Market Characteristics of Future Oil Tanker Operations

by

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B.S. Naval Architecture and Marine Engineering, Webb Institute (2010)

Submitted to the Department of Civil and Environmental Engineering and Department of Mechanical Engineering in partial fulfillment of the requirements for the degrees of

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Abstract

This work analyzes the market characteristics of future oil tanker operations with a particular emphasis on those aspects which will have a potential impact on the design of future vessels. The market analysis model used is unique in that it segments historical distributions of time charter equivalent rates to account for market variability in ship design. Market cycles, trade routes, refinery locations, cargo prices, and fuel prices are all targeted as key evolving factors over the next twenty-five years and are considered in a sensitivity analysis on metrics of profitability and tanker operations.

The study's analytical approach to accounting for market factors in speed selection can serve as a tool for shipowners in scenario planning by better preparing them for projected market conditions. It is intended that shipowners and operators would refer to this analysis in conjunction with market forecasts to determine which speed a ship should be designed at to maximize return. If the market is expected to be reaching a peak, this study's model can determine how much higher TCE rates need to be than historical values to justify speeding up by a given increment. Though slow steaming saves costs when the market is down, to fully take advantage of market peaks and maximize profit over a ship's lifetime, ships must have sufficient reserve power.

Thesis Supervisor: Henry S. Marcus
Title: Professor Emeritus of Marine Systems of Mechanical Engineering

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Foremost, I would like to express my deepest thanks to Professor Hank Marcus. His wise guidance, patience, and dedicated passion for teaching gave me the encouragement to thrive at MIT. He not only selflessly shared his knowledge of shipping with me, but while I wrote this paper he also greatly helped me with organization of thought, communication, and several other skills that are more difficult to teach and pass on than they sound.

Professor Marcus challenged me to explore different strategies to approaching problems while simultaneously working productively toward a meaningful end deliverable. I cannot imagine working for a better advisor. His lasting legacy has and will continue to influence generations of minds both locally at MIT and globally in the maritime shipping industry.

I also thank my parents Don and Amrita, Preeta, and Chris for faithfully cheering me on in all that I attempted while at MIT. And I am grateful for the invaluable friends who positively defined my experience here – Simone, Sunny, Meisy, Anna, Esther, Yi-Hsin, and Kim.

Lastly, a special mention to Chris Wiernicki and the American Bureau of Shipping for their critical and much appreciated support.

"Admire a small ship, but put your freight in a large one;

for the greater the lading, the greater will be your piled gain,

if only the winds will keep back their harmful gales."

— Hesiod
Works and Days
(circa 700 BCE)

Content

Nomenclature and Definitions

BPD	Barrels Per Day
CAPEX	Capital Expenditures
CDF	Cumulative Distribution Function
DWT	Deadweight Tonnage
EEDI	Energy Efficiency Design Index
EIA	U.S. Energy Information Administration
HFO	Heavy Fuel Oil
ICC	Inventory Carrying Cost
IEA	International Energy Agency
MCR	Maximum Continuous Rating
MDO	Marine Diesel Oil
MEG	Middle East and Gulf
NPC	National Petroleum Council
OECD	Organisation for Economic Co-operation and Development
OPEX	Operating Expenses
PDF	Probability Density Function
RJC	Relative Joint Contribution
RFR	Required Freight Rate
SFOC	Specific Fuel Oil Consumption
TCE	Time Charter Equivalent
TOE	Tonne of Oil Equivalent
TPY	Tonnes Per Year
ULCC	Ultra Large Crude Carrier
VLCC	Very Large Crude Carrier
WTI	West Texas Intermediate

1. Chapter 1

Introduction

1.1. Executive Summary

This study represents MIT's role in the American Bureau of Shipping's Innovative Tanker Design Study with Herbert Engineering Corporation and other collaborators from industry and academia. To support ABS's vision, the market characteristics of future oil tanker operations are analyzed with particular emphasis on those aspects which will have a potential impact on the design of future vessels. Market cycles, trade routes, refinery locations, cargo prices, and fuel prices are all targeted as factors to consider over the next twenty-five years.

As slow economic growth weakens global oil demand, most tanker owners and operators are slow steaming their vessels in order to increase earnings and expedite recovery. However, tanker rates will not always remain at depressed levels, and future tankers should be designed to operate profitably for entire market cycles.

1.1.1. Trade Routes

The geographical dislocation of oil production and consumption centers drives the demand for ocean transportation. As regions of oil supply and demand develop, ocean trade routes will be altered along with the distance that vessels are required to travel. The primary factors affecting the evolution of shipping movements include refinery construction, oil production, and changing global demand. A comparison of OGJ's Worldwide Construction Update on refinery capacity additions and BP's energy demand outlooks shows a positive correlation between refinery construction trends and demand forecasts. Oil demand in Eastern Asia, South America, and other developing regions will continue to steadily increase, while oil demand in the US and Europe is projected to level out.

Decomposition of trade routes by ship size and type provides further insight into the evolution of trade routes and the estimation of future patterns. There are established patterns governing the relationship between ship size and specific trade routes where typically tankers will be of a maximum size that the origin and destination ports can accommodate. Overall, major import and export regions remain the same, and the consensus is that future crude oil tanker trade routes will not be subject to significant restructuring.

1.1.2. Freight Rates

Oil tanker freight rates are volatile and vary cyclically with vessel supply and demand, global economic growth, and other factors. The two main types of tanker freight rates are spot and time charter. A spot charter is a contract to transport cargo for a single voyage on a per ton basis, whereas a time charter is a contract for a stated period of time on a daily basis. In spot charters, the owner pays for capital, operating, and voyage costs. In time charters, the owner pays the capital and operating costs, and the charterer is left to pay the voyage costs. Both spot and time charter rates are volatile with few opportunities to reap high revenues. For instance, the time charter equivalent (TCE) rate for 1990 150-160k DWT Suezmax tankers peaked at $158,000 in November 2004 compared to the average value over the last twenty years of $38,000.

To provide a conservative perspective on historical market rates, time charter rates are selected with rolling averages of annual subsets. Probability density functions of TCE rates sampled at monthly resolution and represented by one-year rolling averages are relatively bimodal in nature with long tails into the high-profit rates. The average rate occurs infrequently, and, typically, a positive return on invested capital can only be achieved for a little more than half a tanker's lifetime. The Suezmax market is therefore segmented into the top 10%, middle 20%, and bottom 70% of historical TCE rates with average market segment values of $76,557, $55,612, and $26,381, respectively, corresponding to the percentage of time the market is expected to spend in each segment. These historical freight data calibrate the market model used in this study's sensitivity analysis.

1.1.3. Sensitivity Analysis

A sensitivity analysis is conducted to assess the impact of market factors, primarily freight rate variability, on the determination of design speed. In addition to the rolling averages of historical one-year TCE rates, the following factors are varied in the sensitivity analysis:

- Vessel speed (11-18 knots)
- Fuel projection ($300/MT-$1200/MT)
- Capital cost
- TCE Rate
- Inventory Carrying Cost (ICC)

The benchmark ship is a 15-knot Suezmax tanker servicing the port pair of Bonny Offshore, Nigeria to Lavera, France. There are several tradeoffs to be considered in the sensitivity analysis. As ship design speed increases, the distribution of costs reflects a larger engine size, higher fuel costs, and more revenue to be gained from moving more cargo annually. For instance, increasing ship speed from the benchmark 15 knots to 18 knots results in a 79% increase in daily fuel costs and 16% increase in the number of tons moved. The model reflects this increase by holding the revenue per ton constant with the 15-knot ship's daily revenue based on rolling averages of historic one-year TCE rates.

1.1.4. Impact of Market Factors on Ship Design

A series of scenarios are considered from the perspective of the shipowner to address two key questions. The first set of scenarios addresses whether or not to purchase a new oil tanker and which design speed it should have. The second set prepares the shipowner for how best to operate the tanker after acquisition.

