0.16%	**0.17%**	0.17%	0.18%	**0.17%**
25	0.13%	0.14%	**0.15%**	0.16%	0.16%	**0.15%**

Table 5.6-20: Spread over constant discount rate to account for the off-hire possibility from crack failures

According to Table 5.6-20, we see that the average credit spread ranges from 0.1% to 0.2% over a wide range of reasonable inflation adjusted WACC levels and that the using a value of 0.15% would be a good approximation. The spread increases with the WACC and also with ship age until the age of about 20. Note that these are average values throughout the ship's remaining life. Maximum spreads for particular time periods can be orders of magnitude larger, due to the shape of the hazard function.

It is also important to bear in mind that this does not account for the full effect of cracks. This simply accounts for the possibility of off hire time due to crack failures. The expected cost of repairing crack failures is a full separate term on the numerator of our valuation formula, while the cost of repairing cracks in scheduled repairs is incorporated into the repair costs term (also in the numerator) and has been quantified separately in section 5.1.

An equivalent spread over the discount rate to account for the full effect of cracks can be determined after we carry out the valuation. This can be done by setting the discount rate to arrive at the same valuation after excluding the relevant numerator terms that incorporate expected costs due to cracks.

5.6.3 The Numerator Terms

5.6.3.1 Revenues

As discussed earlier, we will use futures to quantify the revenues because futures rates can be hedged. Futures only span out for 5 years, so we have to make some kind of projections beyond that. The forward curve flattens out towards the end and we also have rates on recent time charters of approximately 10 years, which can be used as a guidance.

An argument could be made that the revenues for the first 5 years can be hedged through futures, so they should be discounted at the risk free rate, whereas revenues beyond that have a greater risk and therefore require a different approach. In order to make that

assessment, we need to examine the relationship between the forward and the spot market. Hedgers and speculators trade in the futures markets and together, their actions determine the basis, which is the difference between the spot and the forward price. [Clark et al 2001] summarize the elements that motivate their actions and ultimately determine the basis as follows:

- Expected evolution of the spot price
- Carrying cost
- Convenience returns
- Speculators premium
- Systematic risk premium

As discussed by [Clark et al 2001], the above elements are not necessarily present simultaneously at all times, while the basis converges to zero at maturity. In the shipping industry, it turns out that the first element (market expectation) heavily outweighs the others meaning that the futures prices reflect the market expectations. This is mainly due to the high volatility of the shipping market, while factors such as a high orderbook, an iron-ore price agreement or an expansion plan announcement by a country like China, imply changes in supply or demand that can have a drastic impact on future freight rates. This makes the effect of market expectation very high, while the effects of the other factors are very small by comparison.

The underlying asset is ton-miles for which there are no storage costs, no dividends or holding benefits, and a limited risk of a stock out (the market rates vary but there generally is a supply of ships). Consequently, carrying costs and convenience returns do not come into play.

The speculators premium is based on the hypothesis of normal backwardation suggested by economists John Maynard Keynes and John Hicks. They argued that the natural hedgers of a commodity will hold a net short position and will accept loosing money on their positions since they enter contracts to reduce risk. Speculators on the other hand have to expect a profit to enter into a contract and they hold a net long position. This gives rise to a premium by which futures rates trade lower than the market expectation.

One reason why this is not relevant in shipping is that, unlike other commodity futures markets, the shipping futures market is very small compared to the physical market. The other important reason is that there are hedgers on both sides of the trade with relatively equal negotiating power. Ship owners and shipping banks (who finance ship acquisitions) go long on futures to hedge their owned ton-miles. Charterers and cargo owners go short on the futures market to hedge their need for ton-miles. Speculators are few in comparison and generally cannot command a premium against those two groups of natural hedgers who generally have no trouble finding a counterpart.

The systematic risk premium is to compensate the investor for taking on systematic risk by holding on to an asset whose value will vary and is correlated to some extent with the market. By discounting the expected market value with the CAPM rate, and the futures value with the risk free rate, you can derive the differential between the two, which is the systematic risk premium. Based on the analysis by [Copeland & Antikarov 2001], we can say:

$$PV = \frac{E(S_t)}{(1+r_{CAPM})^t} = \frac{E(S_t) - SRP}{(1+r_f)^t} = \frac{F_t}{(1+r_f)^t} \qquad (5.6\text{-}103)$$

$$E(S_t) = F_t\left(\frac{1+r_{CAPM}}{1+r_f}\right) = F + SRP \qquad (5.6\text{-}104)$$

Where: $E(S_t)$: Expected value under the objective measure (not risk-neutral)

F_t: Futures price

r_{CAPM}: CAPM returns

r_f: Risk-free rate

PV: Present value

SRP: Market price of the risk in CAPM (Systematic Risk Premium)

Eq. 5.6-92 shows that the expected market price is higher than the futures price by the systematic risk premium which accounts for the variability of the price and its correlation to the market (meaning it is an un-diversifiable risk).

While hedging eliminates the variability of the spot market, the alternative is typically a period time charter which has the same effect. It is not direct exposure to the high volatility of the daily spot rate, so hedging does not eliminate that risk. As discussed earlier, the time charter rate for a year in the future can generally be hedged with a counterpart who needs to hedge their need for the equivalent ton-miles; therefore, no premium is required to eliminate the variability of time charter rates.

One could argue that by hedging also eliminates credit risk (charter default). However, additional cash is required for marking-to-market. This is an alternative to the cost of insuring against the charterer default risk. As market volatility increases, both the charterer default risk increases and the required cash for marking-to-market increases. Note that we will use the futures as a proxy of the expectation for the time charter rates with a reputable charterer. Surely, there may be higher expectations for rates with risky charterers.

Another argument could be made that the risk premium associated with the ship earning the spot market rate (operating risks) should be applied when discounting physical rates but not futures rates. In fact, even when the earnings are hedged, the shipowner still bears these risks. From the long position in the future, the owner receives the futures price and pays the market price. Then the owner relies on the ship to get back the spot market rate. Thereby, the shipowner is still exposed to the same ship operating risk as they would be had they not hedged the earnings in the first place. For that reason, the ship risk premium should be applied to the discount rate of the earnings regardless of whether they are hedged or not. What follows is a short mathematical explanation:

$$\frac{E(S_t)}{\left(1+r_{\lambda_S}\right)^t} \equiv \frac{E(S_t)-\lambda_S}{(1+r)^t} \qquad (5.6\text{-}105)$$

Where: λ_S : Risk premium to account for ship risks

r: Discount rate without ship risks

r_{λ_S} : Discount rate adjusted for ship risks

As with the hazard function in the discount rate, we are incorporating the expected default losses as a risk premium of default by treating the ship operating risks or the hazard function as a fictitious credit risk. This is essentially merging the theories presented by [Copeland & Antikarov 2001] for incorporating the financial risk and by [Duffie and Singelton 2003] for incorporating the credit risk.

Now consider the present value of ship revenues, of a long futures position, and of a hedged ship's revenues, which is the sum of the two.

$$PV\left(Ship\,\mathrm{Re}v\right)=\frac{E\left(S_t\right)}{\left(1+r_{\lambda_S}\right)^t}=\frac{E\left(S_t\right)-\lambda_S}{\left(1+r\right)^t} \tag{5.6-106}$$

$$PV\left(LongF\right)=\frac{F_t-E\left(S_t\right)}{\left(1+r\right)^t} \tag{5.6-107}$$

$$PV\left(Ship\,\mathrm{Re}v\right)+PV\left(LongF\right)=\frac{F_t-E\left(S_t\right)}{\left(1+r\right)^t}+\frac{E\left(S_t\right)-\lambda_S}{\left(1+r\right)^t}$$

$$=\frac{F_t-\lambda_S}{\left(1+r\right)^t}=\frac{F_t}{\left(1+r_{\lambda_S}\right)^t} \tag{5.6-108}$$

Where: $PV\left(Ship\,\mathrm{Re}v\right)$: Present value of the expected earning of the un-hedged ship

$PV\left(LongF\right)$: Present value of a long futures position

This discussion implies that futures rates are a good indicator of market expectations. To test this hypothesis, we can compare historical futures rates and physical market rates. Note that it is meaningless to regress futures rates that are known in advance with the actual

spot rates that materialize during the futures period, because market expectations keep changing. The right way is to compare time charter rates and futures rates on the same day for equivalent periods in the future. However, we can expect the time charter rates to be slightly higher because there is typically a grace period for the ship re-delivery, meaning that a small optional period is included at the end of the charter. The analysis was carried out in Section 2.8 and the difference between futures and charter rates was statistically insignificant. An extensive study was carried out by [Alizadeh and Nomikos 2009] who also found that futures are the best predictors of market rates meaning which essentially means that market expectations are the dominant factor affecting the forward curve.

Futures rates will be applied in place of the revenue projections, and discounted at the rate that incorporates all the risk premiums. Another way to look at this is that futures are used as a means of getting the best forecast of the earnings for an un-hedged vessel. Since the futures rates are equivalent to the market expectations, the predicted revenues that would be used in valuing an un-hedged ship would be the same as those for valuing a hedged ship (equal to the futures rates). Since hedging is done at zero cost, the value of the hedged ship should be identical as that of the hedged ship. In other words, the discount rate used to value both would have to be the same and equal to the risk adjusted weighted average cost of capital.

The futures rates are for a Baltic Cape which is defined as a 172,000dwt vessel up to 7 years old. Futures rates are published for months, quarters and whole years. By applying the no-arbitrage condition, we can deduce the futures level for various periods from the futures levels of other overlapping periods. For example, the futures rate for one year is related to the futures rates of its constituent months and the futures rates of its constituent quarters as follows:

$$F^{Y}\left(t,T_{y}\right)=\sum_{q=1}^{4}\frac{e^{-r_{f}\left(T_{q}-t\right)}}{\sum_{q=1}^{4}e^{-r_{f}\left(T_{q}-t\right)}}F^{Q}\left(t,T_{q}\right)=\sum_{m=1}^{12}\frac{e^{-r_{f}\left(T_{m}-t\right)}}{\sum_{m=1}^{12}e^{-r_{f}\left(T_{m}-t\right)}}F^{M}\left(t,T_{m}\right) \qquad (5.6\text{-}109)$$

Where: r_f : Continuously compounded risk free interest rate

t: Time variable

T: Time of maturity

m: Index that denotes the month

q: Index that denotes the quarter

$F^{Y}\left(t,T_{y}\right)$: Futures level for calendar year "y" with maturity T_{y}

$F^{Q}\left(t,T_{q}\right)$: Futures level for quarter "q" with maturity T_{q}

$F^{M}\left(t,T_{m}\right)$: Futures level for month "m" with maturity T_{m}

Eq. 5.6-96 must hold or else, someone can make money without any risk simply by selling and buying the same underlying portfolio of futures at different prices. We can apply this principle to rates of long period time charters and futures to obtain implied forward estimates of freight levels beyond the 5 years. Since capes are typically chartered for a year or so, we will deduce a freight level for each year and keep it constant throughout the whole year. For example, we will use the rates from BCI futures for calendar years 2010, 2011, 2012, 2013 and 2014. Since these are published daily, we will take the average value for each from the beginning of November 2009 to the end of February 2010 (in order for our range to be centered at the beginning of the year). The results are summarized in Table 5.6-21. There has been very little variation in the values throughout this time interval as indicated by the standard deviation in the third column of Table 5.6-21.

Calendar Year	Futures Rate	Standard Deviation / Mean
2010	$33,773	7.6%
2011	$26,522	3.2%
2012	$25,638	3.1%
2013	$25,203	3.0%
2014	$24,927	2.9%

Table 5.6-21: Average Futures Rates for Calendar Years 2010 to 2014 from Start Nov'09 to End Feb'10 Based on data from [Clarksons 2010]

Before extending the earnings projections, we have to account for the reduction factor in earnings due to age. In Section 4.6.3, we carried out this analysis based on 10-year historic data and determined that the average earnings of a 10-year, 20-year and 30-year old ship to the earnings of a new ship were on average approximately 80%, 70% and 60%. However, these have been affected by the fact that in the very high market, due to the shortage of supply, old ships were commanding relatively higher rates than they normally would.

Today, the earnings of older vessels amount to a smaller percentage of the earnings for a new vessel because there is no shortage of ships. Given the massive orderbook, it is most likely that there will be no real shortage of ships going forward either. It is therefore appropriate to repeat the analysis using post-crash data only. As of March 22, 2010, 28 time charter fixtures have been reported so far in 2010 and 106 for 2009 by Clarksons Shipbrokers. These range from 4 months to 4 years. By comparing charters of similar periods fixed at similar times for ships of different ages, we can repeat the analysis and produce the same results as those used in Section 4.6.3, based on recent data. The results are summarized in Table 5.6-22.

AGE (Years)	Reduction Factor (% of New)
0-5	100%
10	95%
15	90%
20	80%
25	65%
30	50%

Table 5.6-22: Reduction Factor in Earnings Relative to a New Ship as a Function of Ship Age – Based on data from [Clarksons 2010]

Linear interpolation is used between the values of Table 5.6-22 to obtain reduction factors for intermediate ages. Note that we have just quantified gross earnings, on which there is typically an address commission of 3.75% and a broker commission of 1.25%. Therefore, the net earnings, which will be used as the revenues projections in our model, are equal to 95% of the futures values after accounting for the age discount.

Having quantified the levels for the first 5 years for a new ship, the earnings discount factor as a function of ship age, and the commissions, the only thing that is left is projecting the earnings for a new ship from 6 years onwards. Since the futures curve flattens out, one approach would be to simply project the Cap 14 futures rates going forward. However, since the terminal value of earnings will have a significant impact on the valuation, it would be best to obtain a more accurate estimate using long term charters. Of the following list, the first three charters were fixed in January 2010 and the 4th one in May 2009:

1. 12 Year charter at $27,431/day by Chinese charterer with delivery in 1 year
2. 10 Year charter at $24,000/day by major charterer with delivery in 2 years
3. 10 Year charter at $23,500/day by major charterer with delivery in 2 years and only 3% total Commission
4. 15 Year charter at $26,500/day by unknown charterer with prompt delivery

If we account for the commission difference, charters 2 and 3 are almost identical and equivalent to a $24,000/day charter from 2012 to 2022. Having the rates for various tenures, we need to satisfy the no-arbitrage constraint (as in Eq. 5.6-96), but we also need an additional constraint distribute values to each individual year. An example is the flexible functional form suggested by [Pilipovic 2007]:

$$T(t,T) = Ae^{-a_1(T-t)} + B\left(e^{-a_2(T-t)} - e^{-a_1(T-t)}\right) + C\left(e^{-\mu(T-t)} - e^{-a_2(T-t)}\right) \qquad (5.6\text{-}110)$$

The objective is to follow the trend of the established forward curve in a reasonable manner, while satisfying the no-arbitrage constraint. Table 5.6-23 shows the interest rate, the futures levels and the example charters.

Interest Rate	Discount Period	Futures	Charter 1	Charters 2&3	Charter 4
0.91%	0.5	**$33,773**	**$33,773**	**$33,773**	**$26,500**
1.44%	1.5	**$26,522**	$27,431	**$26,522**	**$26,500**
1.90%	2.5	**$25,638**	$27,431	$24,000	$26,500
2.37%	3.5	**$25,203**	$27,431	$24,000	$26,500
2.74%	4.5	**$24,927**	$27,431	$24,000	$26,500
3.11%	5.5	?	$27,431	$24,000	$26,500
3.30%	6.5	?	$27,431	$24,000	$26,500
3.49%	7.5	?	$27,431	$24,000	$26,500
3.68%	8.5	?	$27,431	$24,000	$26,500
3.76%	9.5	?	$27,431	$24,000	$26,500
3.83%	10.5	?	$27,431	$24,000	$26,500
3.91%	11.5	?	$27,431	$24,000	$26,500
3.99%	12.5	?	$27,431	?	$26,500
4.07%	13.5	?	?	?	$26,500
4.15%	14.5	?	?	?	$26,500

Table 5.6-23: Table of Rates to set up the No-Arbitrage Constraint

In the columns for the charters, the years until the charter starts have been filled in with the futures rates for the corresponding years. The question marks denote the futures rates for the years that we are seeking (after accounting for the age reduction factor). The first column indicates the interest rate applicable to each year while the second column shows the period over which earnings will be discounted (it is assumed that all earnings are received at mid-year).

The point of this table is that by discounting all the columns to the present, using the interest rate and discount period in the first two columns, we must get the same results to satisfy the no-arbitrage condition. In practice, it may not be possible to get exactly the same present values, but we must try to get close. Priority will be given to satisfy Charters 2 and 3 because they are more reliable. That is because they were conducted in January 2010, by

major charterers meaning that they don't include a premium due to risk of charterer default etc. Table 5.6-24 attempts to satisfy the constraints while gradually reducing the forward curve towards an asymptote as it seems to be heading. The annual change in the percentage decrease of earnings from year to year was held constant at 0.2% for this purpose.

Calendar Year	Futures Rate	Change From Previous Year	% Decrease	Change in % Decrease
2010	**$33,773**			
2011	**$26,522**			
2012	**$25,638**	$883	-3.33%	
2013	**$25,203**	$436	-1.70%	
2014	**$24,927**	$276	-1.10%	
2015	$24,702	$224	-0.90%	0.20%
2016	$24,529	$173	-0.70%	0.20%
2017	$24,407	$123	-0.50%	0.20%
2018	$24,334	$73	-0.30%	0.20%
2019+	$24,309	$24	-0.10%	0.20%

Table 5.6-24: Projection of Futures Curve Using Long Term Charters and No-Arbitrage Constraint

The terminal value of $24,309/day is held constant going forward. When applied to Table 5.6-22, after accounting for the age discount as per Table 5.6-21, these values result in an error in the present value of +0.86% for Charters 2 and 3, -9.81% for Charter 1 and -5.72% for Charter 4. Indeed, Charters 1 and 4 include a risk premium relative to Charters 2 and 3, which are by major charterers. Since the charters are of similar length, two are underestimated and two are overestimated by the forward curve there is little room for improvement. Furthermore, the error on the two most reliable charters is almost zero, so we shall keep the projections of Table 5.6-24.

Finally, we have to multiply the daily earnings by the earning days per month which also account for off-hire time due to repairs. The earning days per month or equivalently, the percentage earning time, has been determined as a function of ship age in Table 5.6-6 of Section 5.2.7. To get the revenues at month "n", we use the formula:

$$\text{Rev}_n = ED(Age_0 + n) * BCI_n * ARF(Age_0 + n) * (1 - \%Com) \quad (5.6\text{-}111)$$

Where:

- n: Number of months from valuation data (Jan 2010)
- Rev_n: Daily revenues of ship in month "n"
- $ED(Age)$: Earning days per month as a function of age (Table 5.6-6 of Section 5.2.7)
- BCI_n: Daily revenues of a Baltic Cape (new ship) in month "n" (Table 5.6-23)
- Age_0: Age of ship at the beginning (Jan 2010)
- $ARF(Age)$: Earnings reduction factor due to ship age (Table 5.6-22)
- $\%Com$: Address and broker commission (total of 5%)

We also have to account for the residual value of the ship as an earning at the end of its life. For that, we will assume a lightship of 22,000, multiplied by a historical average of 250 $/ltd, which is also used in the Hamburg Valuation Model. Using these values, we get a scrap value of $5.5M. Note that this is in real terms. Therefore, we have:

$$\text{Rev}_{Life} = 5,500,000 \quad (5.6\text{-}112)$$

5.6.3.2 Operating Expenses

The analysis to derive the operating costs was carried out in Section 5.4. Since we accounted for inflation in the discount rate, we have to use the equation developed for the operating costs in real terms (Eq. 5.4-6). Based on that, we have:

$$OpEx_n = \left[8.943\left(Age_0 + n\right) + 3601\right] * \left[1 + MAX\left(0, 0.721 - 0.002n\right) I_n\right]^n \quad (5.6\text{-}113)$$

Where:

n:	Months from valuation date
$OpEx_n$:	Real Operating costs in $/day, "n" months from valuation date
Age_0:	Age of Ship at the valuation date
I_n:	Average monthly inflation until month "n" (Section 5.6.2.6, Fig. 5.6-11)

5.6.3.3 Repair Costs

The repair costs were determined in real terms as a function of ship age in Section 5.2 and summarized in Table 5.6-6 of Section 5.2.7. These are the real values that are assumed to remain constant over time. Since inflation is accounted for in the discount factor, these values will not be a function of time. The values of $\mathrm{Rep}Cost_n$ are only a function of ship age and are held constant throughout each year.