Theoretically, a shipowner may select the design speed that minimizes required freight rate (RFR), where RFR is a function of the ship financing costs or capital expenditures (CAPEX), operating expenses (OPEX), and voyage costs. A 156-158K Suezmax tanker sells for about $66 million (Clarksons). The equivalent daily capital cost and operating cost for such a vessel is around $30,000 (Drewry). These inputs would goad the shipowner of the benchmark vessel to initially consider speeds at the lower end of the speed range from 11 to 13 knots, depending on the projected fuel cost. Inventory Carrying Cost (ICC) is the cost to the cargo owner (who often is the charterer) for having their money tied up in cargo carried on the ship. Modifying the RFR calculation to include ICC slightly pushes the design speed corresponding to the minimum RFR upward to 13 – 14 knots.

With the study's market approach, RFR is calculated as a reflection of the opportunity cost instead of the capital and operating costs. Specifically, equivalent capital costs plus operating costs are replaced with higher TCE segmented market rates. During the bottom 70% of the market, the representative TCE of $26,381 is fairly close to the combined capital and operating cost of $30,000. However, substituting the top 10% TCE of $76,557 for $30,000 results in RFR values up to 70% greater and a higher profitable speed range of 14 to 17 knots. Therefore, when considering market rates instead of simply the capital cost, more reserve power is needed to sail at higher speeds.

After the ship is purchased, CAPEX is a sunk cost and the new objective is to calculate the operating speed that will maximize the difference between revenue and dynamic costs. For this set of scenarios, relative joint contribution (RJC) is used as a metric for speed selection and is equivalent to the revenue derived from TCE rate minus the fuel and ICC costs. For the benchmark Suezmax tanker, revenue is the same as the daily TCE rate. Therefore, for the top 10% market rate and \$300/MT fuel projection, the 16-knot Suezmax yields the highest RJC, when the RJC is considered over all ship speeds.

Future freight rates may not reflect historical rates. If the top 10% rate is relaxed for the benchmark Suezmax tanker such that the RJC objective function yields 17 knots instead of 16 knots, the new top 10% rate would be \$89,334, a 16.7% increase over the historical value. In other words, to justify installing the reserve power required at 17 knots in a Suezmax tanker, peak rates would need to experience a price hike of at least 15%. Pushing the speed up to 17 knots involves covering an additional \$4,762 daily in fuel cost at a fuel price of \$300/MT. This increase in fuel costs decreases the value of reserve power as ship speed increases. If the price of fuel is as high as \$1200/MT, fully allocated costs are not covered above 15 knots in any of the scenarios, and therefore additional reserve power provides no advantage.

For the Aframax, Suezmax, and VLCC size classifications of tankers, several future scenarios are considered, and matrices of speed recommendations fulfilling the RJC maximizing objective function are calculated and provided. Speed profiles for each size of tanker show that varying speed with market rate logically increases a tanker's operational flexibility and allows it to maximize RJC. This flexibility can only be capitalized, however, if the ship is designed with enough reserve horsepower to speed up accordingly at market peaks.

1.1.5. Concluding Comments

This study's analytical approach to accounting for market factors in speed selection can serve as a tool for shipowners in scenario planning by better preparing them for future markets. A shipowner could refer to this study in conjunction with market forecasts to determine what speed a ship should operate at to maximize return. If fuel costs are rising, a shipowner could use this study's model to determine at which critical fuel cost a vessel should slow steam. Similarly, if the market is expected to be reaching a peak, this study's model can determine how much higher TCE rates need to be than historical values to justify speeding up by a given increment. Though slow steaming saves costs when the market is down, to fully take advantage of market peaks and maximize profit over a ship's lifetime, ships must have sufficient reserve power.

1.2. Background

The American Bureau of Shipping (ABS), Herbert Engineering Corporation (HEC), and other collaborators from industry and academia are in the process of designing the tanker of the future. The role of MIT in this study is to determine the impact of market factors on ship design. To support ABS's vision, this report analyzes the market characteristics of future oil tanker operations while focusing on those aspects which will have a potential impact on the design of future crude oil and product tankers. Market cycles, trade routes, refinery locations, cargo prices, and fuel prices are all targeted as important factors to consider over the next twenty-five years.

The impact of market rates on ship design speed and horsepower is of particular interest. A naval architect will typically consider a speed that minimizes the required freight rate (RFR) for the tanker and reflects the capital cost of the vessel. This approach will be compared with determining the design speed from the opportunity costs instead and from other metrics for profitability both before and after ship acquisition. To best anticipate and take advantage of a market peak, a tanker would ideally be designed to efficiently operate at a design speed that reflects the high market rates of the peak. In other words, rather than using an economic analysis with solely one implicit price for service, this study attempts to provide the economic inputs for designing a tanker to operate for a combination of booms and busts in future market cycles.

1.3. Oil Tanker Industry

1.3.1. Oil Tankers

The geographical dislocation of oil consumption and production regions drives the need for ocean transportation. In the oil industry, marine tankers predominantly transport oil between regions, while pipelines transport oil within regions. Figure 1-1 outlines the essential roles crude and product tankers perform in a simplified oil industry value chain. Crude oil tankers provide the link from production centers to refineries, while smaller product tankers connect refineries to consumption centers. In the trade route analysis and oil sector forecast, both tanker markets are considered to estimate how oil trade patterns will evolve. However, this study primarily concentrates on the former link, crude oil tanker operations.

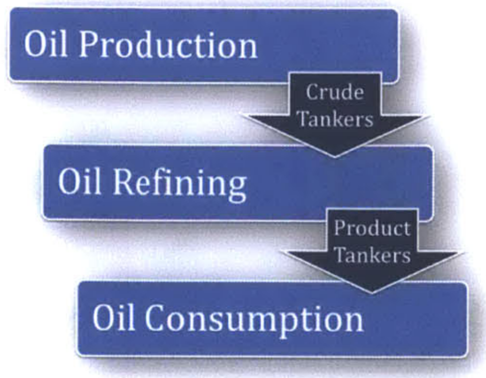


Figure 1-1. Oil industry value chain.

Oil tankers are generally classified into size categories. The size composition as well as age profile is displayed below in Figure 1-2. This study's scope includes the following crude oil tanker size classes, which together cover the majority of the crude oil tanker market:

- Aframax (80 - 120,000 DWT)
- Suezmax (120 - 200,000 DWT)
- VLCC (200 - 320,000 DWT)

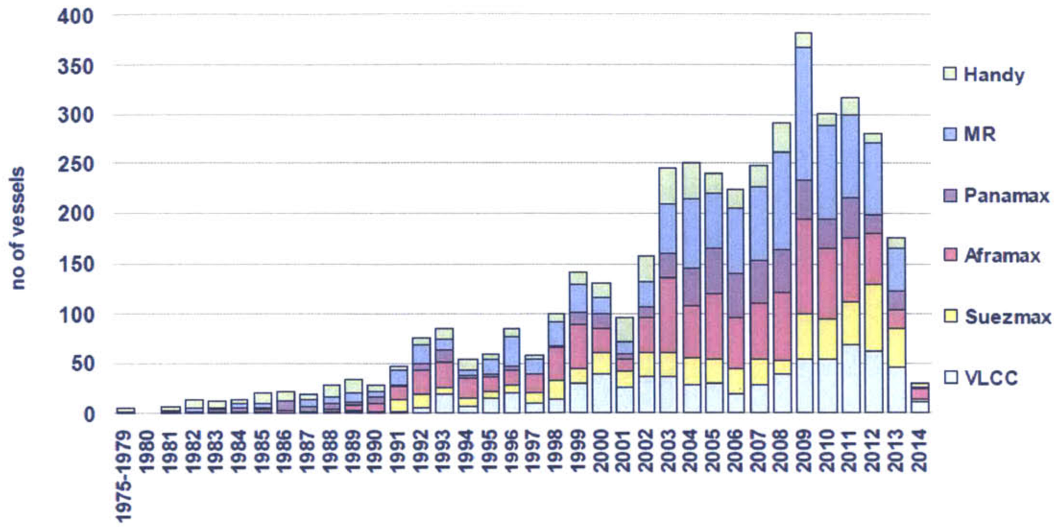


Figure 1-2. Tanker age profile and ship size composition by year of delivery. Source: Clarksons *Overview of Shipping Market*, November 2011.

1.3.2. Tanker Freight Rates

Freight rate, or charter rate, is the cost of hiring a vessel as agreed upon by the tanker owner and charterer. Oil tanker freight rates vary cyclically with vessel supply and demand, global economic growth, and other factors. A small change in oil demand can produce a high freight rate differential if tanker supply is tight. Key drivers of tanker demand include oil demand, oil supply, and ton-mile effect, the transport of oil over long-haul distances. Key drivers of tanker supply include orders for newbuilds, ship recycling, and floating storage. An increase in ton-mile demand, the product of the amount of oil transported in tankers and the distance the oil is transported, generally results in favorable freight rates.

The two main types of tanker rates are spot and period time charter rates. A spot charter is a contract to transport cargo for a single voyage, whereas a time charter is a contract for a stated period of time. In spot charters, the charterer typically pays the tariff on a per ton basis, and the owner is obligated to pay for all voyage expenses including fuel costs, port fees, and canal fees, in addition to CAPEX (capital expenditures) and OPEX (operating expenses) such as crew costs, insurance and maintenance. In a time charter, the charterer pays a daily rate of hire, and the owner only pays the capital and operating expenses, and the charterer is left with the voyage expenses. Time and spot charter rates for different voyages and vessels are best understood and compared by looking at time charter equivalent (TCE) rates. TCE is a standard shipping industry metric for a vessel's average daily revenue performance.

This study examines historical one-year TCE rates to set the stage for future market operations. Considering that market peaks are the central focus of the analysis, the choice to use one-year time charter rates based on a rolling average of twelve consecutive months is a conservative one. Spot market rates have historically climbed to heights over twice the magnitude of time charter rates for the same vessel size market. Playing the spot market provides potentially higher profit margins during booms and less predictable cash flows overall. Some tanker owners may choose to separate assets into both spot and fixed fleets.

1.4. Global Trade Routes

The shipping movements of tanker cargoes will alter by a variety of factors including the discovery of new oil reserves, the construction of refineries, technological improvements or limitations, and international political climates. In studying future port pairs, the determination of where new refineries will be built is a key objective. Figure 1-3, a map of global oil trade from BP's Statistical Review of World Energy, depicts the volumes of crude oil shipped along various regional trade routes. Arctic trade routes are not considered.

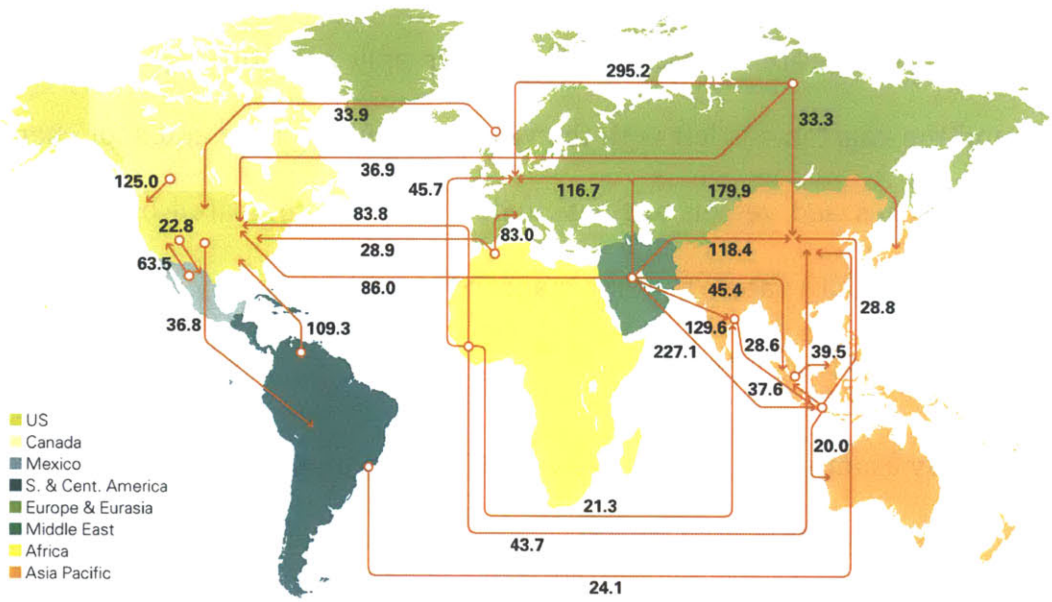


Figure 1-3. Major oil trade movements in 2010. Trade flows in million tonnes. Source: BP *Statistical Review of World Energy*, June 2011.

Further decomposition of the trade routes by ship size and type provides greater insight into the evolution of trade routes and the estimation of future patterns. There are established patterns governing the relationship between ship size and specific trade routes where typically – but not always – tankers will be of a maximum size that the origin and destination ports can accommodate. However, there are instances where vessel size is not commensurate with trade route length unrelated to port draft restrictions. Smaller tankers may service long-haul routes when regional import demand is low, and larger tankers may settle for short-haul routes when they are the most profitable trades available. Figure 1-4 illustrates how ship sizes trade in distinct markets but can overlap in trade route length

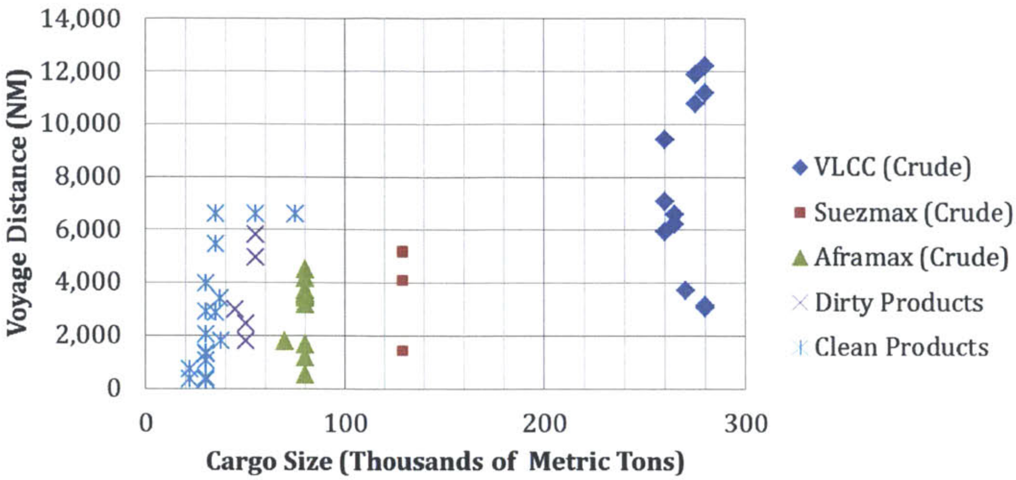


Figure 1-4. Voyage distances by ship size classification.

With the objective of determining trade routes representative of the highest crude oil and product traffic volumes for each vessel size, port pair traffic was studied. High traffic regions for each tanker size are determined from tanker market reports. The types of tankers included in the trade route analysis are VLCC, Suezmax, Aframax, and clean product tankers.

1.5. VLCC Trade Route Analysis Case Study

The following analysis applies to VLCC tankers only. Once the geographic regions are established, a set of port pairs and their respective traffic volumes for each vessel type are analyzed and grouped into inter-regional transactions. Table 1-1 presents the significant export and import regions (Fearnleys, 2004) and Figure 1-5 illustrates the consolidated port pair volumes by region in thousands of cargo tonnes of crude oil transported annually (Clarksons, 2010). Import regions are listed in the legend; export regions line the x-axis.