5.6.3.4 Expected Failure Losses

The expected failure losses for each month are equal to the probability of a failure in that month, multiplied by the cost of failure. The probability of failure in a given month is approximately equal to the hazard function. We can see that by considering the change in the survivor function from one month to the next (that is by definition equal to the probability of failure in that month):

$$P(fail)_n = S(n) - S(n+1) = e^{-\int_0^n \lambda(\tau)d\tau} - e^{-\int_0^{n+1} \lambda(\tau)d\tau}$$
$$\approx -\int_0^n \lambda(\tau)d\tau + \int_0^{n+1} \lambda(\tau)d\tau \approx \int_n^{n+1} \lambda(\tau)d\tau \approx \lambda(n) \qquad (5.6\text{-}114)$$

The hazard function has been developed as a function of time in Section 4.5. The failure cost has also been estimated in Section 4.6 as a weighted average of the various cost of the three types of failures. The three types of failures included a "2 month" emergency repair, a "6 month" emergency repair and a "late" repair (sink / total loss). The cost components included loss of hire, loss of the ship value (in case of total loss, "other costs" including reputational costs, and "repair costs" which also include transportation to and from the shipyard.

In the our model, we have already incorporated the potential loss of hire due to an emergency repair or total loss as a credit spread over the discount rate. Therefore, our measure of failure cost will only consist of the weighted average "repair costs" and "other costs". These have been quantified in Section 2.4 and are not a function of ship age or time (inflation is already accounted for in the discount rate). We have:

$$P(fail)_n FailCost \approx \lambda(n) * [EmRC + EmOC] \qquad (5.6\text{-}115)$$

Where: n: Months from valuation date (Jan 2010)

$P(fail)_n$: Probability of failure in month "n"

$FailCost$: Cost of failure due to cracks

$\lambda(n)$: Hazard function for ship age corresponding to month "n"

5.6.4 Valuation of Non-Standard Ships

There are four methods by which the model can be applied to determine the value of a Cape which has different characteristics from the generic type that we have so far assumed. They are the following:

1. Carry out the valuation for standard Cape and then adjust for the non-standard ship as a broker would, using the standard cape valuation as a comparable.
2. Calculate an Adjusted Present Value (APV) of the expected future cash flows. This is similar to the present value of the tax shields that arise from the tax deductibility of interest payments. Each difference from a standard ship can be associated with additional cash flows. For example, a ship with better fuel efficiency or a better coating specification will result in a certain amount of savings throughout its life relative to the standard ship. By projecting these additional cash flows and discounting them to the present, one can find the price adjustment over the standard valuation. This method has the benefit that it separately defines the value of the specific non-standard ship attributes.
3. Adjust the numerator terms of the RAFL ship valuation model to reflect those of the non-standard Cape. For example, projected revenues, operating and repair costs may be different for a double hull Cape (discussed in Section 3.7.2). A smaller ship may command lower earnings, and often brokers have been kept track of these (e.g. Clarksons' time series for 127,500dwt Cape earnings since the 1970s). Adjusting the terms accordingly will result in the valuation of the specific ship.

4. Use a large database of transactions to statistically determine the historical impacts of ship characteristics on transaction prices. Using regression analysis, one can determine the price premium due to factors such as engine type, shipyard, ship condition or special survey due, ore carrier etc. It is important in the regression analysis to make sure that the parameters are not too correlated. The RAFL ship valuation model is then adjusted with a summation term that accounts for these parameters, multiplied by the remaining ship's life (assuming a 28 year life). The summation term includes calibrated constants "a" for these effects, multiplied dummy variables "D" that take a value of one if the characteristic applies and zero otherwise. The RAFL model then becomes:

$$ShipValue = \sum_{n=1}^{Life-Age_0} \frac{\mathrm{Rev}_n - OpEx_n - \mathrm{Rep}Cost_n - P(fail)_n FailCost}{(1+i_n)^n} + (28 - AGE)\sum a_i D^i \quad (5.6\text{-}116)$$

$$\sum a_i D^i = \left[a_1 D^{Condition} + a_2 D^{Yard} + a_3 D^{Eng} + a_4 D^{Cranes} + a_5 D^{OreCarrier} \right] \quad (5.6\text{-}117)$$

Each of the four methods described is more appropriate for different adjustments. It is therefore most appropriate to combine them when incorporating effects of different kinds. For example, one may use method 2 or 3 to account for a difference in ship size, coupled with method 4 to account for a non-conventional ship engine such as a Pielstick or Mitsubishi instead of a Sulzer or B&W make.

5.7 Results, Analysis and Comparisons

5.7.1 RAFL Ship Valuation Model Results

The new Risk-Adjusted Forward-Looking (RAFL) ship valuation model was applied as described in Section 5.6, to Capes of various ages, using data centered about the beginning of 2010. The results are summarized in Table 5.7-1.

Ship Age (Years)	RAFL Valuation
0	$61,854,689
5	$52,207,769
10	$41,918,214
15	$30,825,049
20	$19,521,489

Table 5.7-1: Summary of Cape Valuations using the RAFL Model

Fig. 5.7-1 to 5.7-5 show the expected profits each month throughout the ship's life (the black line) and their present value (in red bars). Note that in each case, the final payment at the end of the ship's life is $5.5M (the predicted scrap value). The current value of the ship is equal to the sum of the present values, which is equal to the area in red.

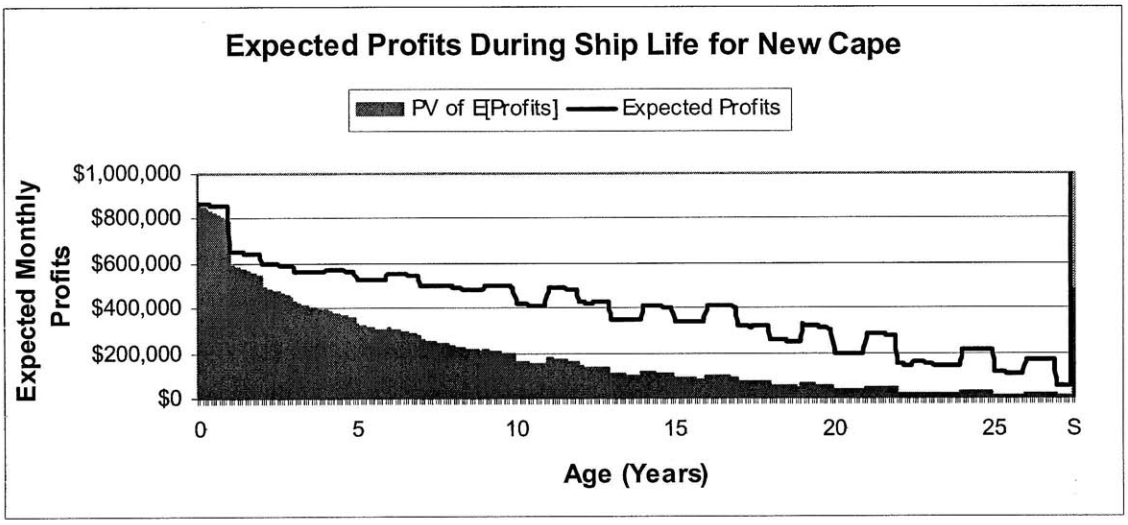


Fig. 5.7-1: Expected Profits and their Present Value Throughout the Life of a New Cape

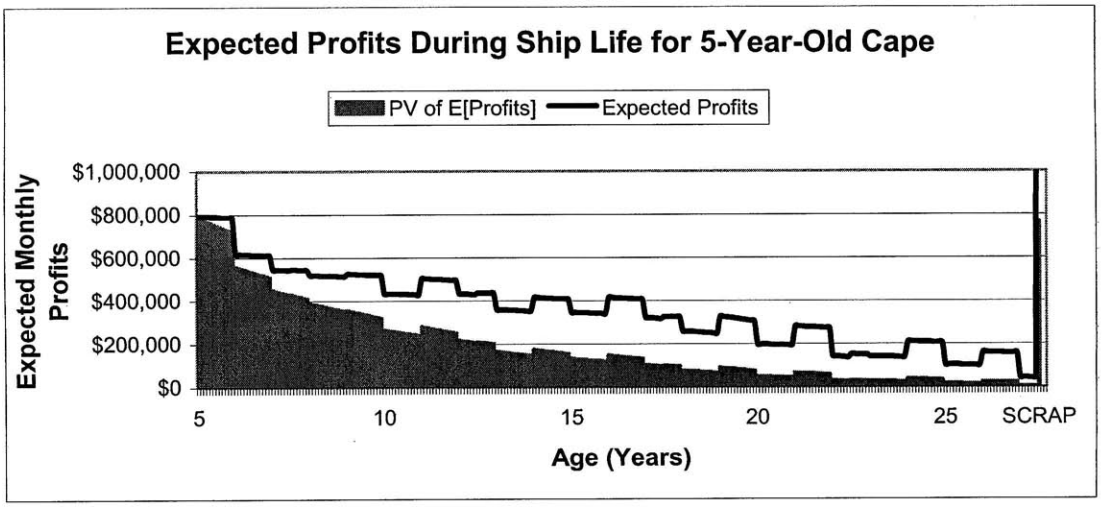


Fig. 5.7-2: Expected Profits and their Present Value Throughout the Life of a 5-Year-Old Cape

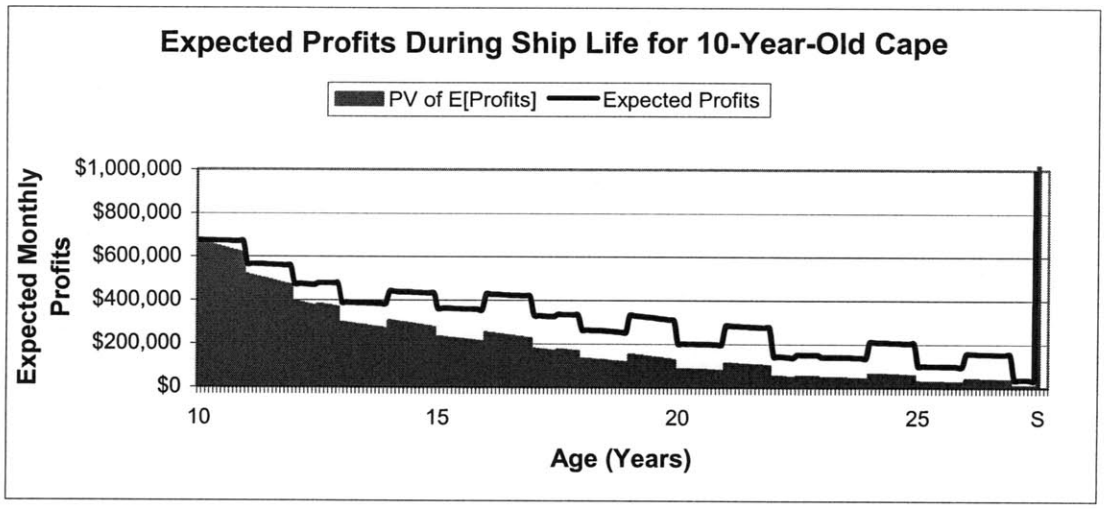


Fig. 5.7-3: Expected Profits and their Present Value Throughout the Life of a 10-Year-Old Cape

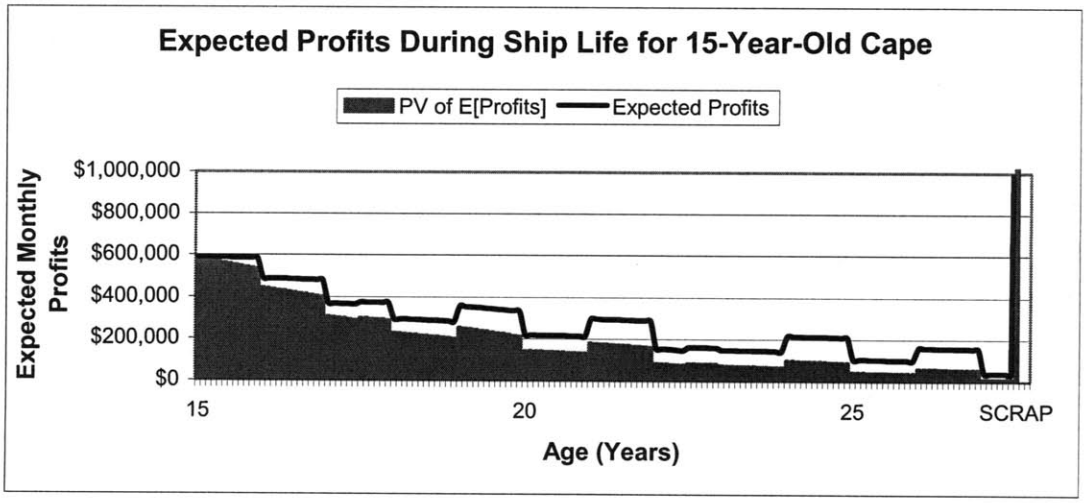


Fig. 5.7-4: Expected Profits and their Present Value Throughout the Life of a 15-Year-Old Cape

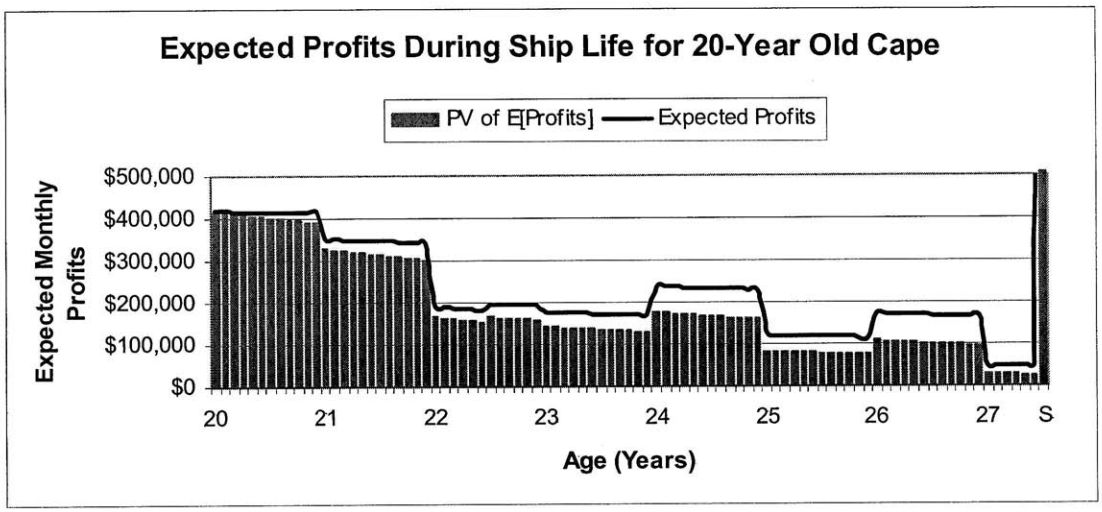


Fig. 5.7-5: Expected Profits and their Present Value Throughout the Life of a 20-Year-Old Cape

Fig. 5.7-6 to 5.7-10 show the discount rate and the resulting discount factor throughout the ship's life. The discount rate (blue line) is determined by the cost of equity, the risk free rate, the leverage, the inflation and the history of the hazard function. The combination of these factors which vary throughout the ship's life gives rise to the resulting shape. The discount factor is the number by which expected profits are multiplied to get their present value. That is only dependent on the time from the present and the corresponding discount rate at that point in time (the blue line is not integrated to calculate the discount factor).

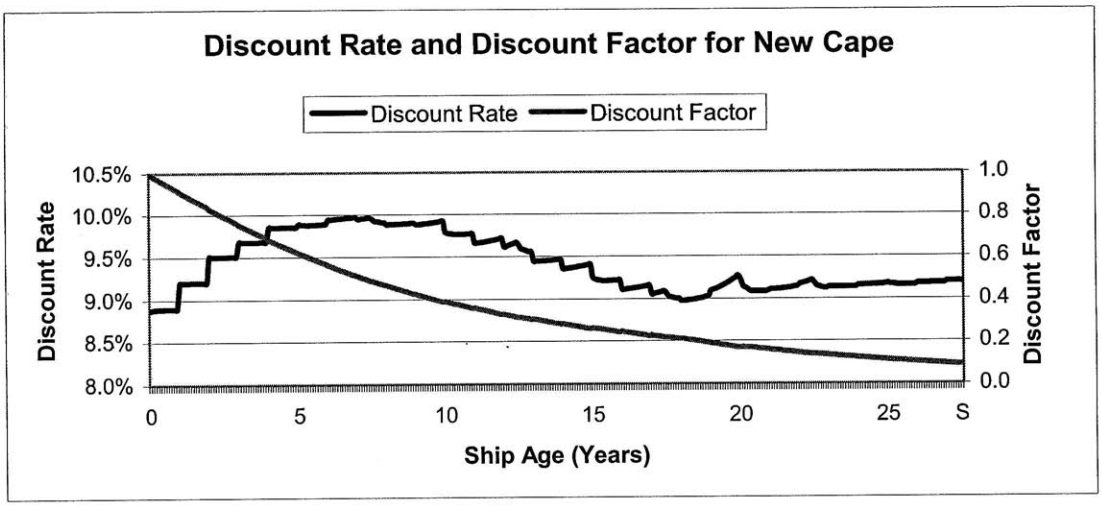


Fig. 5.7-6: Discount Rate and Resulting Discount Factor Throughout the Life of a New Cape

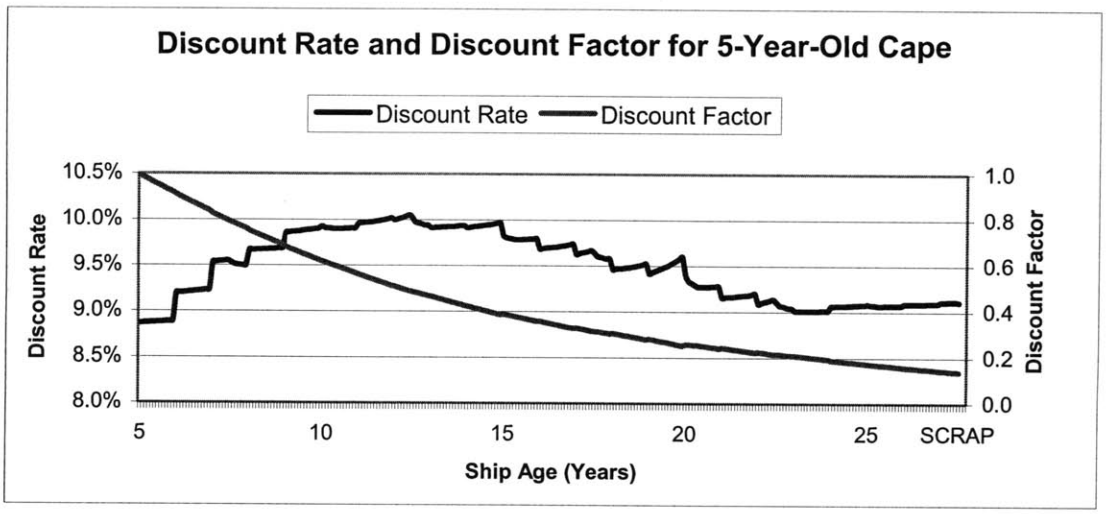


Fig. 5.7-7: Discount Rate and Resulting Discount Factor Throughout the Life of a 5-Year-Old Cape

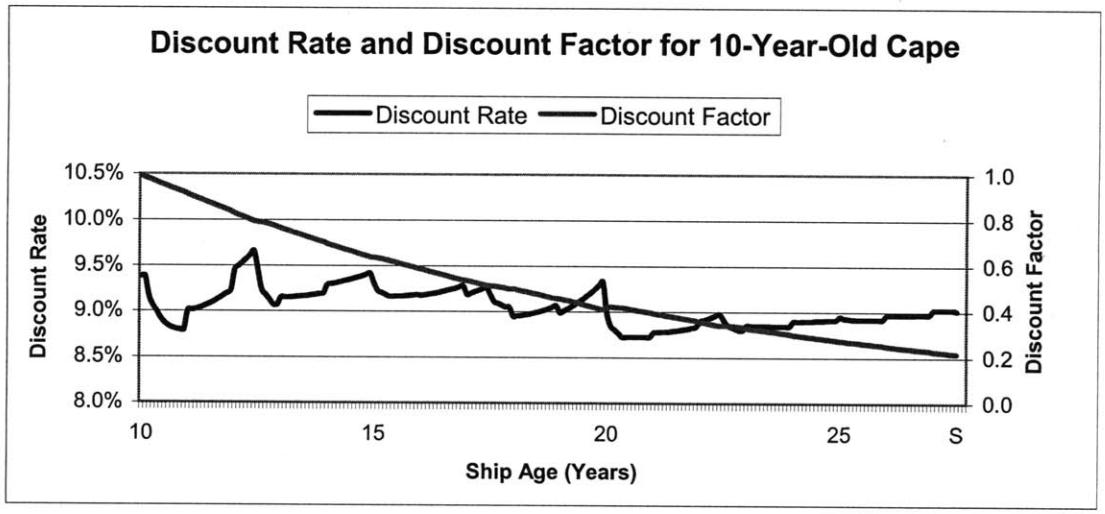


Fig. 5.7-8: Discount Rate and Resulting Discount Factor Throughout the Life of a 10-Year-Old Cape

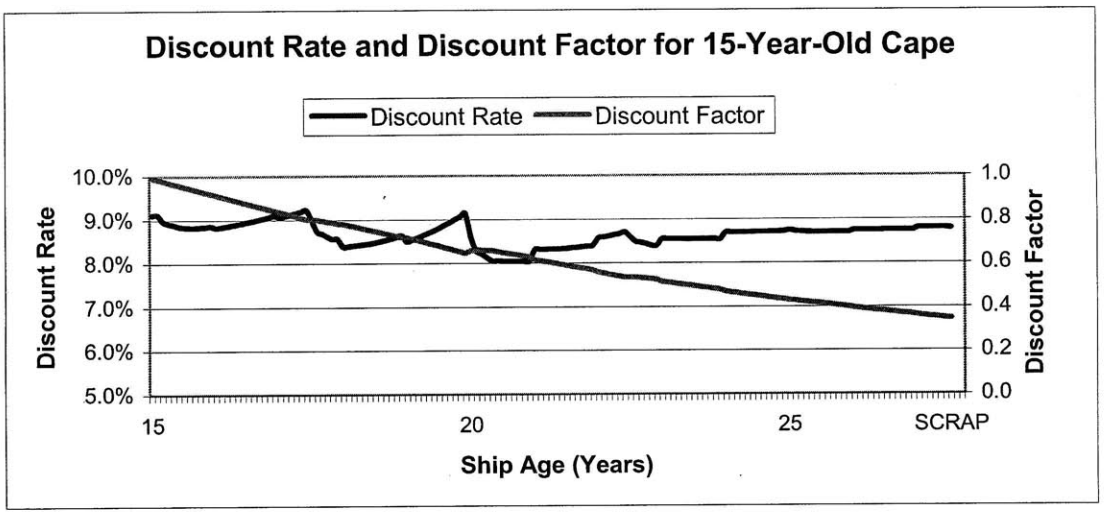


Fig. 5.7-9: Discount Rate and Resulting Discount Factor Throughout the Life of a 15-Year-Old Cape

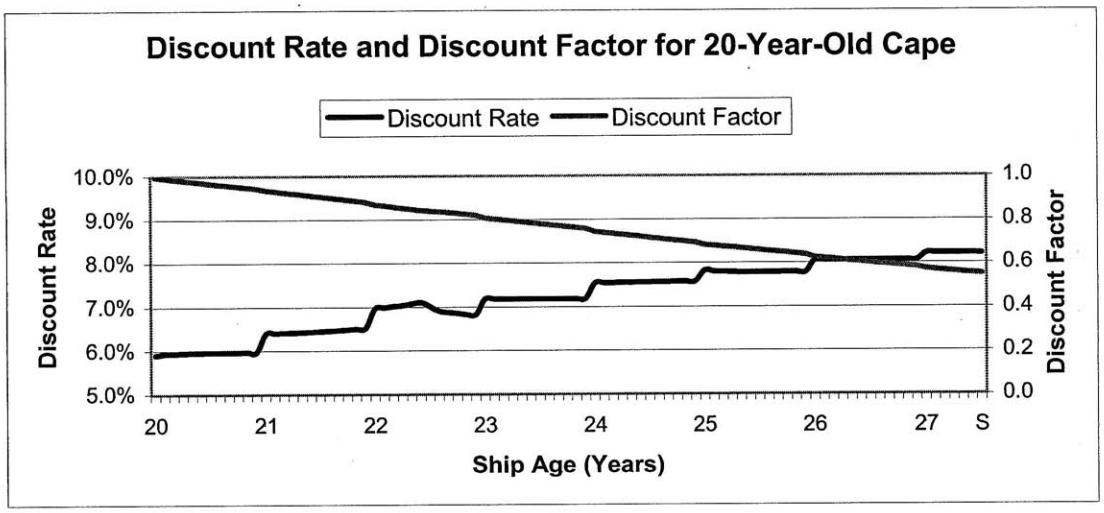


Fig. 5.7-10: Discount Rate and Resulting Discount Factor Throughout the Life of a 20-Year-Old Cape

Note that the increase in the discount rate with age for the 20-year-old ship in Fig 5.7-10, is mostly due to the increase in the risk free rate (time value of money).

5.7.2 RAFL Model vs. Transaction Prices

The valuations were carried out by taking average values between November 2009 and February 2010. That was because the market was relatively stable over this time period. Table 5.7-2 summarizes all the Cape transactions that took place between November 2009 and February 2010.

Month	Cape	Dwt	Yard	Engine	Notes	Age	Price
NOV	Knock Nevis	564,650	Sumitomo		for storage	31	?
NOV	NB Resale	177,000	China	MAN-B&W		0	59
NOV	Long Charity	174,000	Hitachi	B&W		25	13.7
NOV	Grand Fortune	150,877	Sanoyas	Sulzer		16	28
NOV	NB Resale	180,000	STX		Dely 12/10	0	62
DEC	Azul Glory	178,633	Daewoo	B&W		12	40.6
DEC	Cape Victory	177,359	Namura			7	52
DEC	Alameda	170,726	Samho	B&W		9	45
DEC	CHS Star	150,149	Hyundai	B&W		19	17.5
JAN	Oriental Bay	179,764	Sasebo	MAN-B&W		0	71.5
JAN	NB Resale	179,000	Sasebo	MAN-B&W	Cido resale	0	71.5
JAN	Azul Glory	178,633	Daewoo	B&W		12	39
JAN	Star Beta	174,691	Poland	Sulzer		17	22
JAN	Cape Africa	149,533	Taiwan	B&W		19	18.8
JAN	Peace Blossom	148,982	Spain	Sulzer		23	11.6
FEB	Oriental Cosmos	179,764	Sasebo	MAN-B&W		0	71
FEB	Cape Olive	169,963	Mitsui	B&W		14	27
FEB	Lowlands Billiance	169,631	Samho	B&W		8	48.5
FEB	Ocean Comfort	149,477	Taiwan	B&W		18	19.5
FEB	Marine Corona	139,496	Kawasaki	B&W		28	7.2

FEB	Constantinoupolis	128,150	Hyundai	Sulzer		29	7.8
FEB	North King	127,907	Hyundai	B&W	SS due 2/11	29	7.6

Table 5.7-2 Summary of Reported Cape Sale and Purchase Transactions Between Nov'09 and Feb'10

Fig 5.7-11 shows the transactions of Table 5.5-2 along with the valuation results of Table 5.5-1. The transaction prices are shown in blue circles while the valuations are in red triangles. The current scrap value which is approximately $8.8M is assumed to apply at the age of 27.5 onwards, and is shown in black triangles. The dotted line is the valuation line showing the values obtained for each ship age through linear interpolation between the valuations.

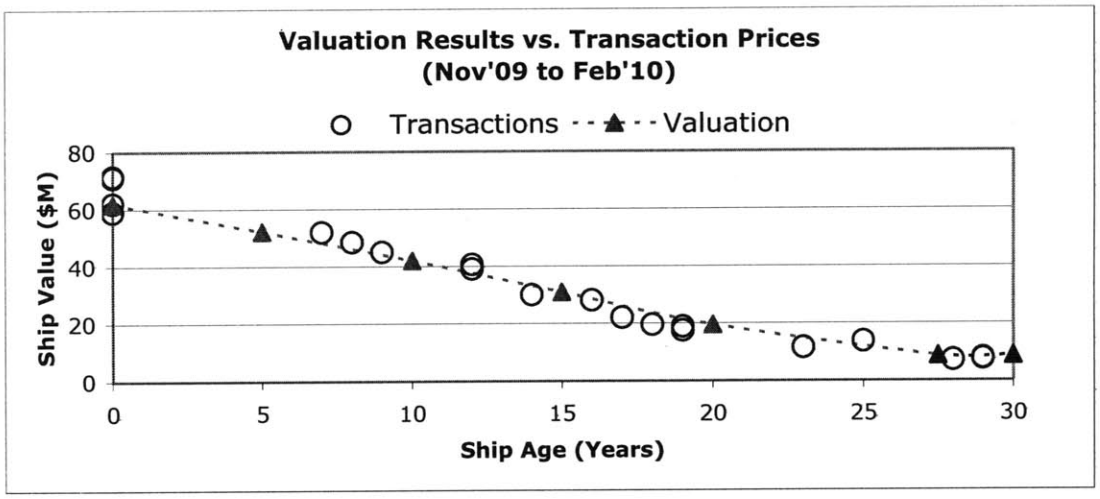


Fig 5.7-11 RAFL Valuation Results and Actual Transaction Comparison

The valuations are surprisingly close to the transaction prices across all ages. The new ships that were bought in excess of $70M, all went to a single buyer, Indian-based Five Stars. If we exclude that buyer, we get an almost perfect match. The vessels over 27.5 years old went for slightly less than scrap value because they are smaller (less lightship) and one also needs to account for transportation costs to the scrap yard. This is particularly true for the 29-year-old 127,907dwt *"North King"* which has a special survey due and will almost certainly not be further traded.

This means that current ship prices appear to be close to the intrinsic ship value. It shows that the model is reliable and can be used to estimate the value of a ship when there

are no comparable sales. More importantly, it can be used to determine when a ship is worth buying or selling by looking at its current market price relative to the valuation line. Ship values fluctuate with the market but will tend to return to their intrinsic value. This creates investment opportunities which can be identified using our model. The valuation line will also vary with time but this can be hedged against as we will show in Section 5.8. Furthermore, it can be used to make sure one doesn't overpay or undersell a ship given a certain market.

Since ships are trading at prices almost equal to the valuations, a case can't be made about the effect of cracks not being incorporated. Market participants probably account for this and other factors intuitively or by applying crude safety margins which, for this case, appear to be in the ballpark. One advantage of the model is that it can be used to quantify the various effects on value, including cracks and also break down the value into components. We will see this in the next subsections.

Note that the transaction prices used in Table 5.7-2 and Fig. 5.7-11 are for ships that are not identical to those being valued. Furthermore, our valuation for a new ship assumes that the ship is in the water, whereas a newbuilding with a later delivery would sell at a discount to our valuation. For greater accuracy we would have to adjust these values for size, shipyard, special survey due etc. This was avoided because it introduces subjectivity which would undermine the results. However, brokers have done this work using these transactions and we can use their results directly. Table 5.7-3 shows the standard Cape valuations by Cotzias Shipbrokers, as published in their monthly reports, along with the mean values between November 2009 and December 2010.

SHIP AGE	NOV	DEC	JAN	FEB	MEAN
Newbuilding	67.0	68.0	69.0	70.5	68.6
5	50.0	51.5	53.0	55.1	52.4
10	42.1	42.1	42.1	42.1	42.1
20	19.0	17.8	17.0	16.0	17.5

Table 5.7-3 Cotzias Shipbrokers Valuations [Cotzias 2009a, 2009b, 2010a, 2010b]

As discussed in Section 5.5, along with others, Clarksons had stopped publishing valuations after the market crash until early 2010. However, they have now also published valuations for some of the later months (in retrospect). Table 5.7-4 shows their standard Cape valuations between November 2009 and February 2010, along with the mean over that period. Note that some of the valuations published by Clarksons are for slightly different deadweights than the standard, as indicated in Table 5.7-4

SHIP AGE	NOV	DEC	JAN	FEB	MEAN
Newbuilding (175-180kdwt)	56.5	56	56	56	56.1
5	52.5	55	55	56.5	54.8
10	44	44	44.5	44.5	44.3
20 (150 kdwt)	16.5	16	18	17.5	17.0

Table 5.7-4: Clarksons Shipbrokers Valuations [Clarksons 2010]

Fig 5.7-12 shows a plot of the mean values (between the two sets of quotations), along with our valuations.

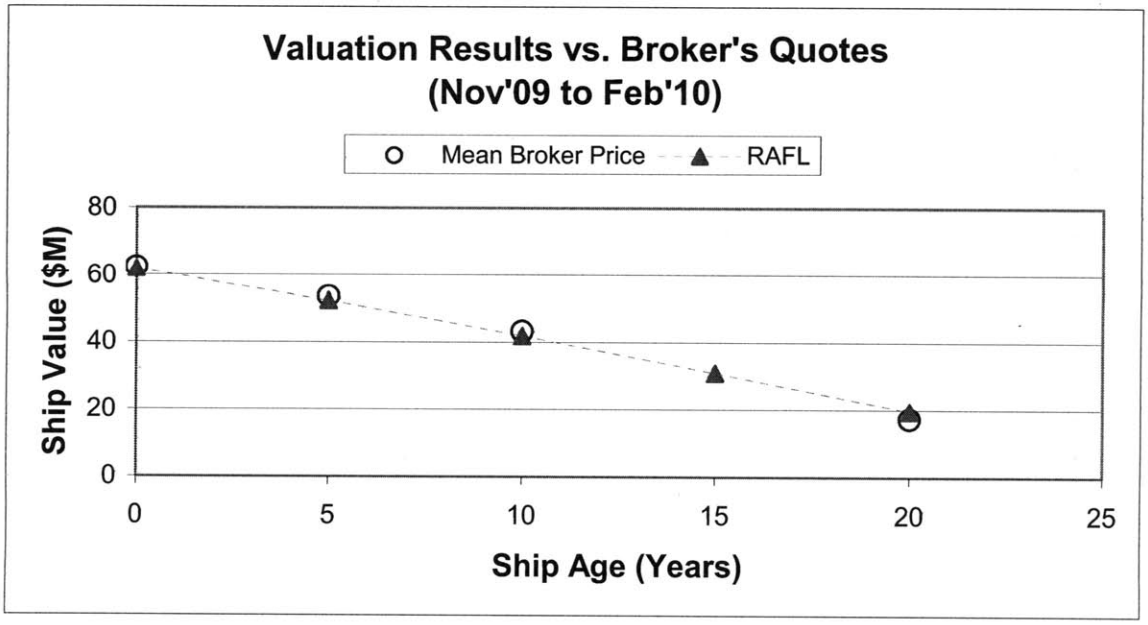


Fig 5.7-12 New RAFL Model Valuation Results and Broker Price Quotations

The results are almost identical to the average of the broker quotes over the period considered. The differences are smaller than those observed between the two sets of prices quoted by brokers, which are interpretations of the same set of data.

5.7.3 Crack Credit Spreads

Here, we will deduce the effective credit spread that should be applied on the discount rate to account for the effect of cracks. Recall our valuation model:

$$ShipValue = \sum_{n=1}^{Life-Age_0} \frac{\mathrm{Rev}_n - OpEx_n - \mathrm{Rep}Cost_n - P(fail)_n FailCost}{(1+i_n)^n} \tag{5.7-1}$$

Where:

$$i(t) = \left(1 + r'_{WACC}(t)\right) e^{12S_t(t)} - 1 \tag{5.7-2}$$

$$r'_{WACC}(t) = w_e(t) r_e + w_D(t) r_D(t) - I(t) \tag{5.7-3}$$

$$S_t(t) = \frac{1}{t}\left[\frac{1}{18}\int_0^t \lambda(\tau)\,d\tau + \frac{9}{36}\int_{t-5}^t \lambda(\tau)\,d\tau + \frac{25}{36}\int_{t-1}^t \lambda(\tau)\,d\tau\right] \tag{5.7-4}$$

We have broken down crack costs into three components. The first is the potential revenue losses as a result of off-hire time due to crack failures. This was incorporated into the discount rate as shown in Eq. 5.7-4 and 5.7-2. The second is the expected cost of failures excluding loss of hire, which appears in the last numerator term of Eq. 5.7-1. The third is the cost of scheduled crack repairs which forms part of the third term in the numerator of Eq. 5.7-1.

Having solved for the ship values, we can solve for the effective spread on the discount rate that would account for each of these costs. We write the valuation formula in the following equivalent forms, where we introduce the credit spreads:

$$ShipValue = \sum_{n=1}^{Life-Age_0} \frac{\mathrm{Rev}_n - OpEx_n - \mathrm{Rep}Cost_n - P(fail)_n \left(FailCost + OffHire_n\right)}{(1+r'_{WACC,n})^n} \tag{5.7-5}$$

$$ShipValue = \sum_{n=1}^{Life-Age_0} \frac{\mathrm{Rev}_n - OpEx_n - \mathrm{Rep}Cost_n - P(fail)_n FailCost}{(1+r'_{WACC,n}+s_1)^n} \tag{5.7-6}$$

$$ShipValue = \sum_{n=1}^{Life-Age_0} \frac{\mathrm{Rev}_n - OpEx_n - \mathrm{Rep}Cost_n}{(1+r'_{WACC,n}+s_2)^n} \tag{5.7-7}$$

$$ShipValue = \sum_{n=1}^{Life-Age_0} \frac{\mathrm{Rev}_n - OpEx_n - NonCrack\mathrm{Rep}Cost_n}{(1+r'_{WACC,n}+s_3)^n} \tag{5.7-8}$$

$$s_1 \le s_2 \le s_3 \tag{5.7-9}$$

Where: s_1: Spread to only account for crack failure off-hire losses

s_2: Spread to account for the total cost due to crack failures

s_3: Spread to account for all crack-associated costs (failure and scheduled repairs)

To determine the spreads, we simply solve Eq. 5.7-5 to 5.7-9 iteratively to get equal ship values as determined by 5.7-1. To get the non-crack repair costs required for Eq. 5.7-8, we turn to the analysis of Section 5.2-4 where we got the crack costs as a fraction of total repair costs throughout the ship's life. We first solve for the crack repair costs by multiplying the predicted total repair costs by the fraction for the corresponding age (from Section 5.2-4). Then we deduct the crack repair costs from the total repair costs to get the non-crack repair costs, and solve for s_3. The results of the analysis for all ship ages are summarized in Table 5.7-5 and Fig. 5.7-13.

Ship Age (Years)	0	5	10	15	20
s_1 (Failure Offhire Only)	0.10%	0.12%	0.30%	0.40%	0.12%
s_2 (All Failure Costs)	0.17%	0.25%	0.54%	0.80%	0.51%
s_3 (Total Crack Costs)	0.31%	0.49%	1.05%	1.65%	2.02%

Table 5.7-5: Crack Credit Spreads

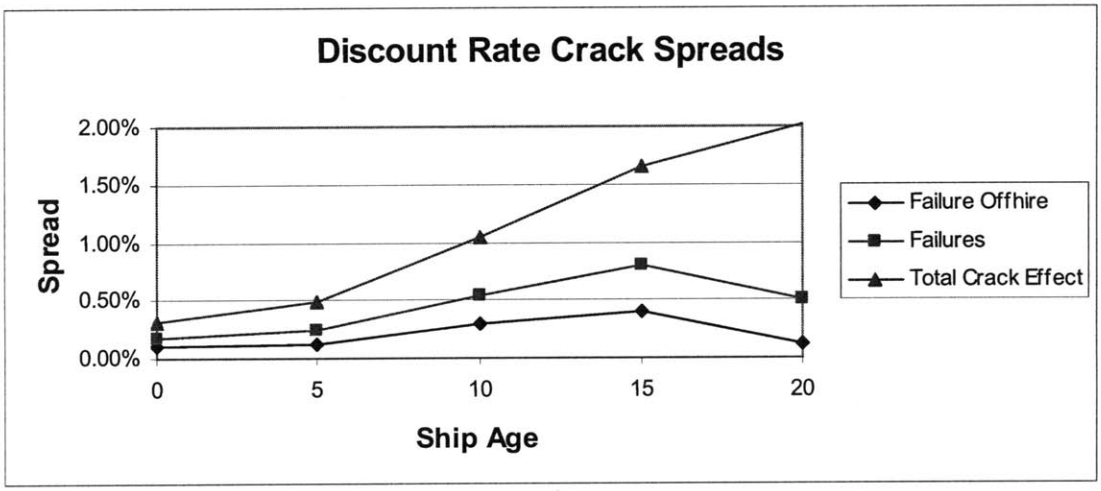


Fig 5.7-Fig. 5.7-13: Crack Credit Spreads as a Function of Ship Age

Here, we see that crack credit spreads are substantial, particularly for mid-aged ships. Keep in mind that this is a spread directly over the weighted average cost of capital, after adjusting for inflation. In practice, one would probably include all repair costs in the numerator and not account for crack repair costs in the discount rate. Therefore, one would probably be using the s_2 credit spread to only account for potential crack failure losses. That would be the red line in Fig 5.7-13.