Export	Import
MEG	Europe
North Africa	N/C America
West Africa	Japan
North Sea	Far East
Others	Others

Table 1-1. Clean product export and import regions. Source: Fearnleys, 2004.

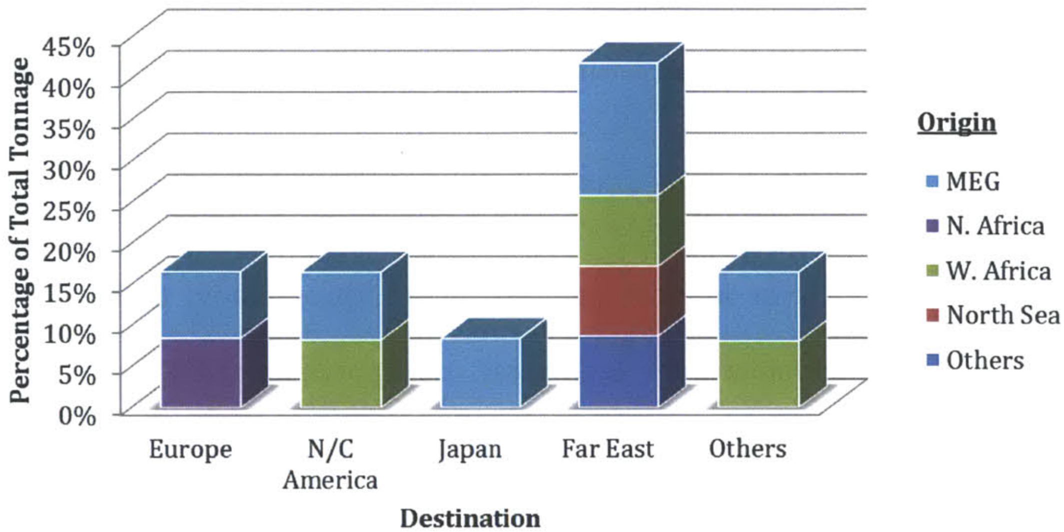


Figure 1-5. VLCC regional trades, consolidated by port pair traffic. Source: Clarkson Research Services Limited's *Sources & Methods for the Shipping Intelligence Weekly*, 2010.

Three representative trade routes are chosen for each ship size: a long-haul, a short-haul, and a highly-trafficked route. In the case of the VLCC, the selected high-traffic geographic corridor is Middle East and Gulf (MEG) to Japan, which can logically be grouped with the high consumption Far East region. The Ras Tanura, Saudi Arabia to Chiba, Japan port pair, with a voyage distance of 6,605, is selected as the representative dominant route of the MEG-Japan inter-regional trade movement. Voyage distances for the three VLCC port pairs and relevant Clarksons voyage parameters are presented in Table 1-2.

Description	Origin	Destination	Cargo Tonnes	Trade Route Length (nm)	Voyage Duration (days)
Short-haul	Sidi Kerir	Rotterdam	270,000	3,159	23.7
High-traffic	Ras Tanura	Chiba	250,000	6,605	45.3
Long-haul	Ras Tanura	LOOP	270,000	12,225	80.4

Table 1-2. Selected port pairs by ship size.

A similar process is used to determine dominant routes and regional trade movements for other ship types as well. For crude oil tankers, the high-traffic port pairs selected for the Suezmax, Aframax, and 30,000 DWT clean product tankers are Bonny Offshore, Nigeria to Lavera, France; Curacao to Texas City, USA; and Curacao to New York, USA, respectively. These port pairs and the regional flows they represent are in agreement with the high traffic flows inferred from several publications.

1.6. Framework of This Report

Following Chapter 1's introduction to the oil tanker industry and global trade routes, Chapter 2 anticipates how these trade routes will evolve. Oil industry forecasts on oil price, supply and demand, and refineries are assessed to determine the impact of future events on trade route dynamics.

Chapters 3 and 4 address two key decisions on the part of the shipowner: whether or not to purchase a new oil tanker and how best to operate the tanker once it is purchased. There are several tradeoffs to be considered in both decisions. In Chapter 3, a freight rate distribution analysis is performed to estimate time charter equivalent rates over a vessel's lifetime. The parameters for the sensitivity analysis are introduced and the variation of design speed described. HEC's methods of ship design are then utilized to account for these market characteristics in determining the design speed in the tanker design process in Chapter 4, where design speeds are estimated for market rates which take into account projected trends in the tanker market and the highest time charter equivalent rates experienced over a ship's lifetime. In Chapter 5, post-acquisition scenarios are studied using a joint contribution metric and by varying operating speed.

Of particular interest are speeds that reflect high market rates and would, therefore, generate maximum revenue in an economic boom. The speed calculation models are calibrated with historical data and have value added from consultation with industry experts in the marine engineering and shipping management sectors. The final chapter, Chapter 6, contains this study's conclusions and recommendations.

2. Chapter 2

Trade Route Dynamics

2.1. Overview

The origins and destinations of oil tanker trade routes are defined by global regions of production and consumption. As these centers evolve over time owing to new sources of oil and economic growth, trade routes will change, along with the distances required for tankers of each size to travel. If trade route distances in 2030 appear to significantly differ from current trade route distances, then the design range for relevant tanker ship sizes would need to reflect such change. Chapter 2 provides an analysis of events that would alter trade routes over the next twenty-five years. Forecasts on the future price of oil and supply-demand dynamics are discussed along with a description of the complex and fragile global environment at hand. The supply-demand forecasts tie into an analysis in future refining using both stated refinery construction plans and forecast data. Lastly, this chapter summarizes how trade routes are expected to change.

2.2. Oil Sector Forecast

Though global energy consumption is projected to grow almost linearly over the next twenty-five years, growth in liquids consumption is overshadowed by rising markets in alternative fuels, as shown in Figure 2-1. In 2010, growth in global oil consumption was 3.1%, the weakest among fossil fuels (BP, 2011). However, the role of oil in global energy markets is likely to be no less important in 2030 than it is today.

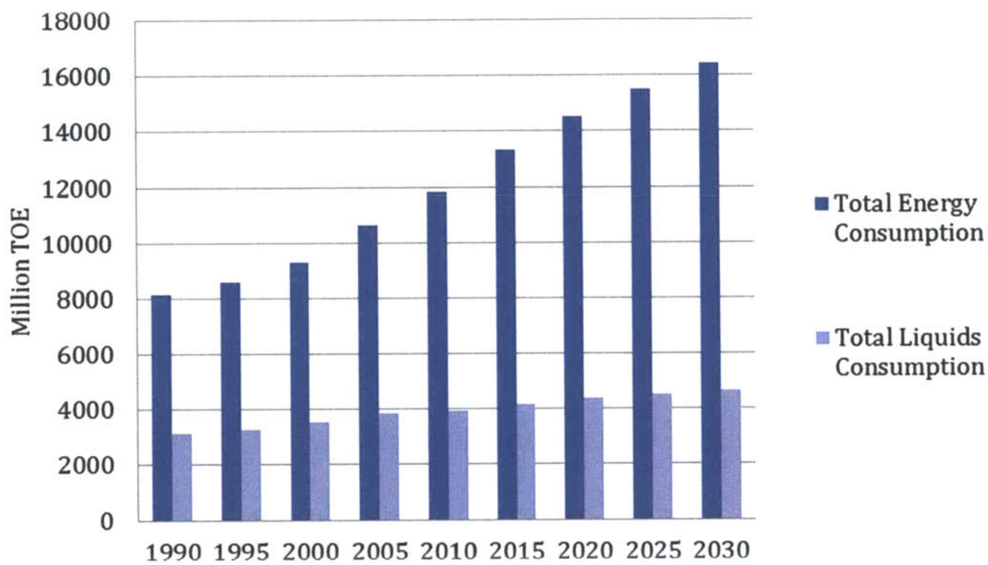


Figure 2-1. Global energy consumption. Source data: BP's Energy Outlook, 2011.