The spreads corresponding to the failure costs are determined by the hazard function (and its history). Since the hazard function peaked at age 20 (4^{th} special survey) and did not increase as much thereafter, the crack failure spreads applied to a 20-year old ship (until scrapping age) are slightly lower than those for the 15 year old ship. However, crack repair costs tend to increase substantially after the age of 15, causing the total crack spread to keep increasing.

We can also solve for the equivalent constant discount rate that would result in the same ship valuations using Eq. 5.7-10. The results are summarized in Table 5.7-6.

$$ShipValue = \sum_{n=1}^{Life-Age_0} \frac{\mathrm{Rev}_n - OpEx_n - \mathrm{Rep}Cost_n - P(fail)_n FailCost}{(1+i_{eff})^n} \tag{5.7-10}$$

Ship Age (Years)	0	5	10	15	20
i_{eff}	9.53%	9.60%	9.07%	8.65%	7.64%

Table 5.7-6: Effective Constant Discount Rate

Note that this is highly affected by the term structure of interest rates, which is upward sloping, causing the discount rate for the 20-year old ship to be lower. It is also important to note that the spreads calculated above assume a discount rate that varies with time, they are not spreads over the constant discount rate. The results are very close to what is typically used by analysts for shipping company valuation. BDP1 Consulting Ltd has been applying a weighted average cost of capital for shipping companies that typically ranges between 5% and 12.5% [bdp1(a), bdp1(b)]. In November 2009, Credit Suisse was using a weighted average cost of capital of 10% for the valuation of Diana Shipping [Lewis 2009]. Note that these rates are typically used for nominal discounting meaning that they have not been adjusted for inflation.

Next, we can also solve for the present value of each of the crack costs (an alternative to applying the spreads over the discount rate). We get this by keeping the discount rate of the original valuation and removing the relevant costs. This is the intermediate step in the previous analysis, just before adding the calculated spread in order to bring the value back to the original level. The present value of the relevant costs are summarized in Table 5.7-7 and Fig 5.7-14.

Ship Age (Years)	0	5	10	15	20
PV(Failure Offhire Only)	$387,842	$330,764	$597,316	$481,856	$73,399
PV(All Failure Costs)	$656,817	$706,335	$1,087,831	$968,002	$309,272
PV(Total Crack Costs)	$1,183,448	$1,399,211	$2,114,887	$2,004,248	$1,209,764

Table 5.7-7: Present Value of Crack Costs

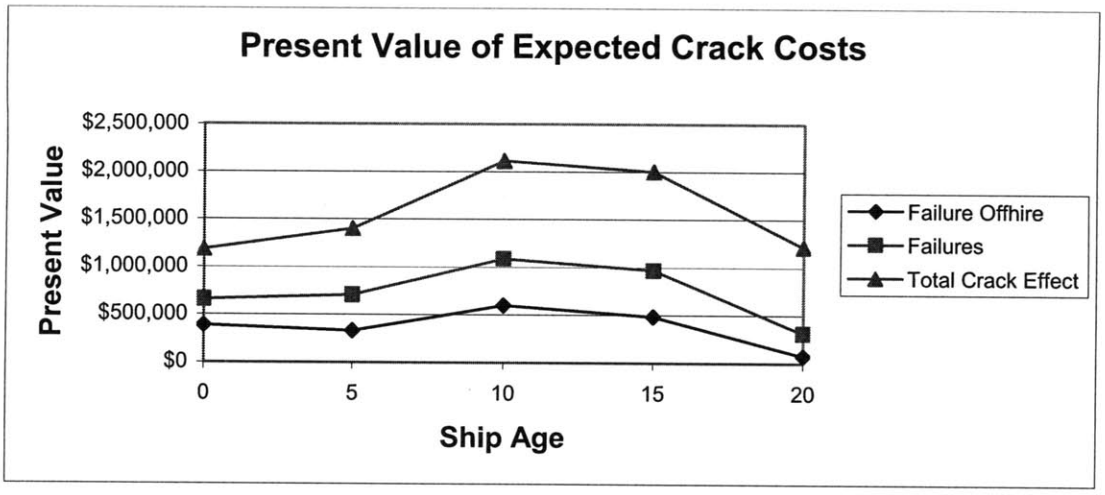


Fig 5.7-14: Present Value of Expected Crack Costs as a Function of Ship Age

The results show that the present value of all crack-associated costs considered is consistently over $1M between the age of 0 and 20 years, and exceeds $2M, when the ship is around 10 years old. This highlights the importance and need for research on fracture mechanics and methods to eliminate cracks in ships. Approximately half the cost is due to potential crack failures. The present value of crack costs declines with ship age after a certain point because as the ship gets older, there are fewer years remaining and therefore fewer remaining future crack costs.

5.7.4 Sensitivity Analysis

The sensitivity of the valuations was examined with respect to four key variables. The first one is the continuation value of the base revenue which is the daily revenues of a new Cape beyond the period that is observable from futures prices and long term charter rates. The second parameter is the residual or scrap value at the end of the ship's life. Those two parameters resemble the revenues that are more difficult to hedge. Therefore, sensitivity with respect to these two parameters indicates the amount of risk involved when buying the ship.

The third parameter is the discount rate which was the most complicated variable to estimate and on which we spent the most effort and time. The sensitivity of ship values to the discount rate will tell us if all that effort is worthwhile. The fourth parameter is the operating cost which was chosen because the shipowner has significant influence over it. The sensitivity analysis will quantify the potential benefits to the ship owner who makes an effort to reduce operating costs.

To carry out the sensitivity analysis, we calculate the percentage change in the ship value following a one percent change in each of the parameters. Note that most of the parameters are functions of time or ship age, in which case all the values taken by the parameter throughout the ship's life are changed by one percent. The sensitivity of the ship value is examined for both an increase and a decrease of each parameter (by one percent) and the mean response is recorded. The responses were symmetric except with respect to the discount rate for which the ship values were slightly more elastic when decreasing it. In other words, negative and positive changes in the parameters had an equal impact on the ship value, except for the discount rate, in which a decrease had a slightly bigger impact than an increase. The results of the mean responses are summarized in Table 5.7-8 and Fig 5.7-15.

Age (years)	Cont.Rev	Disc.Rate	OpExp	ResVal
0	0.4006	-0.5814	-0.2927	0.0079
5	0.3668	-0.5118	-0.3582	0.0147
10	0.3128	-0.4258	-0.4537	0.0288
15	0.1535	-0.3355	-0.5637	0.0618
20	0.0000	-0.2966	-0.6855	0.1642

Table 5.7-8: % Change in Ship Values given a +/-1% Change in Sensitivity Parameters

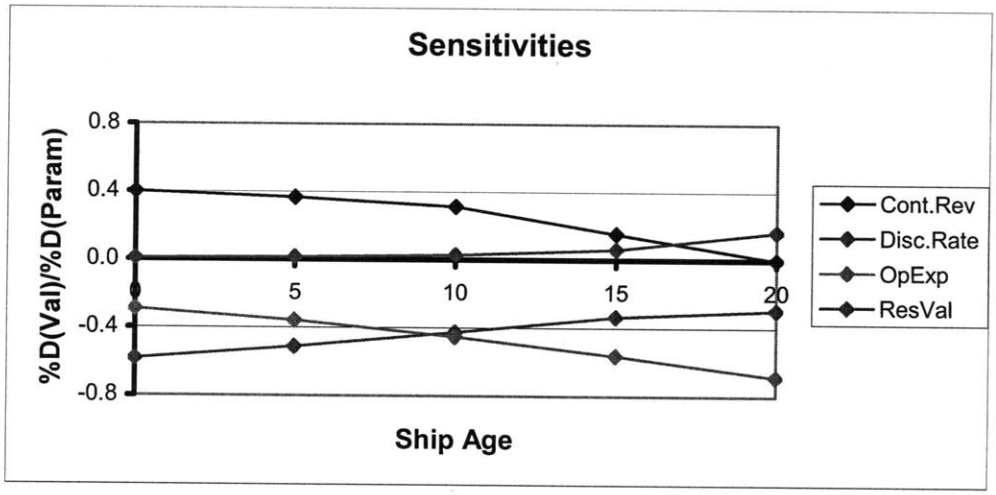


Fig 5.7-15: Sensitivity Analysis of Valuations

The continuation revenues have a significant impact when the ship is young and no impact after the age in which the remaining ship's life is short enough to infer all revenues from observable market data. On the other hand, when the ship is young, the residual value has almost no impact and that increases substantially when the ship gets older. Note that the residual value is more easily hedged as the ship gets older and it becomes more significant. Therefore, it poses less of a problem in terms of risk hedging relative to the continuation revenue.

We see that the discount rate has the biggest impact on the valuation of a new ship and the second biggest impact in the case of a 20-year old ship. This justifies the detail and effort we put in its calculation. The operating expenses have a significant impact on the ship value, which increases with age meaning that this is an area well worth focusing on for the shipowner.

5.7.5 Valuation Model vs. Alternative Methods

5.7.5.1 Introduction

Alternative ship valuation methods were discussed in Section 5.6. These include methods that are adopted by the industry as well as proposed modifications and alternatives. As we did with our ship valuation model, we will carry out valuations for ships 0, 5, 10, 15 and 20 years old using those methods as of the start of 2010. Then we will compare the results to each other and to market transaction prices.

5.7.5.2 Valuation by Adopted Alternatives

5.7.5.2.1 Comparables-Based Valuation

The quotations from brokers that are based on adjustments and interpretations of the observed transaction prices were considered in Section 5.7.2. Fig. 5.7-16 shows a plot of the quoted prices by Cotzias and Clarksons, along with the mean of the two and the transactions that occurred during the same period.

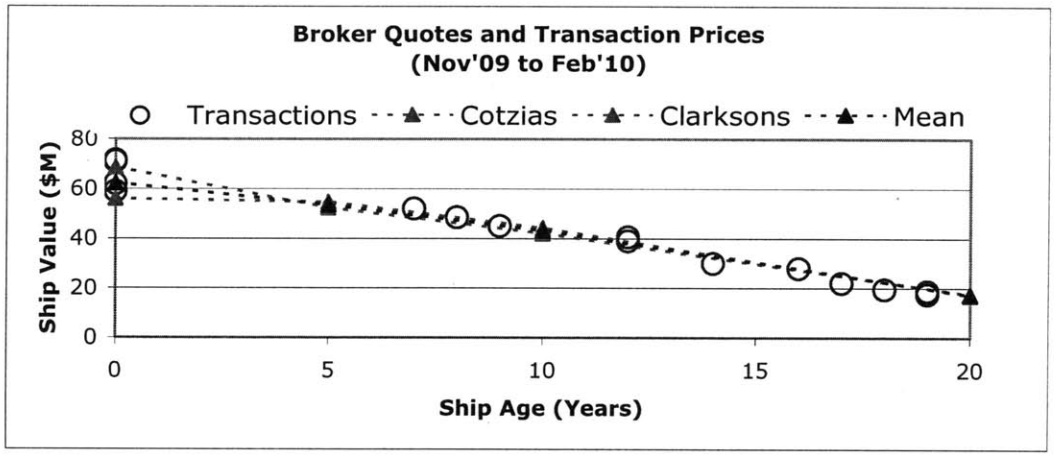


Fig 5.7-16 Broker Quotations and Transaction Prices

There is some discrepancy between the two brokers at age equals zero. All the broker valuations are for a newbuilding as opposed to a delivered ship, whereas the transaction prices also include ships with prompt delivery (re-sales). The discrepancy may arise from looking at newbuilding quotations from different shipyards.

There is no point in using this graph in assessing the accuracy of this method since the valuations are based on the actual transaction prices observed in the market. The major limitation of this method is the fact that it cannot be applied in the absence of observed transaction prices.

5.7.5.2.2 Short Term Forecasting

Short-term forecasting relates to the method Marsoft uses to predict the average ship values within the same quarter. For example, if we take Marsoft's predictions for the values of the first quarter of 2010, as published in mid-January 2010, we can essentially treat that as a current valuation. These values are summarized in Table 5.7-9 and are plotted along with the Cape transactions between November 2009 and February 2010 in Fig, 5.7-17.

Ship Age (Years)	Short Term Forecasts
0	52.5
5	48.6
10	39.5
15	27.7

Table 5.7-9: 2010 Q1 Cape Value Forecasts as of Mid-January 2010 [Marsoft 2010b]

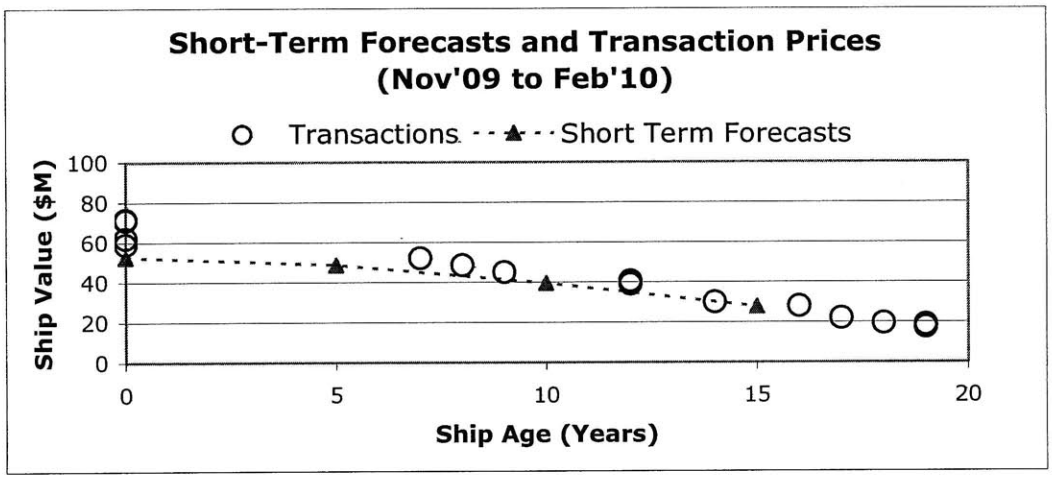


Fig 5.7-17: Short-Term Forecasts vs. Actual Transaction Prices

There is a close match between the results and the data. However, similarly to the previous case of comparables, this cannot be considered an external and independent valuation method because transaction prices up to the data of the valuation are taken into account when producing the results.

5.7.5.2.3 Hamburg Valuation

The Hamburg valuation was applied by GmbH to value a 2-year-old Cape as of March 31st 2009. However, it was applied in a more conservative way than suggested by the method, using earnings of $36,900/day after the first year and without multiplying the scrap

value by 3.45 to get the 20-year residual value. The result was $100.958M using a 20 year horizon and $106.934M using a 25 year horizon [VHSS 2009].

The Hamburg valuation method has been described in great detail in Section 5.5.2.4. We will follow the exact method, step by step to produce valuations for Capes of the various ages considered for the period of November 2009 to February 2010. Fig 5.7-18 shows the average daily earnings of a Baltic Cape (BCI) since they were have been reported by the Baltic Exchange.

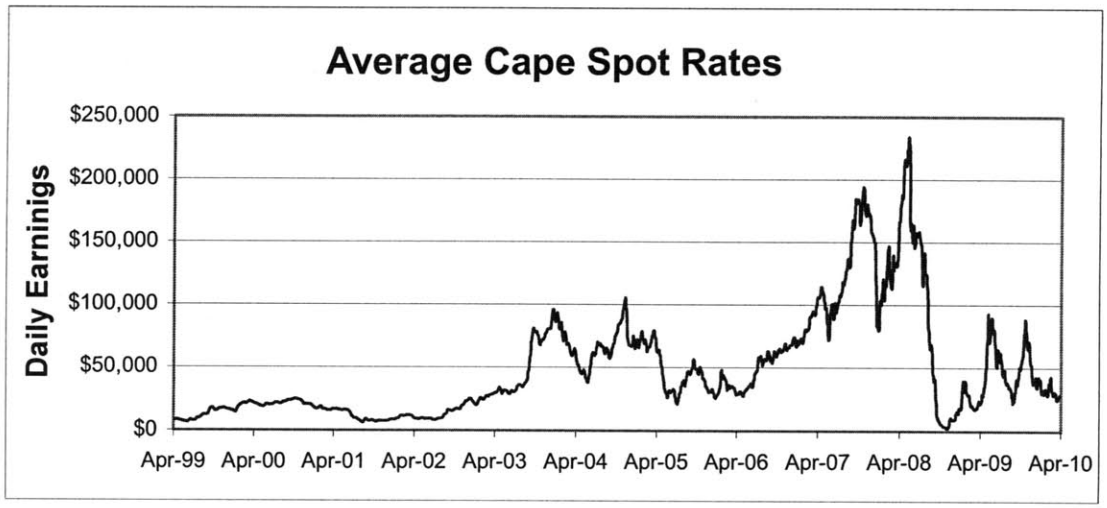


Fig. 5.7-18: The Baltic Cape Daily Earnings (Average of 4-TC Routes) Since Reported

We start by a brief reminder of the main assumptions. For the first year, we have to use current earnings so we take the average BCI between November 2009 and December 2010 which is $48,622/day. For the remaining life, we need the 10-year average, so we take the average between January 2000 and December 2009, which is $51,523/day. As per [VHSS 2009], we assume 6.5% commissions, annual discounting with a 6.6% discount rate, 360 days/year except for years of class renewal (every 5 years) where we use 345 days/year, annual operating expenses of $2,323,590, and a residual value of $5.5M. According to the method, for ships up to 15 years old, we use a 20 year horizon and multiply the residual value by 3.45. For ships older than 15 (our 20-year-old ship valuation), we use a horizon of 25 years with a residual value of 5.5 years, and discount the earnings after the 20th year by 30%. Table 5.7-10 to 5.7-14 show the valuations. Fig 5.7-19 shows the results along with the transaction prices.