2.2.1. Global Environment

An intricate globally integrated industry is intrinsically vulnerable to potential supply chain disruptions. In the case of the oil industry, its spatial differentiation is marked by a handful of swing producers with concentrated reserves often far from high growth and demand consumption centers.

Chokepoints are high-traffic high-volume areas of greatest vulnerability in the oil trade, where disruption in trade or blockage could severely impact global oil trade. About 46% of the world's traded oil supply flows through the top three chokepoints (Hofstra, 2012). Key chokepoints, as shown in Figure 2-2, include the Strait of Hormuz, the Strait of Malacca, the Suez Canal, Bab el-Mandab, Bosporus, and the Panama Canal, in order of millions of BPD (barrels per day).

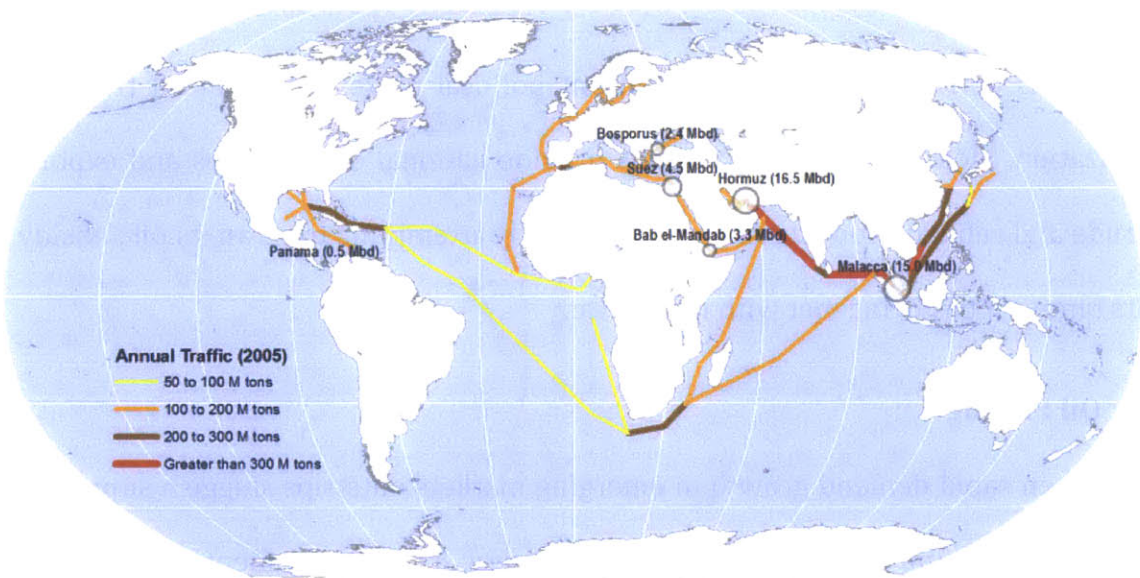


Figure 2-2. World oil transit checkpoints. Source: Hofstra University, 2006. Adapted from The International Tankers Owners Pollution Federation Limited & Energy Information Administration.

The Strait of Hormuz connects the Persian Gulf with the Arabian Sea and is the most critical of all global chokepoints with an oil flow of almost seventeen million BPD last year (EIA, 2011). Political relationships with Iran could result in restricted flow through the narrow waterway, behind which the majority of the world's spare capacity lies. If Iran is able to follow through with recent threats to shut down the Strait of Hormuz in response to new sanctions, then Saudi Aramco's port of Ras Tanura, the biggest crude oil export port, will be blocked (Lehman Brothers, 2008). Tanker sizes ranging from Aframax's to ULCC's transport oil from Ras Tanura to almost all world regions, and nearly half of Clarksons' representative trade routes analyzed in Chapter 1 depart from Ras Tanura. Reduced exports could also result directly from such trade sanctions. For instance, international sanctions on Iran also bar payment mechanisms for crude oil shipments to refiners in India and South Korea.

A less detrimental but still significant political player in global oil trade is price subsidization. Most oil producing nations provide national oil subsidies and export taxes for crude and refined products. Nigeria is currently attempting to scrap its oil subsidy plan, but its tampering is being met with resistance.

2.2.2. Oil Pricing

When rapid demand growth in emerging markets outstrips sluggish supply growth, prices can shoot up, inhibiting economic recovery. The most salient characteristics of today's oil market dynamics are the juxtaposed triple-digit oil prices and 4-5% global economic growth (IEA, 2011). The short-term price inelasticity of oil allows a rise in oil prices despite demand growth in emerging markets, since supply and demand are relatively unresponsive in the near term.

It is controversial how volatile the oil market is now in comparison to the past. There are arguments for exchange rates and speculative money flows driving the price of oil, and also for the converse. Forecasts on energy markets over the next decade are strikingly uncertain, as Middle Eastern politics and the Eurozone crisis hold unknown implications on the upstream and downstream oil sectors. Any increases in spare capacity will provide relief from high oil prices, though the IEA medium-term base case, with an annual global GDP growth averaging 4.5% per year, shows a tight market with little upstream spare capacity during 2012-2016 even if market conditions improve.

The IEA medium term case's forecast of oil price is shown in Figure 2-3. West Texas Intermediate (WTI) and Brent are two types of crude oil typically used as benchmarks in crude oil pricing. WTI is produced and refined within the US; Brent is a blend from several oil fields in the North Sea. While both grades are light, or low in density and viscosity, and sweet, or below 0.5% in sulfur content, WTI is sweeter than Brent and produces more gasoline. In the past year, there has been a significant differential between the WTI and Brent prices, but the IEA does not expect WTI to continue trading at a deep discount to Brent.

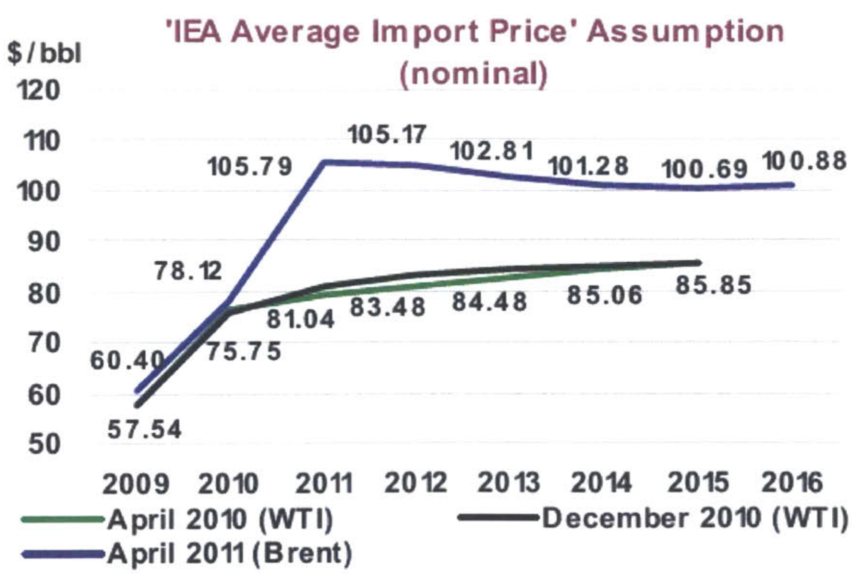


Figure 2-3. IEA Average Import Price Assumption (nominal). Source: IEA Medium-Term Oil & Gas Markets, 2011.

The Energy Information Administration's (EIA) International Energy Outlook forecasts the price of light sweet crude oil to 2035 in 2008 dollars. Figure 2-4 shows their reference case, high oil price case, and low oil price case. The EIA's projection to 2016 compares well with WTI trends in the IEA's medium-term projections but does not provide enough temporal resolution to provide a solid direct comparison.