Year	Operating Days	Gross daily Rate	Net Revenue	Operating Expenses	Net Income	PV(Income)
1	360	$48,622	$16,366,165	$2,323,590	$14,042,575	$13,173,147
2	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$13,216,854
3	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$12,398,550
4	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$11,630,910
5	345	$51,523	$16,620,032	$2,323,590	$14,296,442	$10,385,847
6	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$10,235,270
7	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$9,601,566
8	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$9,007,098
9	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$8,449,435
10	345	$51,523	$16,620,032	$2,323,590	$14,296,442	$7,544,942
11	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$7,435,553
12	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$6,975,190
13	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$6,543,330
14	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$6,138,209
15	345	$51,523	$16,620,032	$2,323,590	$14,296,442	$5,481,127
16	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$5,401,660
17	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$5,067,223
18	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$4,753,493
19	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$4,459,186
20	360	$51,523	$36,317,642	$2,323,590	$33,994,052	$9,468,013
						$167,366,605

Table 5.7-10: Hamburg Valuation for New Cape

Year	Operating Days	Gross daily Rate	Net Revenue	Operating Expenses	Net Income	PV(Income)
1	360	$48,622	$16,366,165	$2,323,590	$14,042,575	$13,173,147
2	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$13,216,854
3	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$12,398,550
4	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$11,630,910
5	345	$51,523	$16,620,032	$2,323,590	$14,296,442	$10,385,847
6	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$10,235,270
7	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$9,601,566
8	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$9,007,098
9	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$8,449,435
10	345	$51,523	$16,620,032	$2,323,590	$14,296,442	$7,544,942
11	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$7,435,553
12	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$6,975,190
13	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$6,543,330
14	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$6,138,209
15	360	$51,523	$36,317,642	$2,323,590	$33,994,052	$13,033,014
						$145,768,916

Table 5.7-11: Hamburg Valuation for 5-Year-Old Cape

Year	Operating Days	Gross daily Rate	Net Revenue	Operating Expenses	Net Income	PV(Income)
1	360	$48,622	$16,366,165	$2,323,590	$14,042,575	$13,173,147
2	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$13,216,854
3	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$12,398,550
4	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$11,630,910
5	345	$51,523	$16,620,032	$2,323,590	$14,296,442	$10,385,847
6	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$10,235,270
7	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$9,601,566
8	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$9,007,098

9	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$8,449,435
10	360	$51,523	$36,317,642	$2,323,590	$33,994,052	$17,940,349
						$116,039,027

Table 5.7-12: Hamburg Valuation for 10-Year-Old Cape

Year	Operating Days	Gross daily Rate	Net Revenue	Operating Expenses	Net Income	PV(Income)
1	360	$48,622	$16,366,165	$2,323,590	$14,042,575	$13,173,147
2	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$13,216,854
3	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$12,398,550
4	360	$51,523	$17,342,642	$2,323,590	$15,019,052	$11,630,910
5	360	$51,523	$36,317,642	$2,323,590	$33,994,052	$24,695,448
						$75,114,910

Table 5.7-13: Hamburg Valuation for 15-Year-Old Cape

Year	Operating Days	Gross daily Rate	Net Revenue	Opex	Net Income	PV(Income)
1	360	$34,035	$11,456,316	$2,323,590	$9,132,726	$8,567,285
2	360	$36,066	$12,139,849	$2,323,590	$9,816,259	$8,638,366
3	360	$36,066	$12,139,849	$2,323,590	$9,816,259	$8,103,533
4	360	$36,066	$12,139,849	$2,323,590	$9,816,259	$7,601,813
5	360	$36,066	$17,639,849	$2,323,590	$15,316,259	$11,126,708
						$44,037,705

Table 5.7-14: Hamburg Valuation for 20-Year-Old Cape

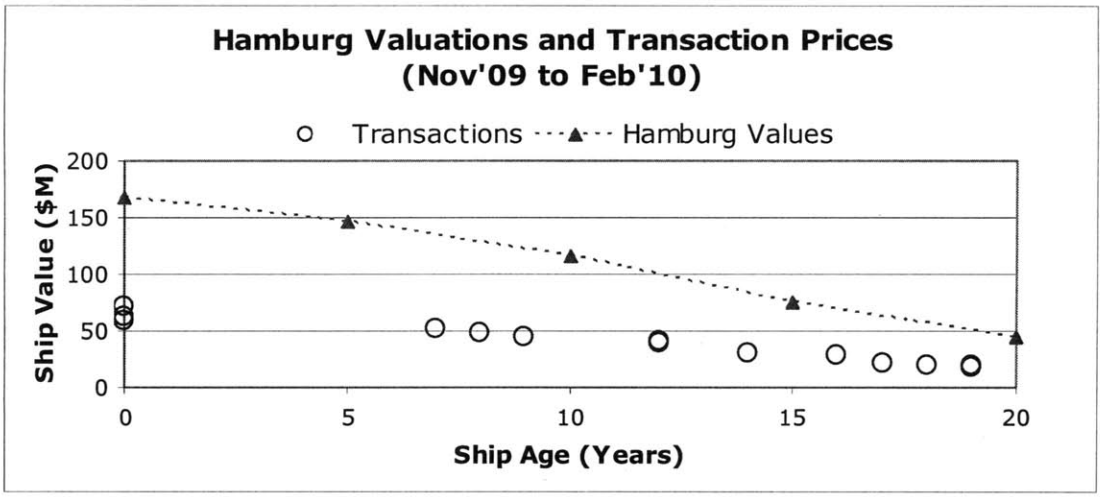


Fig. 5.7-19: Hamburg Valuation Results Compared to Actual Transaction Prices

It is clear from Fig 5.7-19 that the Hamburg valuations are much higher than current transaction prices across all ship ages.

5.7.5.2.4 Shadow Pricing

We will apply the shadow pricing method as described in Section 5.5.2.2, using our database of ~700 Cape Transactions between 1987 and 2010. This is a very complete database of reported Cape transactions, compiled with data from many sources and also includes the database of Sydney Levine who introduced the Shadow Valuation method. The first step is to identify the periods during which charter rates were the same as today.

According to the method, we have to look at the rates of specific fixtures over time. However, that would introduce uncertainty, because the details of the ship and the particular route and cargo come into play. Therefore, it is better to look at time series of average charter rates, as reported by brokers. Fig 5.7-20 shows historic 6-Month charter rates for 150,000dwt Capes and their current value (average from November 2009 to February 2010, which is $35,981/day), and the 1-Year charter rates for 127,500dwt Capes.

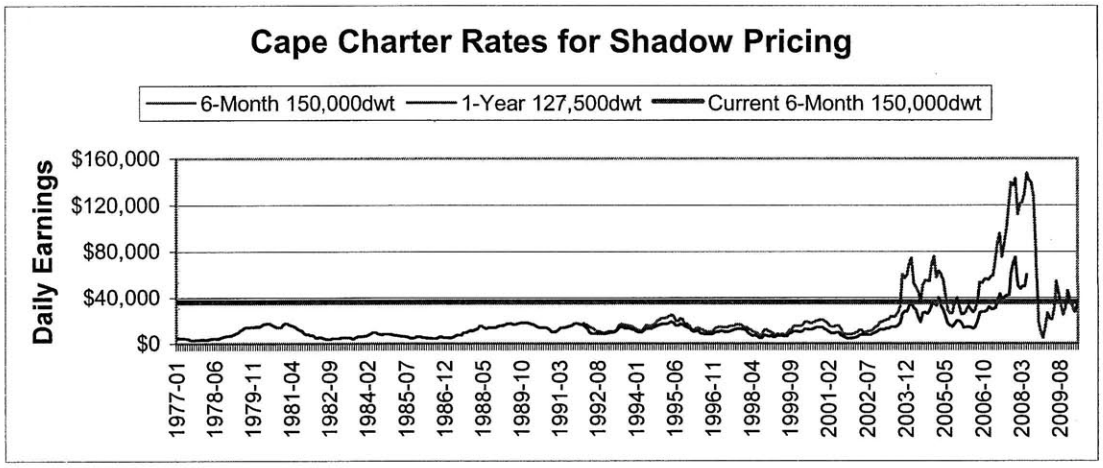


Fig 5.7-20 cape Charter Rate Series for Shadow Pricing

The reason for including the 1-Year charter rates of 127,500dwt Capes was because its is highly correlated to the more relevant data series and because that data goes further back in time. We see that the periods we are concerned with are all after 2003. As we saw in Chapter 2, all the Cape time charter series are almost perfectly correlated, so it doesn't make a big difference, which we look at. However, due to the extreme volatility of the market, particularly after 2003, it is important to look at daily data. With these considerations in mind, the most transparent and simplest thing to look at would be the BCI. This shows the spot rate which is almost identical to 6-month charter rates suggested by the Shadow pricing method.

The average BCI between November 2009 and December 2010 was $48,622/day. In the Shadow Pricing example of Section 5.5.2.2, a range between $14,000/day and $14,999/day was used when current rates were $14,000/day. Therefore, we will examine the range between $48,000/day and $48,999. Table 5.7-15 shows all the dates during which the BCI was within this range, along with the number of transactions closed on these dates.

Dates when BCI was Between $48,000 and $48,999	BCI ($/day)	Number of Cape Transactions Closed
13-May-04	48,820	0
3-Jun-04	48,011	0
1-Jul-04	48,809	0
24-May-05	48,136	0
7-Oct-05	48,972	0
24-Oct-05	48,890	0
25-Oct-05	48,608	0
26-Oct-05	48,835	0
27-Oct-05	48,992	0
28-Oct-05	48,773	0
31-Oct-05	48,356	0
10-Nov-05	48,627	0
17-Nov-05	48,248	0
31-Jul-06	48,363	0
6-Aug-09	48,000	0

Table 5.7-15: Dates When BCI was at Current Levels and Number of Cape Transactions

We identified 15 days during which the BCI was within our range, a zero transactions closed within those days. This shows the weakness of the Shadow-Pricing method, particularly for the valuation of Capes. The Ship-Charter rate pair that we examined is far less popular than the Panamax-$14,000/day pair used in the example by [Levine 2009]. More importantly, the Cape market is very volatile (see Fig 5.7-18), so earnings do not stay within a small range for long enough periods to allow transaction data to accumulate. Furthermore, if we try to relax the constraints and look at dates surrounding those of table 5.7-15, we will be looking at transactions that took place when rates were very different. Even doing so within reasonable limits, however, does not result in enough transactions to produce a distribution for each of the considered ship ages (from which we would then infer a shadow price).

I am sure one could relax some of the constraints and make alterations to increase the data sample in order to produce some shadow prices. However, we see that the method is currently inapplicable in its original form for this specific valuation.

5.7.5.2.5 Summary of Adopted Alternatives

The Comparables-based pricing and Short-Term forecasts cannot be considered independent valuations since they take market prices into account. We are mainly concerned about methods that produce independent valuations, in order to validate them using current transactions. These are essentially the Hamburg Valuation, the Shadow Pricing method, and our risk-adjusted forward-looking (RAFL) ship valuation model. Unfortunately, we saw that Shadow pricing cannot be used in the current situation due to various limitations. Fig. 5.7-21 compares our valuation model results and the Hamburg valuations to current transaction prices.

We see that our model produces results very close to real transaction prices, whereas the Hamburg Valuation method grossly overestimates ship values. Table 5.7-22 shows our valuation model results along with the real transaction prices, the comparables based valuations and the short-term forecasts.

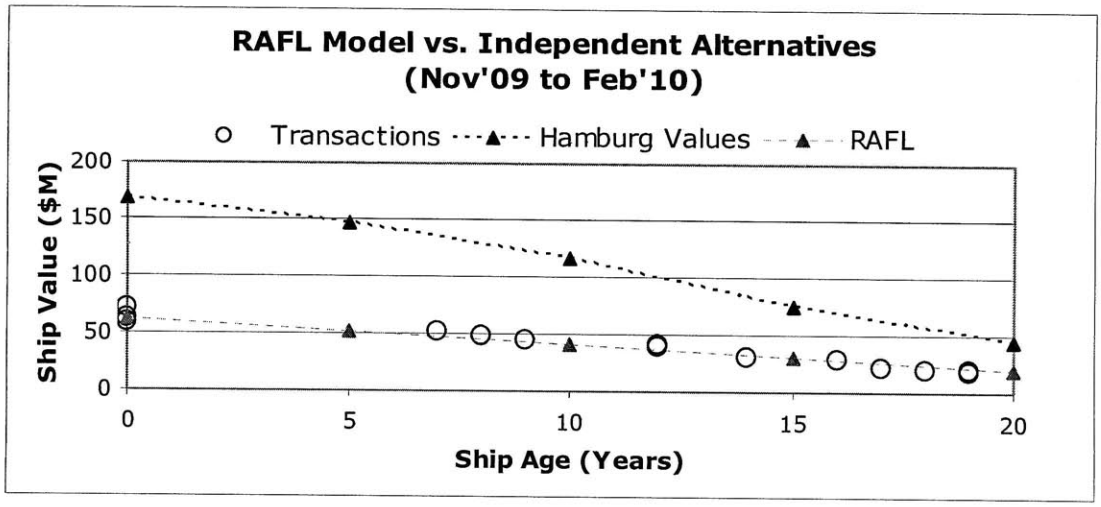


Fig. 5.7-21: Comparison of New Valuation Model (RAFL) with Alternative Independent Methods

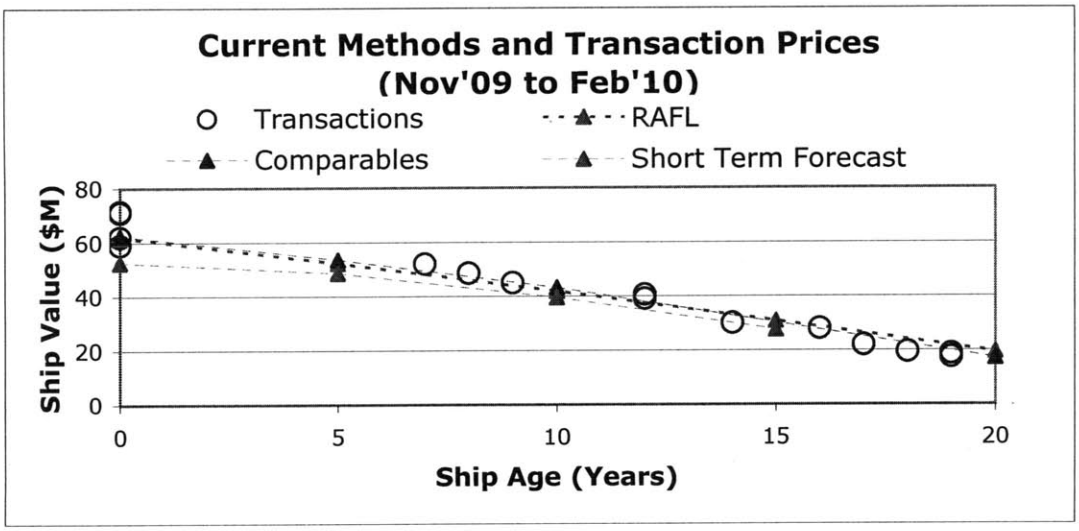


Fig. 5.7-22: Comparison of RAFL with Comparables-Based values and Short-Term Forecasts

In Fig 5.7-22, we see that the RAFL ship valuation results are almost identical to the Comparables-based values, which are inferred directly from the transaction prices. The Short-Term forecasts, which are partly based on market levels (until mid January), produce slightly lower results throughout all ship ages.

5.7.5.3 Valuations by Proposed Alternatives

5.7.5.3.1 Three Modified Shadow Price Versions

Here we will propose some modifications to the conventional shadow pricing method. We noticed that the method could not be applied in it original form because there was not enough data. The first modification attempts to solve that problem simply by looking at a wider range of dates. Instead of using the daily BCI, we will use the monthly data of average 6-Month time charters of 15,000dwt capes, that were shown in Fig 5.7-20. The current (over our 4 month period) average rate was $35,981/day (shown as a straight red line in Fig 5.7-20).

We identify 14 months in 5 distinct historical periods, during which the corresponding earnings passed through that range. Within this wide time frame, 60 Cape transactions are identified in our database. By taking the mean of the transaction prices for each age, we obtain the shadow price modification-1 valuations.

In the first modification, we only used a fraction of the 60 transactions (those of relevant ages). Alternatively, we can plot all the 60 transactions on a price vs. age plot and conduct a linear regression. Then we can calculate the shadow price modification-2 valuations for any age by simply solving the regression formula. A plot of the 60 transactions is shown in Fig 5.7-23, along with the linear regression.

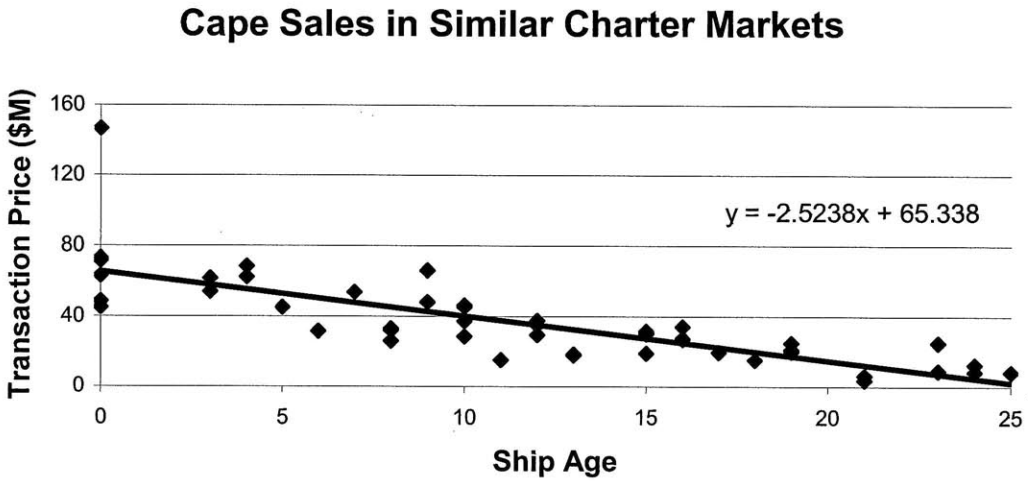


Fig. 5.7-23: Shadow Price Transaction Sample with Linear Regression for Modification-2

The scatter of the data reduces our confidence in the data. The outlier new Cape that cost $146.6M in August 2009 could have been a renegotiation from an earlier transaction that occurred before the market decline. Using the regression formula, we calculate the shadow price modification-2 valuations.

The third modification is based on value time series as opposed to real transactions. This is the modification discussed in Section 5.5.2.3 along with its reasoning and advantages. Instead of using the 60 identified Cape transactions, we look at Clarksons' valuations during the 5 identified periods with charter rates similar to current levels. Valuations had been discontinued by Clarksons but were recently filled out in retrospect. For each of the 5 periods, we calculate the average monthly valuation, and then we take the average across the

5 periods. That is because we want each period as opposed to each month to have the same impact on the result (to net out effects specific to each period). The results are summarized in Table 5.7-16. Table 5.7-17 summarizes the results of the three modifications to Shadow Pricing.

Month	Newbuilding (175-180kdwt)	5-Year-Old	10-Year-Old	20-Year-Old (150kdwt)
Sept - Oct 2003	43.00	38.00	25.75	8.50
June 2004	56.00	45.00	32.50	14.00
May - Nov (Exc. Jul) 2005	61.08	64.13	44.67	19.50
Jun - Jul 2006	61.50	58.25	41.00	18.50
May - Aug (Exc Jun) 2009	66.00	56.33	46.33	19.33
Average	**57.52**	**52.34**	**38.05**	**15.97**

Table 5.7-16: Clarksons Valuations for 5 Periods with Similar to Current Charter Levels

Ship Age (Years)	MODIF 1	MODIF 2	MODIF 3
0	70.84	63.34	59.25
5	45.00	51.20	56.52
10	37.15	39.06	40.93
15	28.40	26.91	-
20	29.14	14.77	17.36

Table 5.7-17: Modified Shadow Price Method Results

The results of the three modified shadow price methods are plotted along with transaction prices in Fig. 5.7-24

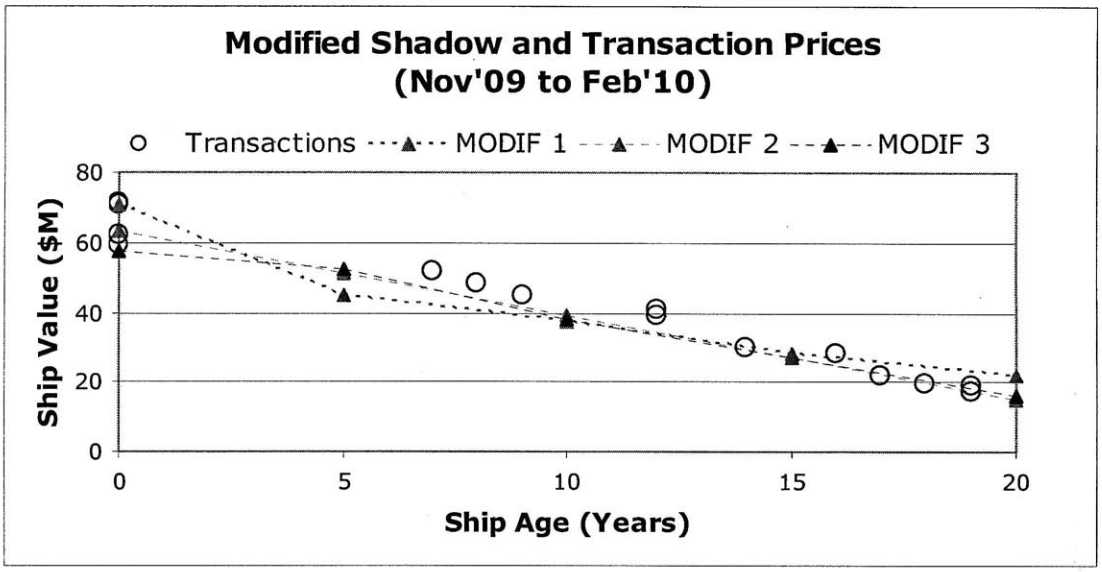


Fig. 5.7-24: Modified Shadow Price Method Results and Transaction Prices

We see that the modified shadow price valuations are very close to transaction prices but they all generally understate the values across all ship ages. Modifications 2 and 3 in this case give the results closest to the transactions. Modification 1, which is the most similar to the original method gives the least accurate results, though it is again in the ballpark. It is important to note that Modification 3 is the only one that can be applied without requiring a whole database of transactions.

5.7.5.3.2 Three Company Value-Based Valuations

In Section 5.5.3, we discussed the prospect of extracting ship values from company valuations. In Section 5.5.3.5, we carried out a valuation of DSX as of December 2009, using financial statements (discounting of abnormal earnings), and used it as an example. The reason we chose Diana Shipping was that it is very convenient for the valuation of Capes due to the composition of its fleet. The results of that analysis (found in Section 5.5.3.5) will be our first set of ship values based on company valuations ("Our DSX Valuation").

A second alternative would be to look at the average stock price at which DSX traded between November 2009 and February 2010. That was approximately $14.8. The price history of the DSX shares over that period is shown in Fig. 5.7-25.

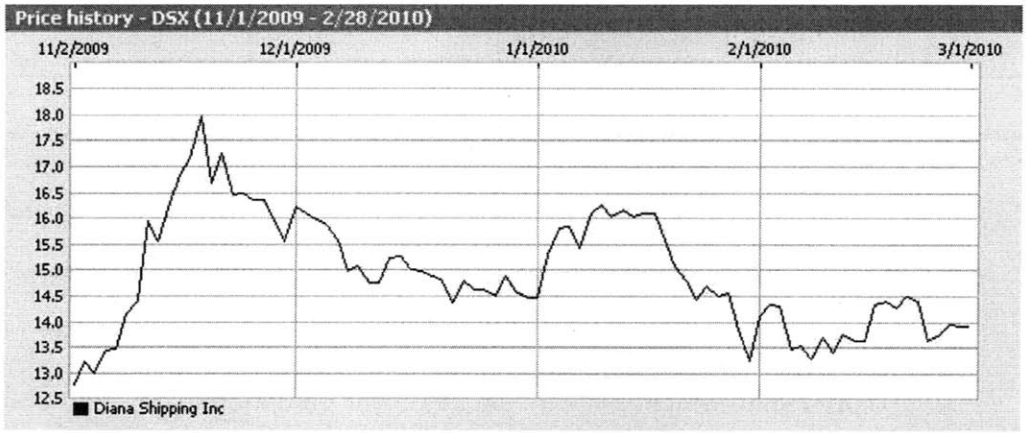


Fig 5.7-25 DSX Share Price Between November'09 and February'10 [moneycentral 2010]

We can simply use the $14.8 share price instead of our $12.34 share valuation, in the analysis of Section 5.5.3.5 to calculate a second set of Cape valuations with the same set of assumptions and fleet point allocation system.

The third alternative is to base the company valuation on external valuations by analysts, which are normally carried out using discounted cash flows. In November 2009, Credit Suisse carried out a valuation of Diana Shipping (using a 10% WACC) and to get a target price of exactly $20 (when the stock price was trading at 14) [Lewis 2009]. We will apply that value in the analysis of Section 5.5.3.5 to obtain the third set of Cape Valuations ("Analyst Valuation").

Table 5.7-18 summarizes the resulting Cape valuations based on company values, and Fig 5.7-26 compares them to the actual transactions.

Ship Age (Years)	Points	DSX Valuation	DSX Share Price	DSX Analyst Valuation
0	1	$82.77	$96.27	$125.27
5	0.82	$67.87	$78.94	$102.72
10	0.64	$52.98	$61.61	$80.17
15	0.46	$38.08	$44.28	$57.62
20	0.28	$23.18	$26.96	$35.07

Table 5.7-18: Company Value-Based Results

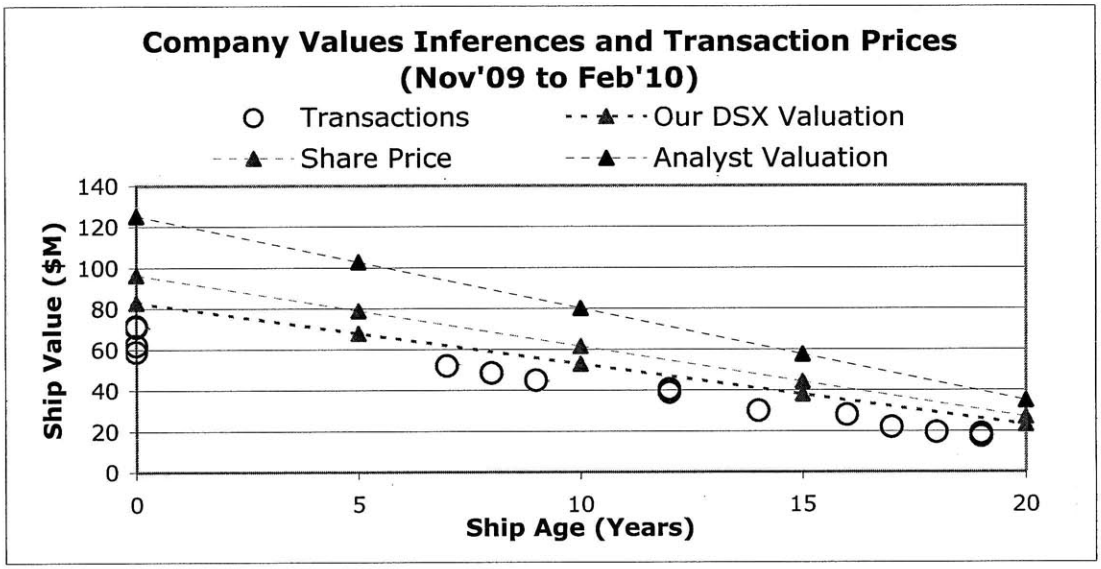


Fig. 5.7-26: Company value-Based Results and Transaction Prices

All the company value-based valuations tend to overstate the ship values relative to actual transactions. That could be partly because we may have underestimated the value attributable to intangible assets, company strategy, reputation etc. We simply used the book value of the non-ship assets (including goodwill and intangible assets), which may not be very accurate. The results based on our valuation lie the closest to the transaction prices, followed by the actual trading price of the stock, and the least accurate results are those inferred from the aggressive company valuation by Credit Suisse.

5.7.5.3.3 Summary of Proposed Alternatives

Our three modifications to shadow pricing tend to understate ship values, and our three company value based valuations tend to overstate ship values relative to ship prices in the considered time frame. The best results of each category were produced by the third shadow price modification and our DSX valuation. Fig 5.7.27 shows a plot of those two, along with our RAFL ship valuation model and the Cape transaction prices.

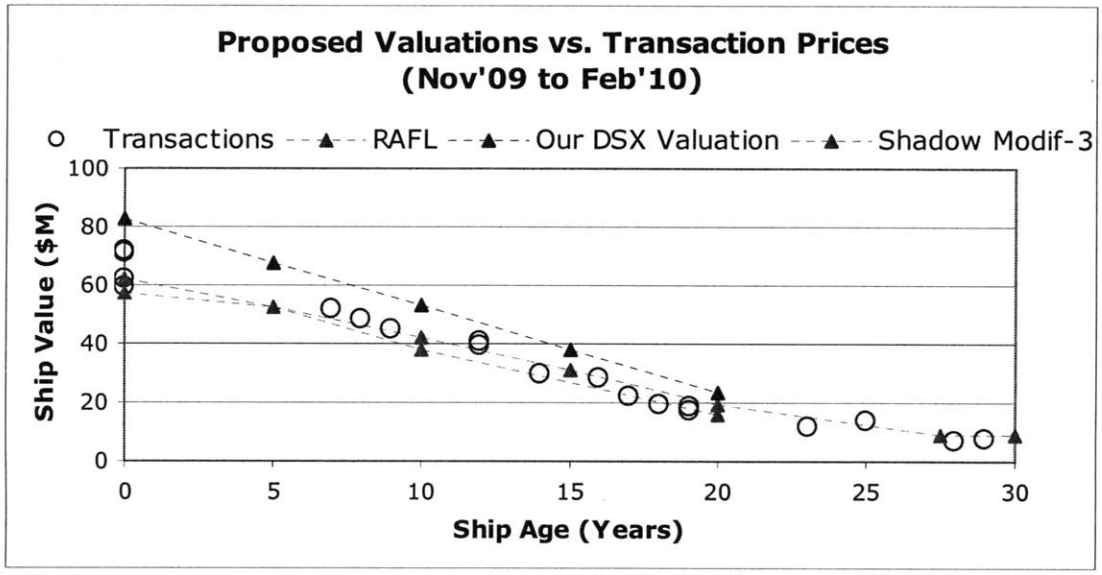


Fig. 5.7-27: Best Proposed Valuation Results and Transaction Prices

Of the three, the most accurate and reliable appears to be our RAFL model. The easiest to apply for a ballpark estimate is Shadow Modification-3, which appears to slightly understate the results in this case. The results inferred from our valuation using financial statements overstate ship values in this case but they are also useful to have as an alternative ballpark estimate.

5.8 Real Option Valuation

5.8.1 Introduction

An important issue during ship transactions is the subject to board of directors approval placed by the buyer or the seller. After the price and terms are agreed upon, one of the parties may not (or may pretend not to) have the authority to finalize the deal before the Board of Directors (BoD) approves it. The deal is signed "subject to BOD approval".

Depending on the company, the frequency of BOD meetings can vary. Typically, US listed companies require subjects of 1 week, while the major Japanese companies, commonly referred to as "the Big Three" (NYK, Mitsui and K-Line), often place subjects of 2 weeks. In the past few years, so called "hunting licenses" have also emerged, under which a buyer makes purchase agreements subject to raising the equity from investors. In those cases, typical subjects last for about 2 months. Options of longer tenures are also relevant when a vessel is sold with forward delivery in which case the buyer puts a deposit of 10% to 20%. Therefore, we will also consider a 6-month option and evaluate its value as a percentage of the ship value.

More often than not, the BOD approval to carry out the transaction is granted when the market value has moved favorably since the price was agreed, while the deal often fails on the subjects when the market moves unfavorably. Due to the high volatility of the shipping market, the implicit option to buy or sell a ship at the agreed upon price is very valuable. The party placing the subjects has that option, while the counterparty is tied to their agreement. It is vital to understand the value of these options when negotiating. A price premium can then be commanded in exchange for the option.

Modern financial technology allows us to estimate the value of these options by combining portfolio theory, option pricing theory, and the ship valuation model that we have developed.

5.8.2 Estimating the Volatility of Base Revenues

The key parameter required to value the option is the volatility of the ship value. In the valuations, we used average data over a 4 month period centered about Jan 1st, 2010, during which the markets were relatively stable. We could assess the daily volatility of the ship value by re-calibrating using the data available each day. This approach is limited by the time over which we can apply it. We could examine the historic volatility of earnings projected throughout the ship's life using time series of futures with various tenures. This is more practical but is arbitrary in the historic period that we choose to consider and its relevance going forward.

A more relevant approach would be to consider the forward looking volatilities for the ship's revenues based on today's at-the-money option prices. This was discussed in Section 5.6.3.1.10 and the results are repeated again here for your convenience.

	Description	Average	Movement
IV_CTC_CURMON	Mar (10)	81.86	0.46
IV_CTC_CURQ	Mar (10)	81.86	0.46
IV_CTC_+1Q	Q2 (10)	84.29	0.29
IV_CTC_+2Q	Q3 (10)	71.07	-0.43
IV_CTC_+3Q	Q4 (10)	62.21	-0.49
IV_CTC_+4Q	Q1 (11)	61.00	-0.4
IV_CTC_+1CAL	Cal 11	56.14	-0.66
IV_CTC_+2CAL	Cal 12	51.71	-0.39
IV_CTC_+3CAL	Cal 13	49.57	-0.23

Table 5.8-1: Implied Volatilities for Baltic Capesize Earnings as of March 22nd 2010 [Baltic 2010]

Using the same method as for projecting the base revenues throughout the ship's life, we can estimate the volatility for each year's base revenues for the next 10 years, including a continuation value. Base revenues refer to the earnings of a Baltic Cape before discounting for age. The results are shown in Fig. 5.8-1.

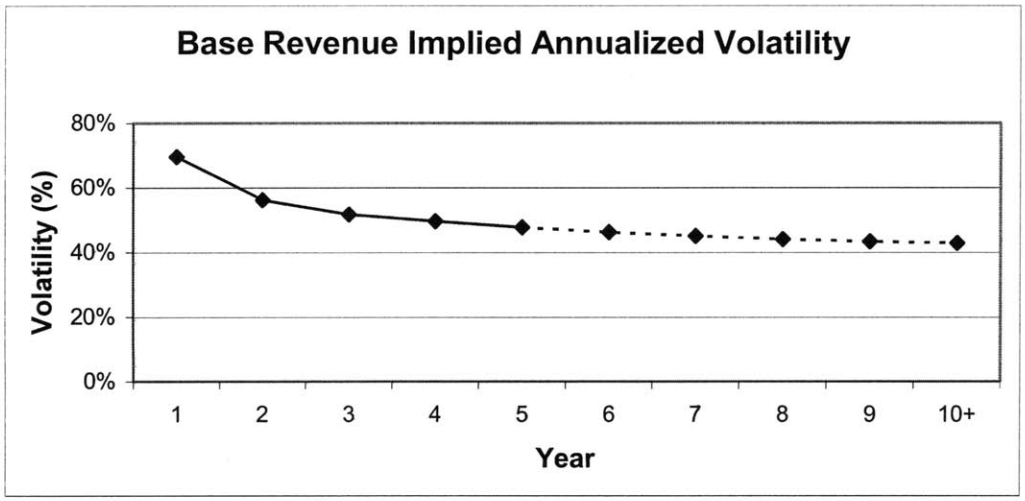


Fig.5.8-1 Implied Volatility of Revenues of a Baltic Cape, with Projections

The next step is to use portfolio theory in order to convert this result to a volatility of the ship value.

5.8.3 Application of Portfolio Theory

First, let's start with some basic definitions and identities of volatility (σ) and expectation (E):

$$\begin{aligned}
&\sigma_x^2 = E\left[\left(x-\overline{x}\right)^2\right] \\
&\sigma_{xy} = E\left[\left(x-\overline{x}\right)\left(y-\overline{y}\right)\right] = \rho_{xy}\sigma_x\sigma_y \\
&E\left(A+B\right) = E(A)+E(B) \\
&E(cA) = cE(A)
\end{aligned} \tag{5.8-1}$$

We are concerned with the volatility of a portfolio (p) of several assets (a, b, c etc). It is easier to start by deriving the volatility of a small portfolio. Below, we derive the volatility of a 2-asset portfolio and a 3-asset portfolio before moving on to the general case.

2-Asset portfolio: $p = w_a x_a + w_b x_b$ (5.8-2)

$$\begin{aligned}
\sigma_p^2 &= E\left[\left(w_a x_a + w_b x_b - w_a \bar{x}_a - w_b \bar{x}_b\right)^2\right] \\
&= E\left[\left(w_a \langle x_a - \bar{x}_a \rangle + w_b \langle x_b - \bar{x}_b \rangle\right)^2\right] \\
&= E\left[w_a^2 \langle x_a - \bar{x}_a \rangle^2 + 2 w_a w_b \langle x_a - \bar{x}_a \rangle \langle x_b - \bar{x}_b \rangle + w_b^2 \langle x_b - \bar{x}_b \rangle^2\right] \\
&= w_a^2 E\left[\langle x_a - \bar{x}_a \rangle^2\right] + 2 w_a w_b E\left[\langle x_a - \bar{x}_a \rangle \langle x_b - \bar{x}_b \rangle\right] + w_b^2 E\left[\langle x_b - \bar{x}_b \rangle^2\right] \\
&= w_a^2 \sigma_a^2 + 2 w_a w_b \sigma_{ab} + w_b^2 \sigma_b^2 \\
&= w_a^2 \sigma_a^2 + w_b^2 \sigma_b^2 + 2 w_a w_b \sigma_a^2 \sigma_b^2 \rho_{ab}
\end{aligned} \tag{5.8-3}$$

3-Asset portfolio: $p = w_a x_a + w_b x_b + w_c x_c$ (5.8-4)

$$\begin{aligned}
\sigma_p^2 &= E\left[\left(w_a x_a + w_b x_b + w_c x_c - w_a \bar{x}_a - w_b \bar{x}_b - w_c \bar{x}_c\right)^2\right] \\
&= E\left[\left(w_a \langle x_a - \bar{x}_a \rangle + w_b \langle x_b - \bar{x}_b \rangle + w_c \langle x_c - \bar{x}_c \rangle\right)^2\right] \\
&= E\left[\begin{array}{l} w_a^2 \langle x_a - \bar{x}_a \rangle^2 + w_b^2 \langle x_b - \bar{x}_b \rangle^2 + w_c^2 \langle x_c - \bar{x}_c \rangle^2 + \\ 2 w_a w_b \langle x_a - \bar{x}_a \rangle \langle x_b - \bar{x}_b \rangle + 2 w_a w_c \langle x_a - \bar{x}_a \rangle \langle x_c - \bar{x}_c \rangle + 2 w_b w_c \langle x_b - \bar{x}_b \rangle \langle x_c - \bar{x}_c \rangle \end{array}\right] \\
&= w_a^2 \sigma_a^2 + w_b^2 \sigma_b^2 + w_c^2 \sigma_c^2 + 2 w_a w_b \sigma_{ab} + 2 w_a w_c \sigma_{ac} + 2 w_b w_c \sigma_{bc} \\
&= w_a^2 \sigma_a^2 + w_b^2 \sigma_b^2 + w_c^2 \sigma_c^2 + 2 w_a w_b \sigma_a^2 \sigma_b^2 \rho_{ab} + 2 w_a w_c \sigma_a^2 \sigma_c^2 \rho_{ac} + 2 w_b w_c \sigma_b^2 \sigma_c^2 \rho_{bc}
\end{aligned} \tag{5.8-5}$$

General Case: $p = \sum_i^N w_i x_i$ (5.8-6)

$$\sigma_p^2 = E\left[\left(\sum_i^N w_i x_i - \sum_i^N w_i \bar{x}_i\right)^2\right] = E\left[\left(\sum_i^N w_i \langle x_i - \bar{x}_i \rangle\right)^2\right]$$
$$= \sum_i^N w_i^2 \sigma_i^2 + \sum_i^N \sum_{j \neq i}^N w_i w_j \sigma_{ij} = \sum_i^N w_i^2 \sigma_i^2 \rho_{ii} + \sum_i^N \sum_{j \neq i}^N w_i w_j \sigma_i \sigma_j \rho_{ij} \qquad (5.8\text{-}9)$$
$$= \sum_i^N \sum_j^N w_i w_j \sigma_i \sigma_j \rho_{ij}$$

Where:

p:	Returns on portfolio
N:	Number of assets in portfolio
w_i	Percentage of portfolio in asset "i"
x_i:	Returns of asset "i"
σ_i:	Volatility of returns on asset "i" (% volatility of asset "i")
ρ_{ij}:	Correlation between returns of asset "i" and "j"
σ_{ij}:	Covariance of returns of asset "i" and "j"

Note that by setting N equal to 2 and 3 we get the expressions for the volatility of the 2-asset portfolio and the 3 asset portfolio respectively.