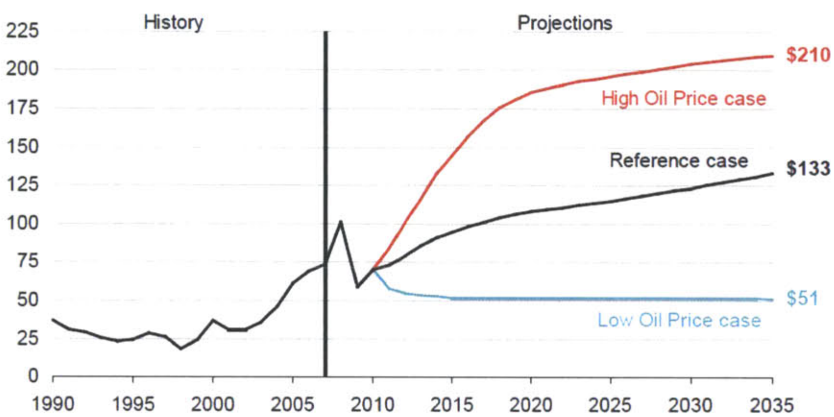


Figure 2-4. Projections on the price of light sweet crude oil in 2008 dollars per barrel. Uncertainty reflected in oil prices through a wide set of price cases. Source: EIA, International Energy Outlook 2010

Over the next 25 years, natural gas prices are not expected to return to the high levels they reached before the 2007-09 recession, while crude oil prices have already been restored. According to the EIA's Annual Energy Outlook 2011, the price ratio of light sweet crude oil to natural gas is expected to be at least 3:1 projected to 2035, as shown in Figure 2-5. Though LNG terminals are still not permitted in many ports, entry barriers for the LNG market have been lowered this year. We must be sensitive in our design to the price difference between oil and LNG, as it suggests that dual fuel engines may be a profitable investment not only in the short-term, but also in the next quarter-century.

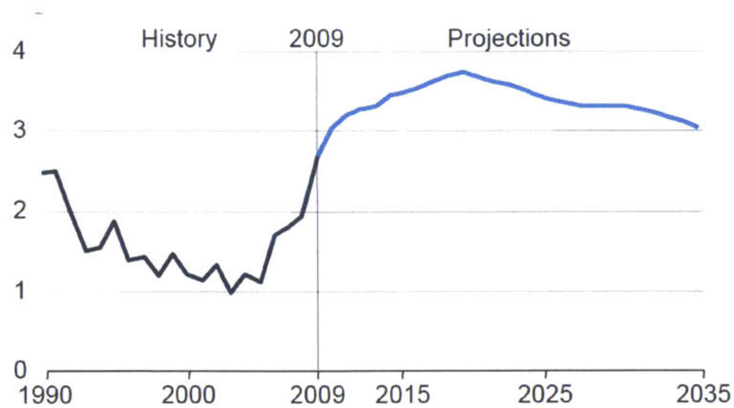


Figure 2-5. Price ratio of light sweet crude price to Henry Hub natural gas price on an energy equivalent basis. Source: EIA Annual Energy Outlook 2011.

2.3. Oil Supply-Demand Forecast

Refer to Appendix A for regional oil consumption and production figures, which are plotted using data from BP's Energy Outlook 2011. It is evident that there will be greater consumption and production of oil in the Middle East, Africa, and South and Central America. The United States has already reduced demand over the past decade, and its future consumption can only be projected with a high market uncertainty as it will be a function of planned energy policies and economic incentives for alternative fuels. Additionally, US demand for foreign oil will decrease as local production increases.

Figure 2-6 shows the predicted ratio of oil production to consumption by region. Based on the magnitude of the ratio, Table 2-1 classifies the world regions into import, export, or stable categories based on their supply and demand characteristics. The only expected regional change is Europe's change from the status of "importer" to "stable." While Asia and the South Pacific will experience steadily increasing demand with a nearly constant oil supply available, Europe is reaching a sustainable ratio of supply to demand.

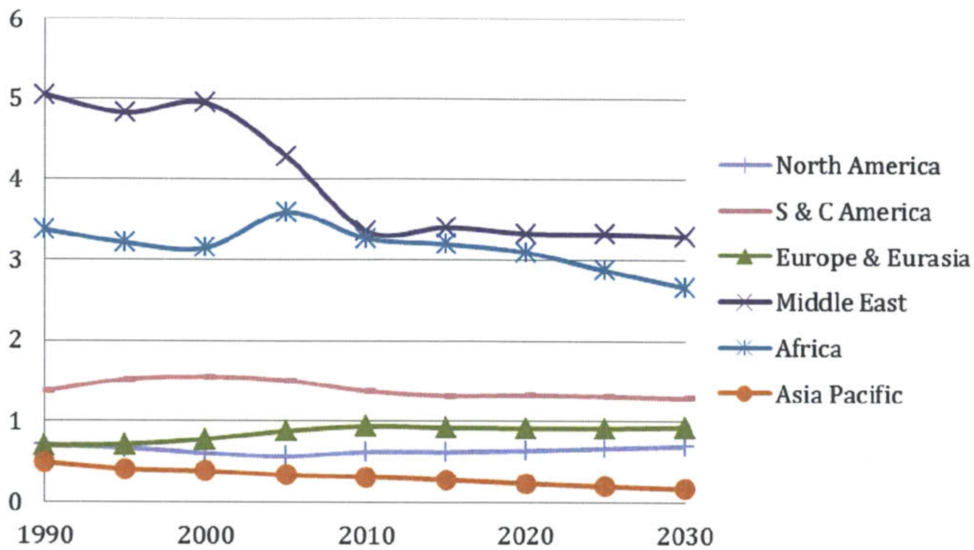


Figure 2-6. Ratio of oil production to oil consumption. Source data: BP's *Energy Outlook 2011.*

Region	1990	2010	2030
North America	Import	Import	Import
S & C America	Export	Export	Export
Europe & Eurasia	Import	Stable	Stable
Middle East	Export	Export	Export
Africa	Export	Export	Export
Asia Pacific	Import	Import	Import

Table 2-1. Oil import and export regions.

Since the major oil import and export regions are expected to remain the same, the dominant trade routes are expected to not change as a result of regional consumption and production trends. Europe is the only exception, as it is will become less dependent on Middle Eastern oil according to the forecasts.

2.4. Refinery Study

2.4.1. The Refining Industry

The past year has seen several refinery closures with significant impacts on product supply, freight rates, and futures. The geographic location of future refineries is another critical driver in the evolution of both crude and product tanker trade routes. As explained in Chapter 1, oil refining serves as the key downstream link in the oil industry value chain. Appendix B contains plots of oil refinery throughputs and capacities from 1985 to 2010. Within this period, surging refinery runs in one region often offset weaker runs in another. In this chapter, planning refinery construction and refinery trends are analyzed and compared to supply-demand forecasts.

2.4.2. Planned Refinery Construction

Regional refining throughput and capacity are both expected to change over the next twenty-five years in accordance with redistributed supply and demand. While supply and demand forecasts are plagued by market uncertainty, planned refinery construction projects provide information on where capacity is expected to increase from 2013 through 2017.

As this chapter's objective is to determine the effect of refinery capacity dynamics on trade routes, a threshold of 200,000 BPD or 10 million TPY (tonnes per year) was established as the minimum refinery capacity for planned projects included in the study. In addition, only projects scheduled for completion after 2012 were considered. To compare barrel and ton parameters for refinery construction capacity, a crude oil density of 873 kg/m^3 at 60 degrees Fahrenheit was assumed.

In addition to refinery throughputs and capacities, Appendix B also contains a breakdown of total added refinery capacity projects by country and year. The construction data are further summarized into regional added capacity values in Table 2-2. China and India have clearly enjoyed high rates of added refining capacity in comparison with other regions (OGJ, April 2011).

To test the hypothesis that regions with the greatest planned added capacity match regions with the greatest projected demand, the oil consumption forecasts presented in Section 2.2 and added refinery capacities are compared. Table 2-3 compiles the projected oil demand data by region, which is equivalent to the difference in consumption between 2030 and 2010. Note that the regional groupings between the two compared tables differ slightly but not enough to alter any inferences on major trade route patterns.