5.8.4 Volatility of Ship Value

The next step is to treat the ship as a portfolio of assets, each with its own volatility. Each year in the remaining life of the ship is treated as a separate asset. The volatility of the expected cash flows in each year is then the volatilities of the assets. Recall the ship valuation formula in which the time increment is months.

$$ShipValue = \sum_{n=1}^{Life-Age_0} \frac{\text{Rev}_n - OpEx_n - \text{Rep}Cost_n - P(fail)_n FailCost}{(1+i_n)^n} \qquad (5.8\text{-}10)$$

The numerator is the cash flow that can be evaluated for each year "j". The denominator corresponds to a discount factor applied to each cash flow. The numerator defines the year's cash flows "CF_j" or equivalently, the value of the portfolio's assets, while the denominator defines the weight of each asset "w_j" as shown in Eq. 5.8-11:

$$ShipValue = \sum_j \frac{CF_j}{(1+i_j)^j} = \sum_j w_j CF_j \qquad (5.8\text{-}11)$$

First, let's concentrate on the volatility of the assets. Due to the nature of the shipping industry, the volatility of the revenues will be orders of magnitude greater than the volatility of the other terms (operating, repair and failure costs). The volatility of the residual value will also be low and far out, so we can neglect it in this part of the analysis. Recall our calculation of the monthly revenues:

$$\mathrm{Rev}_n = ED\left(Age_0 + n\right) * BCI_n * ARF\left(Age_0 + n\right) * \left(1 - \%Com\right) \qquad (5.8\text{-}11)$$

The revenues are equal to a constant that is defined for each time period multiplied by the daily earnings of a new ship for the same time period. The cash flows, will therefore be of the form:

$$CF_j = c_{1,j}\left(BCI_j\right) + c_{2,j} \qquad (5.8\text{-}12)$$

Where: $c_{1,j}$: Constant to account for commissions, age and off-hire time in year "j"

$c_{2,j}$: Constant to account for the non-revenue cash flows in year "j"

CF_j :Cash flows of year "j"

BCI_j :Equivalent daily revenues of a new (Baltic) ship for year "j"

Since $c_{1,j}$ and $c_{2,j}$ are constants, the following identities apply, where "c" is a constant, "X" is the variable and the bar denotes the mean value:

$$\sigma^2(c+X)=E\left[\left(c+X-c-\bar{X}\right)^2\right]=E\left[\left(X-\bar{X}\right)^2\right]=\sigma^2(X) \qquad (5.8\text{-}13)$$

$$\sigma^2(cX)=E\left[\left(cA-c\bar{X}\right)^2\right]=E\left[c^2\left(X-\bar{X}\right)^2\right]=c^2E\left[\left(X-\bar{X}\right)^2\right]=c^2\sigma^2(X) \qquad (5.8\text{-}14)$$

Applying Eq. 5.8-13 and 5.8-12 to 5.8-12 would lead to:

$$\sigma\left(CF_j\right)=\sqrt{c_{1,j}^2\sigma\left(BCI_j\right)} \qquad (5.8\text{-}15)$$

This would be the appropriate approach if we were concerned with absolute volatilities. It is equivalent, and in our case more convenient to carry out the analysis using volatility in percentage terms. This simplifies our analysis because we want to use a 10-asset portfolio where the 10th asset accounts for all years after the 9th. The percentage volatility will have a continuation value allowing us to do that. The value of c_1, however keeps decreasing, so the absolute volatilities keep changing which would require a 28-asset portfolio for a new ship. Also, note that our implied volatilities are in percentage terms, and the portfolio volatility has been derived in percentage terms (volatility of returns), making it more convenient to carry out the whole analysis using % volatilities. Using volatility in percentage terms, we can modify our identities as follows:

$$\sigma_{\%}(X)=\sigma\left(\frac{X}{\bar{X}}\right)=\sqrt{E\left[\left(\frac{X-\bar{X}}{\bar{X}}\right)^2\right]} \qquad (5.8\text{-}16)$$

$$\sigma_{\%}(cA)=\sigma\left(c\frac{A}{\bar{A}}\right)=\sqrt{E\left[\left(\frac{cA-c\bar{A}}{c\bar{A}}\right)^2\right]}=\sqrt{E\left[\left(\frac{A-\bar{A}}{\bar{A}}\right)^2\right]}=\sigma_{\%}(A) \qquad (5.8\text{-}17)$$

$$\sigma_{\%}(c+X)=\sqrt{E\left[\left(\frac{c+X-c-\bar{X}}{c+\bar{X}}\right)^2\right]}=\left(\frac{\bar{X}}{c+\bar{X}}\right)\sqrt{E\left[\left(\frac{X-\bar{X}}{\bar{X}}\right)^2\right]}=w_{\bar{X}}\sigma_{\%}(X) \qquad (5.8\text{-}18)$$

Eq. 5.8-17 tells us that the percentage volatility of the ship's total earnings is equal to the percentage volatility of the daily earnings of a Baltic Cape. Eq. 5.8-18 tells us that the percentage volatility of the cash flows is equal to the weight of the revenues multiplied by the percentage volatility of the revenues. Applying 5.8-17 and 5.8-18 to 5.8-12, we get the percentage volatility of the cash flows as follows:

$$\sigma_{CF,j}=\sigma_{\%}(CF_j)=\sigma_{\%}\left[c_{1,j}(BCI_j)+c_{2,j}\right]=w_{CF_j}\sigma_{\%}(BCI_j)=w_{\mathrm{Rev},j}\sigma_{\mathrm{Rev},j} \qquad (5.8\text{-}19)$$

Note that this also follows directly by considering each year's cash flows as a 2-asset portfolio consisting of revenues and costs, and applying Eq. 5.8-3 for the 2-asset portfolio volatility. The percentage volatility of the cash flows becomes:

$$\sigma_{CF}^2=w_{rev}^2\sigma_{rev}^2+w_{\mathrm{cost}}^2\sigma_{\mathrm{cost}}^2+2w_{rev}w_{\mathrm{cost}}\sigma_{rev}^2\sigma_{\mathrm{cost}}^2\rho_{rev,\mathrm{cost}}\approx w_{rev}^2\sigma_{rev}^2 \qquad (5.8\text{-}20)$$

From now on, we will only be concerned with percentage volatilities denoted by the symbol σ.

The value of the asset is the present value of the cash flows of the corresponding year. The weight of the revenues (in each 2-asset portfolio) is equal to the present value of the revenues divided by the present value of the cash flows. For each year "j" we have:

$$w_{rev,j} = \left(\frac{PV(\mathrm{Re}v)_j}{PV(\mathrm{Re}v - OpEx - \mathrm{Re}pCost - P(fail)FailCost)_j} \right) \tag{5.8-21}$$

The weights of the revenues will be calculated separately for each asset "i". The percentage volatility of the revenues is taken directly from Table 5.8-1. Then we simply calculate the percentage volatilities of each portfolio asset "i" as follows:

$$\sigma_i = w_{rev,i}\sigma_{rev,i} \tag{5.8-22}$$

Note that the absolute volatility of the cash flows is equal to the absolute volatility of the revenues, but the percentage volatility will be higher for the cash flows (the assets). Having the percentage volatilities of the assets "j", we proceed to calculate the percentage volatility of the 10-asset portfolio which is the ship value. Using the portfolio volatility definition derived in Eq. 5.8-9, we get:

$$\sigma_{ShipVal} = \sqrt{\sum_{i=1}^{10}\sum_{j=1}^{10} w_i w_j \sigma_i \sigma_j \rho_{ij}} \tag{5.8-23}$$

The revenues of future years are almost perfectly correlated. In other words, futures rates of earnings for the next years increase and decrease simultaneously. This is a good approximation which allows us to set all the correlations in our portfolio equal to one. Therefore, we have:

$$\sigma_{ShipVal} = \sqrt{\sum_{i=1}^{10}\sum_{j=1}^{10} w_i w_j \sigma_i \sigma_j} \tag{5.8-24}$$

Where the weight of each asset is given by its contribution to the portfolio:

$$w_i = \left(\frac{PV\left(\mathrm{Re}v - OpEx - \mathrm{Re}\,pCost - P(fail)FailCost\right)_i}{ShipVal} \right) \qquad (5.8\text{-}25)$$

Combining 5.8-21 to 5.8-25, we can express the percentage volatility of the ship value as follows:

$$\sigma_{ShipVal} = \frac{1}{ShipVal}\sqrt{\sum_{i=1}^{10}\sum_{j=1}^{10} PV\left(\mathrm{Re}v_i\right) PV\left(\mathrm{Re}v_j\right)\sigma_{rev,i}\sigma_{rev,j}} \qquad (5.8\text{-}26)$$

Using this method, we can proceed to calculate the annualized percentage volatility of the ship value for each ship age.

5.8.5 Application of Black-Scholes To Value Real Options

The final step is to use the Black-Scholes formula (described in section 5.6.3.1.10) to value an at-the money European option (strike price equal to the current ship value). Having calculated the volatility of the ship value, we can use the Eq. for geometric Brownian motion to describe the stochastic evolution of the ship value as follows:

$$\frac{dV}{V} = \mu dt + \sigma dz \qquad (5.8\text{-}27)$$

Where:

V:	Value (log-normally distributed)
dV:	Incremental change in value
μ:	Drift term
σ:	Volatility
dt:	Incremental change in time
z:	Wiener Process (Standard Brownian motion) – Normally distributed

Recall that we have treated the ship value as a portfolio of securities. The fact that the asset is replicable by a linear combination of securities, allows us to replace the drift term with the risk free rate. This enables us to use the risk-neutral valuation of Black-Scholes for option pricing on the ship value.

We choose European as opposed to American options because the ship will often be chartered and non-deliverable until the option expiration. When this is not the case, the real option is equivalent to an American option (exercisable any time before expiration) which is more valuable. We will use European options throughout for consistency.

The tenure will be chosen to correspond to the length of period of the subjects evaluated. We will consider 1-week, 2-week, 2-month and 6-month options and we will value both a call and a put since we are concerned with subjects placed by both buyers and sellers. The call option is the buyer's option (value of buyer's subjects) while the put option is the seller's option.

One approach would be to account for the dividend yield (equal to the present value of the profits per year divided by the ship value), and for the ship depreciation over time. These two effects will counteract each other. In our case, since we are concerned with short option tenures, it is simpler to assume that the delivery will be at a pre-specified date (which is typically at the end of the current voyage) and that the ship will be of the given age upon delivery. That way, convenience yield and depreciation do not come into play and we can apply a zero-dividend yield.

For the 1-week and 2-week options, the annualized risk free rate is taken to be 0.11% (1-Month T-Bill yield). For the 2-Month options, we look at the 2-Month T-Bills which have a yield of 0.15%, and for the 6-Month options we use the 6-Month T-Bill yield of 0.22%.

For a sensitivity analysis, we look at the "Greeks". The Black-Scholes formulae for pricing zero-dividend calls and puts were discussed in Section 5.6.3.1.10 and are presented again here.

$$C = SN(d_1) - PV(K)N(d_2) \qquad (5.8\text{-}26)$$

$$P = C - S + PV(K) = PV(K)\left[1 - N(d_2)\right] - S\left[1 - N(d_1)\right] \tag{5.8-27}$$

Where:

$$d_1 = \frac{\ln\left(\frac{S}{PV(K)}\right)}{\sigma\sqrt{T}} + \frac{\sigma\sqrt{T}}{2} \tag{5.8-28}$$

$$d_2 = d_2 - \sigma\sqrt{T} \tag{5.8-29}$$

The Greeks are defined as follows:

$$Delta = \delta = \frac{\partial F}{\partial ShipVal} \tag{5.8-30}$$

$$Gamma = \Gamma = \frac{\partial^2 F}{\partial^2 ShipVal} \tag{5.8-31}$$

$$Theta = \theta = \frac{\partial F}{\partial \tau} \tag{5.8-32}$$

$$Rho = \rho = \frac{\partial F}{\partial r_f} \tag{5.8-33}$$

$$Vega = \Lambda = \frac{\partial F}{\partial \sigma_{ShipVal}} \tag{5.8-34}$$

Where: F: price of the option (either a put or a call)

τ: time to expiration (in years)

The Greeks tell us how the value of the subjects will change with respect to a change in the ship value, the length of the subjects (how worth is it negotiating the time you or the other party has to decide before the closing), the interest rate and the volatility of the market.

5.8.6 Results

5.8.6.1 New Cape

$$ShipVal = \$61.85M$$

$$\sigma_{ShipVal} = 67.06\%$$

Asset "i"	w(i)	σ(i)
1	0.16	78.83%
2	0.11	66.41%
3	0.09	63.91%
4	0.08	63.25%
5	0.07	60.13%
6	0.06	61.73%
7	0.06	57.04%
8	0.05	58.68%
9	0.04	58.77%
10	0.28	70.34%

Table 5.8-1: Portfolio Volatilities for New Cape

Tenure	1 Weeks	2 Weeks	2 Months	6 Months
Call	**$2,294,602**	**$3,244,238**	**$6,741,625**	**$11,620,174**
Put	**$2,293,294**	**$3,241,621**	**$6,726,162**	**$11,552,171**
Call delta	0.51863	0.52634	0.55480	0.59461
Put delta	-0.48137	-0.47366	-0.44520	-0.40539
Gamma	6.93E-08	4.89E-08	2.33E-08	1.32E-08
Call rho	$572,795	$1,127,405	$4,595,993	$12,579,535
Put rho	-$616,693	-$1,251,521	-$5,710,751	-$18,313,808
Call theta	-$59,632,431	-$42,129,593	-$20,116,760	-$11,425,985
Put theta	-$59,564,392	-$42,061,556	-$20,024,001	-$11,290,054
Vega	$3,418,275	$4,828,896	$9,979,023	$16,955,912
Put theta	-$59,564,392	-$42,061,556	-$20,024,001	0.239412669
Vega	$3,418,275	$4,828,896	$9,979,023	-0.234773138

Table 5.8-2: Option Prices and Greeks for New Cape

	Value	% of Ship Value
1 Week Call	$2,294,602	3.71%
1 Week Put	$2,293,294	3.71%
2 Week Call	$3,244,238	5.24%
2 Week Put	$3,241,621	5.24%
2 Month Call	$6,741,625	10.90%
2 Month Put	$6,726,162	10.87%
6 Month Call	$11,620,174	18.79%
6 Month Put	$11,552,171	18.68%

Table 5.8-Summary of Option Prices for New Cape

5.8.6.2 5-Year Old Cape

$$ShipVal = \$52.21M$$

$$\sigma_{ShipVal} = 71.88\%$$

Asset "i"	w(i)	σ(i)
1	0.17	84.43%
2	0.12	68.75%
3	0.10	66.72%
4	0.09	65.33%
5	0.08	62.35%
6	0.06	67.77%
7	0.06	59.87%
8	0.05	64.19%
9	0.04	72.36%
10	0.23	77.73%

Table 5.8-4: Portfolio Volatilities for a 5-Year Old Cape

Tenure	**1 Weeks**	**2 Weeks**	**2 Months**	**6 Months**
Call	**$2,075,800**	**$2,934,703**	**$6,095,866**	**$10,513,049**
Put	**$2,074,696**	**$2,932,495**	**$6,082,816**	**$10,413,948**
Call delta	0.51996	0.52822	0.55866	0.60175
Put delta	-0.48004	-0.47178	-0.44134	-0.39825
Gamma	7.66E-08	5.41E-08	2.58E-08	1.45E-08
Call rho	$482,118	$947,779	$3,845,104	$10,451,434
Put rho	-$521,856	-$1,060,127	-$4,854,016	-$15,602,901
Call theta	-$53,939,365	-$38,100,776	-$18,171,897	-$10,319,455
Put theta	-$53,881,938	-$38,043,350	-$18,093,605	-$10,121,442
Vega	$2,884,693	$4,074,464	$8,410,858	$14,245,908

Table 5.8-5: Option Prices and Greeks for a 5-Year Old Cape

	Value	% of Ship Value
1 Week Call	$2,075,800	3.98%
1 Week Put	$2,074,696	3.97%
2 Week Call	$2,934,703	5.62%
2 Week Put	$2,932,495	5.62%
2 Month Call	$6,095,866	11.68%
2 Month Put	$6,082,816	11.65%
6 Month Call	$10,513,049	20.14%
6 Month Put	$10,413,948	19.95%

Table 5.8-6: Summary of Option Prices for a 5-Year Old Cape

5.8.6.3 10-Year Old Cape

$$ShipVal = \$41.92M$$

$$\sigma_{ShipVal} = 79.08\%$$

Asset "i"	w(i)	σ(i)
1	0.18	89.51%
2	0.14	71.61%
3	0.11	72.24%
4	0.08	78.95%
5	0.08	69.26%
6	0.06	75.84%
7	0.07	65.35%
8	0.05	75.63%
9	0.04	88.51%
10	0.19	88.08%

Table 5.8-7: Portfolio Volatilities for 10-Year Old Cape

Tenure	1 Weeks	2 Weeks	2 Months	6 Months
Call	**$1,833,352**	**$2,591,686**	**$5,379,915**	**$9,261,493**
Put	**$1,832,466**	**$2,589,913**	**$5,369,437**	**$9,181,924**
Call delta	0.52194	0.53101	0.56442	0.61140
Put delta	-0.47806	-0.46899	-0.43558	-0.38860
Gamma	8.67E-08	6.12E-08	2.91E-08	1.64E-08
Call rho	$385,489	$756,438	$3,046,608	$8,183,721
Put rho	-$420,613	-$855,732	-$3,938,015	-$12,735,601
Call theta	-$47,629,944	-$33,634,578	-$16,011,886	-$9,046,021
Put theta	-$47,583,835	-$33,588,470	-$15,949,024	-$8,887,034
Vega	$2,315,548	$3,269,726	$6,737,907	$11,360,812

Table 5.8-8: Option Prices and Greeks for 10-Year Old Cape

	Value	% of Ship Value
1 Week Call	$1,833,352	4.37%
1 Week Put	$1,832,466	4.37%
2 Week Call	$2,591,686	6.18%
2 Week Put	$2,589,913	6.18%
2 Month Call	$5,379,915	12.83%
2 Month Put	$5,369,437	12.81%
6 Month Call	$9,261,493	22.09%
6 Month Put	$9,181,924	21.90%

Table 5.8-9: Summary of Option Prices for 10-Year Old Cape

5.8.6.4 15-Year Old Cape

$$ShipVal = \$30.83M$$

$$\sigma_{ShipVal} = 88.18\%$$

Asset "i"	W(i)	σ(i)
1	0.22	95.81%
2	0.17	77.09%
3	0.12	83.37%
4	0.08	94.27%
5	0.09	79.48%
6	0.05	109.28%
7	0.07	81.12%
8	0.03	132.91%
9	0.03	134.43%
10	0.14	70.98%

Table 5.8-10: Portfolio Volatilities for 15-Year Old Cape

Tenure	**1 Weeks**	**2 Weeks**	**2 Months**	**6 Months**
Call	**$1,503,147**	**$2,124,616**	**$4,406,502**	**$7,567,473**
Put	**$1,502,495**	**$2,123,312**	**$4,398,797**	**$7,508,961**
Call delta	0.52445	0.53455	0.57169	0.62355
Put delta	-0.47555	-0.46545	-0.42831	-0.37645
Gamma	1.06E-07	7.46E-08	3.54E-08	1.98E-08
Call rho	$281,979	$552,035	$2,202,671	$5,826,701
Put rho	-$310,798	-$633,494	-$2,933,553	-$9,556,568
Call theta	-$39,040,799	-$27,558,575	-$13,085,740	-$7,341,351
Put theta	-$39,006,892	-$27,524,669	-$13,039,514	-$7,224,438
Vega	$1,702,142	$2,402,672	$4,939,108	$8,275,196

Table 5.8-11: Option Prices and Greeks for 15-Year Old Cape

	Value	% of Ship Value
1 Week Call	$1,503,147	4.88%
1 Week Put	$1,502,495	4.87%
2 Week Call	$2,124,616	6.89%
2 Week Put	$2,123,312	6.89%
2 Month Call	$4,406,502	14.30%
2 Month Put	$4,398,797	14.27%
6 Month Call	$7,567,473	24.55%
6 Month Put	$7,508,961	24.36%

Table 5.8-12: Summary of Option Prices for 15-Year Old Cape

5.8.6.5 20-Year Old Cape

$$ShipVal = \$18.41M$$

$$\sigma_{ShipVal} = 98.07\%$$

Asset "i"	w(i)	σ(i)
1	0.25	117.29%
2	0.18	92.22%
3	0.09	133.72%
4	0.08	134.15%
5	0.10	96.41%
6	0.05	162.98%
7	0.07	112.34%
8	0.17	16.97%
9	0.00	0.00%
10	0.00	0.00%

Table 5.8-13: Portfolio Volatilities for 20-Year Old Cape

Tenure	1 Weeks	2 Weeks	2 Months	6 Months
Call	**$998,190**	**$1,410,666**	**$2,922,730**	**$5,005,299**
Put	**$997,800**	**$1,409,888**	**$2,918,128**	**$4,970,355**
Call delta	0.52717	0.53839	0.57957	0.63663
Put delta	-0.47283	-0.46161	-0.42043	-0.36337
Gamma	1.59E-07	1.12E-07	5.30E-08	2.94E-08
Call rho	$167,434	$326,950	$1,291,127	$3,357,258
Put rho	-$186,582	-$381,066	-$1,776,306	-$5,829,872
Call theta	-$25,917,479	-$18,286,507	-$8,656,501	-$4,816,620
Put theta	-$25,897,229	-$18,266,258	-$8,628,894	-$4,746,797
Vega	$1,016,096	$1,433,643	$2,938,418	$4,885,528

Table 5.8-14: Option Prices and Greeks for 20-Year Old Cape

	Value	% of Ship Value
1 Week Call	$998,190	5.42%
1 Week Put	$997,800	5.42%
2 Week Call	$1,410,666	7.66%
2 Week Put	$1,409,888	7.66%
2 Month Call	$2,922,730	15.88%
2 Month Put	$2,918,128	15.85%
6 Month Call	$5,005,299	27.19%
6 Month Put	$4,970,355	27.00%

Table 5.8-15: Summary of Option Prices for 20-Year Old Cape

5.8.6.6 Summary of Results

Fig.5.8-2 shows the percentage volatility of the ship value as a percentage of ship age. Since all the options are at-the-value meaning that the strike price is equal to the current value, and because the dividend yield is zero, the call prices are almost identical to the put options. Fig.5.8-3 shows the mean option value as a function of time to expiration, for ships of various ages.