Figures 2-7 and 2-8 illustrate the planned added capacity and projected increase in demand, respectively. A comparison of the regional percentages in the two figures attests that there are evident correlations between refinery construction trends and demand forecasts. Middle Eastern, South American, and African projected demands are proportional with the refinery capacity additions. Similarly, North America and Europe are the two regions with the least planned added capacity, and BP has net reductions in demand for both continents over the next 25 years.

Planned Refinery Capacity Analysis

Region	Planned Added Capacity (BPD)
Middle East	3317000
South America	1730000
Africa	1351450
Asia Pacific	1094785
South Asia	901395
North America	625000
Eurasia	214000

Table 2-2. Planned added refinery capacity by region from 2012 through 2017. Source Data: OGJ's *Worldwide Construction Update*.

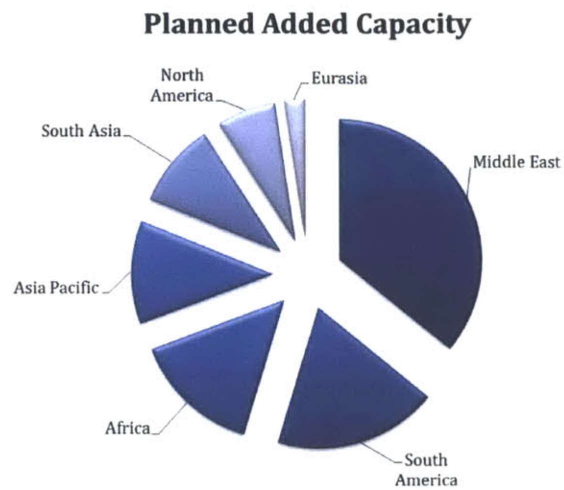


Figure 2-7. Regional breakdown of planned added capacity by 2012-2017.

Demand Projection Analysis

Region	Projected Increase in Demand (Million TOE)
North America	-76
S & C America	101
Europe & Eurasia	-38
Middle East	150
Africa	60
Asia Pacific	531

Table 2-3. Projected increase in oil demand by region from 2010 to 2030. Source Data: BP's *Energy Outlook 2011*.

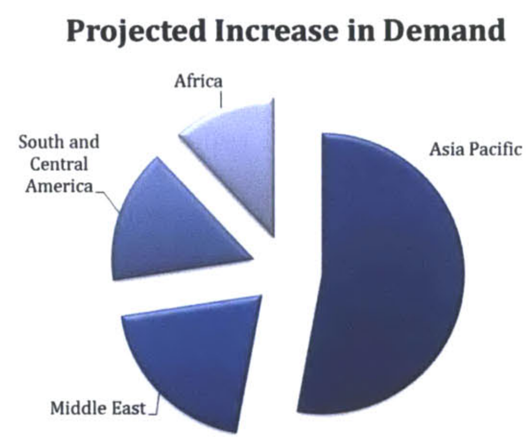


Figure 2-8. Breakdown of projected increase in demand by 2030.

However, there are also exceptions to the direct correlation between demand growth and added refinery capacity. In the case of the Asia Pacific region, forecasted demand is greater than any other world region and far exceeds refinery capacity.

One key trend is the construction of refineries closer to oil production centers. For instance, the region with the greatest global percentage of added refining capacity, the Middle East, is also the largest oil exporter.

While other regions would be able to consume fuel produced locally, China and other Southeast Asian countries will become increasingly reliant on the Middle East and other foreign fuel reserves. These trends are confirmed in the National Petroleum Council's (NPC) Global Oil & Gas Study, which anticipates that half of the world's cumulative increase in oil refining capacity by 2030 will be shared by the Middle East and developing Asia.

2.4.3. Refinery Forecasts

The IEA forecasts that global refinery utilization rates will decrease over the next five years, as shown in Figure 2-9. If refineries in a particular area were overwhelmed and projected to run at their cap rates, then new trade routes would need to be formed to transport surplus fuel to more distant refining locations. However, this downward trend in refinery runs suggests that refining in both OECD and Non-OECD countries will not be a constraint that alters trade route evolution.

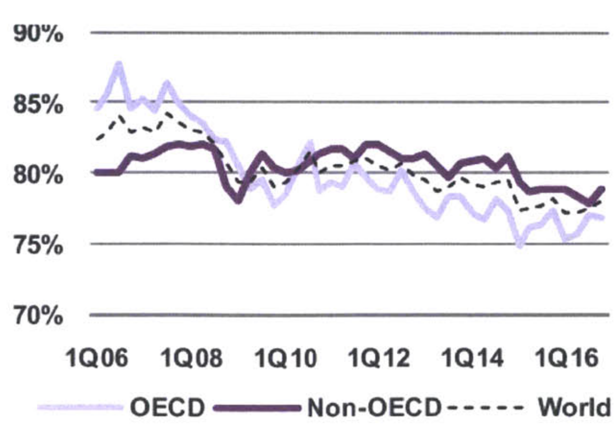


Figure 2-9. Refinery utilization rates. Source: IEA.

According to IEA projections on added capacity, China will gain the most crude distillation additions of any region over the next five years (Figure 2-10). Crude distillation additions only account for less than half of all global refinery capacity additions, which explains why in the planned refinery capacity analysis in Section 2.3.2 the Middle East has a larger percentage of planned added capacity than China. The Middle East, particularly Saudi Arabia, is projected to add significant capacity, possibly resulting in new product trade routes altogether. While China will be expanding its refining industry the most in the near term, India is investing more in refining to export products to the Asia Pacific region. Lastly, Africa is expected to become increasingly dependent on imported refined products, as there has been no progress on refinery construction due to financing problems and political turmoil.

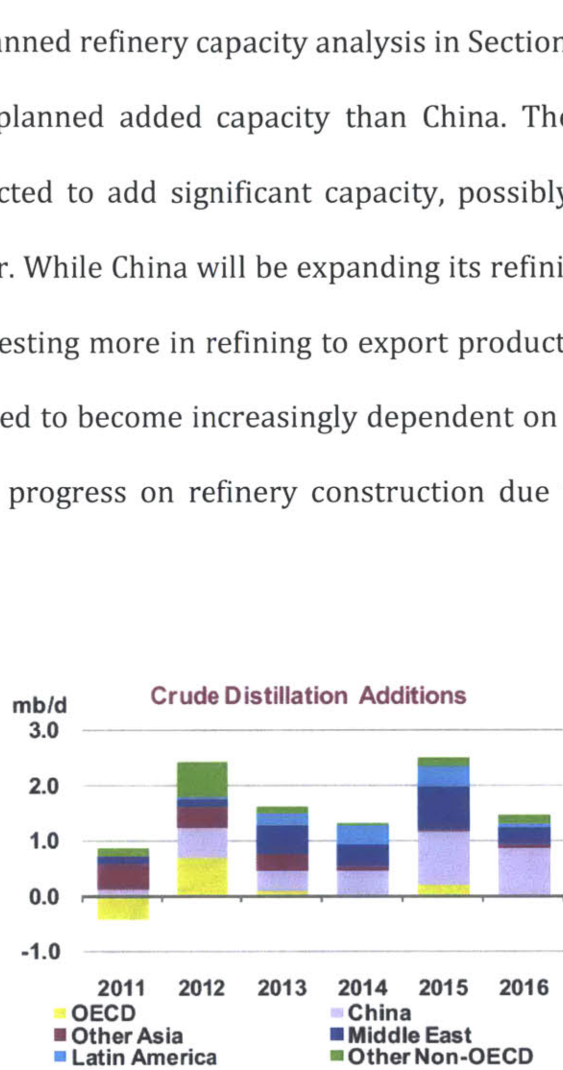


Figure 2-10. Crude distillation additions. Source: IEA.