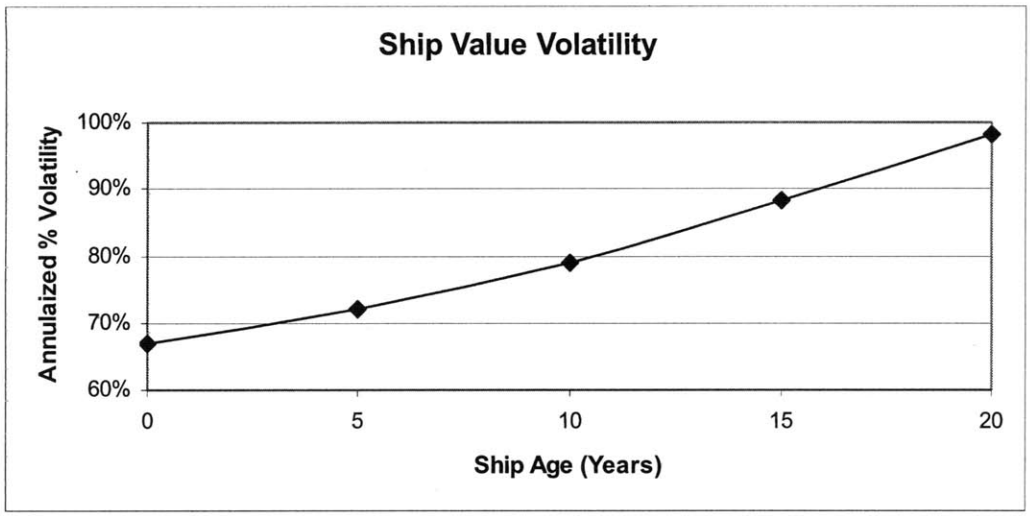


Fig. 5.8-2: Ship Value Volatility as a Function of Ship Age

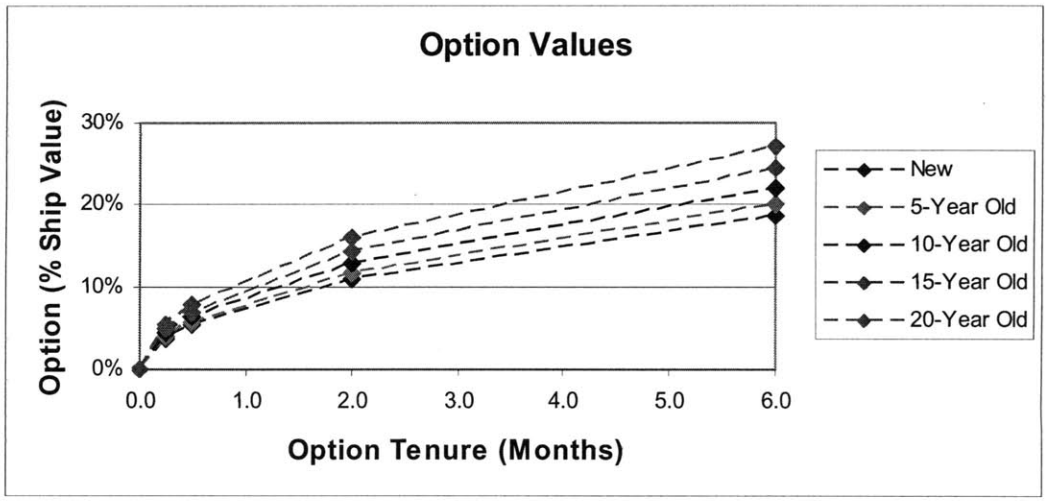


Fig. 5.8-3: Option Value vs. Option Tenure for Various Ship Ages

5.8.7 Discussion

As expected, the percentage volatility of the ship's value increases substantially with age. That is in agreement with historical trends and is partly explained by the fact the costs (which have negative weights and zero volatilities) are higher for older ships. In a bad market, the value of an old ship is close to the scrap value so when freight rates rise it is impacted much more than that of a new ship.

As shown by the results, the option values are very significant and have to be considered when negotiating subjects. The option value as a percentage of the ship value increases with ship age, but more importantly, it increases with the option tenure. This can be seen by examining the "Theta" values of the options and by looking at Fig. 5.8-3. The value of 2-week subjects (typical with Japanese companies) is slightly less than twice the value of 1-week subjects (typical with US listed companies).

In practice, there are reputational constraints that may hinder some companies from failing a deal on the subjects. For many companies, the subjects are simply a formality with no implicit option. In some cases, particularly when a deposit has been paid and a deal has been signed, they might also be legally bound. This would decrease the value of the option assuming that it would still be exercised if the loss is small. There is also a factor that may increase the value of the options in some cases. Sometimes, the option can be exercised before expiration. Modeling the subjects as an American option (as opposed to European) would be more appropriate in that case and would result in a higher value.

It is important to understand that the option prices do not correspond to appropriate deposit amounts. After the expiration of the option, the full value of the ship must be paid. The calculated option values correspond to the fair non-recoverable amount the party who places the subjects should pay.

It is common practice to accept a better price in order to compensate for the option value. This in fact corresponds to giving out an out-of-the-money option (with the strike price being "worse" than the market value), for free. Say we are the seller of a new ship which has a market value at $61.9M. If a buyer wants to lock the price but have a week to decide, they have to pay us $2.3M. This will compensate us for holding on to the ship in the event that the market value increases. Even if the agreed upon price is $100M, the

assumption is that after 1 week, they will only buy the ship if it is worth more than $100M (in which case we would want to keep it). No matter how high the strike price, one should not give out an option at zero value (under our assumptions).

In reality, there may be cases where the buyer values the ship above market values and the need for approvals is sincere. However, we are assuming a liquid market in which they can simply buy another vessel at market value and we can sell ours to someone else at the market value.

One may think that a high enough deposit, which will then be deducted from the price upon delivery, can also compensate for the option value. This is not possible if the agreed upon price is equal to the market value. One is always better off by selling the ship today at its market value. Note that the delivery date is constant so convenience yield does not come into play. We can see that by formulating the problem as follows. We have to value a call option (C) which is paid as a deposit, and for which the strike price (K) is equal to the ship value less the deposit:

$$Deposit = C(K = ShipVal - Deposit) \qquad (5.8\text{-}27)$$

This can be solved by iteration and has only one solution whereby the full amount is paid as a deposit and the strike price is equal to zero. In other words, the total amount paid for the ship should be higher than the market value if an option is involved regardless of the deposit amount.

This analysis can be very valuable when quantifying the fair price premium and deposit when buying or selling a ship with subjects, and also when designing the payment structure for a newbuilding (price and % paid upon signing, steel cutting, keel laying and delivery etc).

CHAPTER 6

Summary Conclusions and Recommendations

6.1 Introduction

The objective of this work was to examine the capesize industry both from a technical and a financial perspective and to analyze data in order to produce results and tools that will be valuable to various constituents of the shipping industry. We examined both market and structural safety characteristics of Capes as well as maintenance costs and hedging options to ultimately produce results that can guide important decisions and also to create a state of the art valuation model that is urgently needed in the industry.

6.2 Summary

We started with a detailed analysis of the economics of the capesize industry and the various factors affecting the market. This involved the use of large amounts of real data to examine ship earnings, second hand values, newbuildings and the paper market. Particular attention was paid to the behavioral aspects and the way these influence newbuilding ordering patterns and ship prices depending on the ship's age. This whole analysis provided the necessary background for making the relevant decisions in the later stages of the thesis, particularly when analyzing existing valuation methods and when deciding the right approach and details for the new valuation model that was developed.

We then shifted gears to focus on cracks which are a technical aspect that is of critical importance to Capes. An extensive literature survey was carried out focusing on several aspects related to cracking. These include factors such as fracture mechanics, monitoring, repairing and designing against cracks, ship design, steels, operating stresses and cargo operations etc. Hull stresses were examined in order to compare their distribution to that of cracks throughout the hull. The still-water bending moments acting throughout a cape's service life were investigated using ships' log books and cargo loading software. Wave induced bending moments were sourced from tabulated values of classification societies.

A location coding system for data recording and processing was specifically devised in order to present the frequency, size and estimated crack growth rates with respect to location in the hull and ship age. It was modified and improved several times throughout the process and is now recommended for further use in future similar projects. It is easily adaptable to a variety of applications. A sample of 29,567 cracks from 240 ships was assembled and analyzed using this system and proved to be representative of the world fleet. This is perhaps the largest ship crack survey ever conducted and is one of the few to be so specific regarding the type of ship and damage. More importantly, it focuses on one of the most critical issues in the industry. Whenever possible, data for each repair was sourced from both shipowners, classification societies' records and ship yards to ensure its completeness.

Similarities were observed between the stress and crack distributions throughout the hull. Some noise exists due to other causes of cracking and the structural enhancement of certain areas. The results indicate that many cracks can be avoided by remaining within certain stress limits. This can be achieved by avoiding heavy weather, adjusting the sailing speed and direction to weather conditions, care during discharging, and reducing the rates of cargo operations to avoid deviating from loading plans. An interesting finding was that the mean and median crack size decreases with ship age. This is due to tighter inspection intervals and requirements combined with, design improvements during repairs.

The results were compared to those of similar surveys conducted over the past 50 years. Many similarities were observed while discrepancies were often attributed to the different focus of each work cited. For example, the work of [Yamaguchi, I. 1968] focuses on relatively young ships and identifies different numbers of cracks per ship with respect to ship age, while [Antoniou, 1977] has probably not captured the initial slope of the crack size vs. ship age graph in oil tankers. Classification societies are often only concerned with a small subset of cracks which are threatening, as is clear by the number and size of cracks in some of their surveys and investigations. The differences in results from other studies highlight the importance of sample size and lead to the conclusion that cracks follow different patterns from other damages and that Capes behave differently from other ships. This emphasizes the importance of highly specific projects based on a large data set, focusing on a particular type of damage in a specific ship type and size range.

The types of repairs and design modifications for the various cracks were also recorded and analyzed. This analysis led to conclusions regarding the general approach depending on the crack size, cause and location. Some of the recommended repairs by classification societies, such as the use of a face plate instead of a collar plate in manholes, were reported less frequently than others, presumably because they are less practical.

Crack growth rates were analyzed and compared to theoretical fracture mechanics predictions. Paris Law was found to be over-conservative, in line with recent independent findings. Three alternative, less conservative approaches were introduced and tested using the data of cracks in shell frame brackets. The one which appears to be most accurate requires the calibration of a parameter throughout the hull which was beyond the scope if this

project. Using the data, we found that a linear approximation is accurate enough within the range that we are concerned with.

Crack growth rates were determined to follow a bathtub curve with respect to age, which is the superimposed effect of an initial value, design modifications during repairs and corrosion as the ship ages. This had not been identified before in shipping. The independent effects that result in the bathtub curve were decomposed at the aggregate level by making some assumptions based on the data and on results of previous research. Crack growth rates were higher at the hull locations where still water bending moment stresses was greater, whereas higher crack frequencies were observed at locations where wave induced bending stresses and deflections are greater. This supports recent independent findings which suggest that crack initiation results mainly from high frequency, low amplitude stresses, while crack growth rates are mainly governed by large amplitude, low frequency stresses.

A Danger Model was developed using the crack growth rates derived from the database and the criticality of each location based on previous accidents, wave induced bending moments and a survey of industry experts. The Model was applied to the ships of the database and an average safety parameter was determined as a function of age. Safety was found to decrease with age until about 20 years, after which it gradually increases again. Although very little scrapping occurred during the past 10 years, during which most the data was collected, the results could be partly influenced by the fact that lower quality ships tend to be scrapped early, resulting in a biased sample of older ships. The Danger Model was also used to determine how much danger is contributed by each location in the hull depending on the ship's age. This is particularly useful to inspectors when deciding which areas to focus on.

A crack failure database was collected, consisting of 82 Capes, 740 ship years, and 36 crack failures (34 emergency repairs and two sinkings). A reliability model was developed by modifying the Weibull duration model so it starts from a non-zero value and then combining a series of modified Weibull models to represent repair intervals. The danger model results were validated using the crack failure database and then the two sets of results were combined and used to calibrate the reliability model which gives hazard function throughout the ship's life. The hazard function gradually increases between repairs with significant

sudden drops during each repair. Its maximum value is reached just before the fourth special survey at 20 years of age.

The present value of expected failure costs was estimated as a function of ship value throughout the ship's life. Historical average values of ship earnings and prices were used to do that, along with the cost of repairs as of Sept 2008, the hazard function throughout a ship's life, average bunker costs and repair times etc. Approximately half of the cost was accounted for by expected loss of hire. The present value of crack failure costs as a percentage of ship value peaks at ~5.7% at 19 years of age based on historical data.

Repair procedures and design modifications were also examined and a model was designed to assess their cost effectiveness based on the present value of projected cracks in each location. The crack repair costs were calculated as a function of ship age to be used in conjunction with the safety assessment for decision making that involves cost and safety tradeoffs.

Having calculated the hazard function, the crack repair costs and the crack failure costs, we proceeded to develop a much needed state of the art ship valuation model. This combines the technical and economic insights gained from earlier chapters with additional analysis, to produce a fundamental valuation based on risk-adjusted discounting of expected cash flows.

Even when looking at the same data, people's perceptions of the market outlook, which translates to ship values, differs greatly. As of April 15th 2010, the world fleet stands at 1,001 Capes of 178.6Mdwt while there are another 768 of 146.8Mdwt on order including VLOCs of 400,000dwt each. Due to the high shipbuilding capacity that has been built over the past decade, shipyards are hungry for orders and are reducing prices prompting more orders. Since the containership and tanker markets are currently in a worse situation, most of the new orders will come from the bulker sector. This means that more ships will probably be delivered over the next four years than indicated by the current orderbook, while scrapping will continue to be limited unless the market declines to the point were older ships are unprofitable. I believe that oversupply will cause the market to decline and that sooner or later we will see ship values at levels comparable to those of the 1990s. Others on the other hand cite the projected needs of developing countries including China and India and have a more optimistic view.

To get around this issue of subjectivity, people often use historical values as projections for the future. This is equivalent to driving on a highway while constantly looking at the rearview mirror. A more relevant approach is to deduce a forward view of what the market currently thinks the various parameters will be in the future. The benefit of this is that one can bet against those views if they disagree. In our new risk adjusted forward looking (RAFL) ship valuation model, a forward view of the main parameters is obtained from derivatives and financial securities that include shipping futures, FFAs, options, interest rate swaps and inflation protected bonds. The inherent risk of cracks is treated as a fictitious credit risk, derived from the reliability model, and is incorporated into the discount rate along with other risk premiums.

Other inputs to the model include repair costs and off-hire time. A database of 348 Cape repairs, involving the replacement of 135,780 tons of steel was compiled and analyzed to estimate these as a function of ship age. The operations of publicly traded and private companies are then compared, before using records and conducting surveys with both types of companies to project operating expenses. An inflation analysis is also carried out for this purpose using inflation protected bonds to get a forward view on inflation.

The valuation results were in very close agreement with real market data. The model was compared against other proposed valuation methods and the results indicate it is significantly more accurate and reliable. A sensitivity analysis was carried out and the credit spreads due to cracks were determined as a function of ship age. The model was also extended to estimate the volatility of the ship value and uses it to price optionalities that are often included in ship transactions. These proved to be very expensive and should be carefully considered during transactions by shipowners, or shipyards. The model provides a framework for doing so.

The derivatives markets are getting traction and new instruments are continuously being introduced. This year, Clarksons introduced a SWAP on container freight, while tanker futures in $/day as opposed to World Scale (WS) were traded for the first time this month. This will increase liquidity and the involvement of non-shipping related investors including hedge funds, prompting more advancements in derivatives markets. It is likely that new derivatives will be introduced relating shipping returns to S&P 500 returns. This will enable us to determine a forward view of the market beta for public investors as a function of time

(described in Section 5.6), allowing us to calculate a completely forward looking estimate of the discount rate. The method for applying it when the financial technology catches up has been described.

6.3 Conclusions

Our analysis of cracks led to results of crack safety and cost with respect to ship age, that is particularly useful to ship owners, classification societies, underwriters and others. The danger contributions of each compartment and specific location in the hull were estimated as a function of ship age. This, together with the crack distribution results can be used to guide inspectors to the most critical locations and to those more likely to have cracks depending on the ship's age. This applies equally to inspectors of classification societies, the port state control or flag authorities. We also used the safety model to analyze inspection intervals and produce results that can be used by classification societies to decide at which ship age and for which locations inspection intervals may be tightened or relaxed.

Regarding the fracture mechanics community and researchers concerned with cracks in ships, our investigation of Paris Law applicability in ships and the three proposed modifications that were tested with the data give some potential direction of future research. They also highlight the need for further research in the area. Equally important is our approach to quantifying the magnitude of the problem in terms of cost and to demonstrate the potential savings that could be achieved by further research. The existence of a Bathtub curve to describe crack growth rates and its decomposition to the constituent components is also an important new discovery.

The model that was used to evaluate the cost effectiveness of design modifications is valuable both to shipyards that make new designs as well as to ship owners who often change the local design following the emergence of cracks. The reliability model which yields the hazard function throughout the ship's life is very useful to insurance companies in deciding which ships to insure and what premiums to demand depending on the ship's age. It is also a useful guide to the IMO and other organizations when setting regulations, classification societies when setting their rules and monitoring the safety of the vessels, charterers when weighing the safety tradeoffs in deciding which ships to charter and to ship owners when making operational or investment decisions such as buying, selling, repairing or scrapping ships of a certain age.

Finally, the RAFL ship valuation model is particularly needed in the shipping industry because market changes have rendered traditional methods inaccurate and very often inapplicable, while alternatives that have been introduced are inaccurate and in several cases have received significant criticism for the bias involved in their design. The integration of the effect of cracks both in the costs, as well as in the discount rate as a risk factor, and the use of derivatives to obtain a forward look on the key model parameters are elements that have not been applied before in the shipping industry and are major contributions of this thesis.

The model's volatility estimation of the ship value is particularly useful for a variety of purposes including the pricing of optionalities included in subjects to deal approval, delivery time, payment structure e.g. in newbuilding contracts etc. No other existing model produces these results. Another important advantage of the model is that it yields the sensitivity and decomposes the ship value in terms of various parameters, over which a shipowner may potentially have some influence. Besides combining the important technical and financial elements in an innovative way, the ship valuation model produces results that are in excellent alignment with the real transaction data and is also applicable even in dysfunctional markets when there are often no alternative methods. This makes it very valuable to many involved in the shipping industry who are concerned with ship values.

In summary, the thesis combines closely interlinked technical and financial elements to produce results and develop tools that are of great value to many members of the shipping industry. This includes brokers, accountants, analysts, shipping banks and investors interested in valuation; ship owners when making managerial or investment decisions; shipyards when designing ships, setting prices and deciding payment structures and options; insurance companies when covering total loss or emergency repairs; the IMO and other organizations when setting regulations; researchers when attempting to quantify the potential benefits and cost savings from their research; and classification societies when scheduling inspections and deciding which areas to examine more closely in each survey.

6.4 Recommendations

Although it hasn't been the main focus of this research, investigating the frequency of cracking with respect to the shipbuilding yard would be an interesting and important area for future research. Classification societies and shipowners would also be interested in the effects of hull maintenance on cracking while the effect of corrosion and wear of scantlings would be useful to IACS and individual classification societies for the development of new rules. Further research in the effect of cracking with respect to ship age would mainly be of interest to underwriters, charterers and cargo terminal operators who have imposed an age limitation of 25 years on Capes that are used for the transportation of iron ore. Another aspect which has become of outmost concern in the last few years is that of high loading and discharge rates. An investigation into the influence of loading rates on cracking and its safety implications would be of great interest to many including ship owners, cargo terminal operators and the IMO.

The demonstrated over-conservativeness of the Paris Law led us to introduce three new modified Paris-law models. One of them can be particularly useful but involves a parameter that needs to be calibrated for each ship location. This could be a useful future project, similar to the calculation of stress intensity factors for various geometries. Future research could also focus on further investigation of the bathtub curve that was identified with respect to crack growth rates and ship age.

A promising area of future research would be to apply various elements of our research to other ship types including tankers or other size groups such as Panamaxes. Examples include the research done on cracks and the valuation model developed. Alternatively, one may investigate the potential of improving the RAFL ship valuation model. One approximation of the model was the risk neutrality of investors when incorporating the Hazard function as a credit spread. This partly relies on adequate diversified investors. In cases where this does not hold, the effect of cracks on the discount rate is understated, resulting in a higher valuation. The effect will be different for each investor. One could examine the possibility of adjusting the hazard-spread in each case by

using the utility function or risk averseness of the investor in question, perhaps based on portfolio Sharpe-Ratios and investment decisions.

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