2.5. Conclusion on Future Trade Routes

According to oil supply and demand forecasts, future crude oil tanker trade routes will not be subject to significant restructuring at a global level. Likewise, industry forecasts on refinery runs and capacities are consistent with the trends inferred from supply-demand forecasts and planned refinery projects, suggesting that product tanker routes will also not change dramatically with the exception of longer trade routes originating from the Middle East. It is also expected that some regions may shift their trade patterns in response to the constantly evolving locations of production, refining, and consumption. Swing factors, particularly political actions, would also engender rerouting. The IEA predicts a fairly stable redistribution of oil flow along existing trade routes, as illustrated in Figure 2-11.

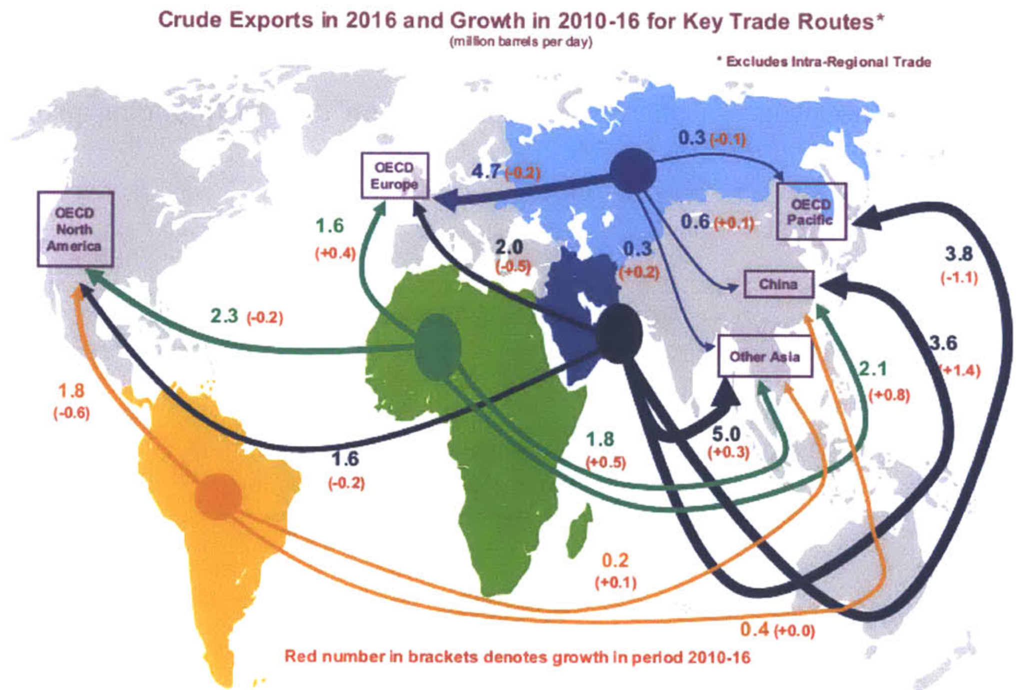


Figure 2-11. Crude exports in 2016 and growth in 2010-2016 for key trade routes excluding intra-regional trade. Units in million BPD. Source: IEA Medium-Term Oil & Gas Markets, 2011.

Refinery construction trends correlate well with the high growth and demand forecasts. Judging from the comparison of regional refinery added capacity and projected demand, exports from the Middle East to China will likely increase. Rising Asian Pacific demand, particularly Chinese demand, will need to be satisfied by a combination of local refinery output and net product imports. In addition, according to the supply-demand forecasts, Europe and Eurasia will import less oil in the future since their combined production nearly matches their combined consumption.

Clarkson Research Services Limited selected the Sidi Kerir, Egypt – Lavera, France port pair as one of the top four dominant high-traffic routes in Suezmax shipping. If Europe becomes less dependent on Middle Eastern oil, as its projected production and consumption trends indicate, then this trade route may no longer be of interest. The Sidi Kerir – Lavera pair is connected by 1,419 nautical miles of seaway, which is the shortest of the representative Suezmax trade routes selected by Clarksons, the next shortest being Ras Tanura, Saudi Arabia to Huizhou, China at 5,156 nautical miles (Veson Nautical, 2012). The vast difference between these two trade route lengths suggests that the Sidi Kerir – Lavera trade route is too short to be taken into consideration in the Suezmax target range and therefore will have no impact on future Suezmax designs. The trade routes connecting other regions are expected to only change nominally, implying that the other ship sizes will continue to be designed for the same distance range.

As the dominant oil supply and demand regions shift, high traffic trade routes for crude oil and refined products will likely see pattern shifts after the next twenty-five year period. The BP projections of supply and demand to 2030 are fairly linear and do not account for the theory that while current global oil production levels will be maintained, higher consumption levels in oil producing regions will cause export levels to decline. Key swing producers such as African and Middle East nations may consume more than expected. If economic growth picks up in Eastern Africa, we may see African oil exports drop off, especially if long-neglected plans for refinery construction in Africa are put into action. Increased refinery capacity in the Middle East may also result in long-haul product routes. Lastly, if oil flow through the Strait of Hormuz is disrupted, then several established trade routes ranging across all major tanker sizes will have to adapt to the global oil imbalance.

3. Chapter 3

Introduction to Sensitivity Analysis

3.1. Overview

With the objective of accounting for market variability in the determination of design speed, a sensitivity analysis is conducted to assess the impact of all relevant factors. First, a freight rate distribution analysis is performed to estimate TCE rates over a vessel's lifetime. A comparison of equivalent daily capital costs with time charter equivalent rates is analyzed for each ship size (i.e. capital plus operating costs are replaced with charter freight rates), and a case study of VLCC rates is provided in Section 3.2.

Next, a sensitivity analysis using HEC's ship design methods is introduced in Section 3.3. Parameters and projections are explained, and the 15-knot Suezmax base case is established. Lastly, the profiles of ships with unique design speeds and their respective transportation costs are detailed in Section 3.5.

3.2. Market Segmentation

A set of historical crude tanker data is studied to determine the market characteristics of tanker operations (Clarksons). An analysis of the TCE rates for each of the following six cases is performed:

- (Case 1) Double-Hulled 285,000-DWT VLCC, 15 years old
- (Case 2) Double-Hulled 310,000-DWT VLCC, Modern
- (Case 3) Single-Hulled 250,000-DWT VLCC, 1970's
- (Case 4) Single-Hulled 285,000-DWT VLCC, Early 1990's
- (Case 5) Modern 1990/1991 Suezmax Tankers
- (Case 6) Modern 1990/1991 Aframax Tankers

Case 5, the analysis of modern Suezmax tankers built in 1990 and 1991, spans a time period from January 1990 to October 2011. Figure 3-1 is a plot of the time charter rates over time that shows the market fluctuations with the peak market rate occurring in November 2004 (Clarksons, 2011). To perform a conservative distribution analysis on the time charter rates, the data are filtered, and rolling averages are taken over 12 month periods to correspond to the time charter lengths (Figure 3-2).

Next, histogram bin sizes representing time charter range increments of $3,732 each are allocated to determine the frequency of months the Suezmax spent within certain time charter ranges. From the frequency counts of TCE rolling averages, probability density and cumulative distribution functions (PDFs and CDFs) are estimated.

Figure 3-3, a plot of the PDF, displays the estimated probability that a time charter rate at any time will be within a particular bin. Note that the average Suezmax TCE rate of $38,234 occurs relatively infrequently in the bimodal PDF. Moreover, a Suezmax is likely to only make positive return over a TCE rate of about $30,000 ($12,000 OPEX + $18,000 equivalent CAPEX). From this approximation, one could infer that a tanker only achieves a positive return for a little more than half its lifetime.

Figure 3-4, a plot of the CDF, visually depicts the nature of the highest freight rates the market produced from 1990 to 2011. The market freight rate segments are separated by the top 10%, middle 20% and bottom 70% time charter equivalent (TCE) rates, where a weighted average TCE rate represents each segment in accordance with the percentage of time the market is expected to spend in each range.

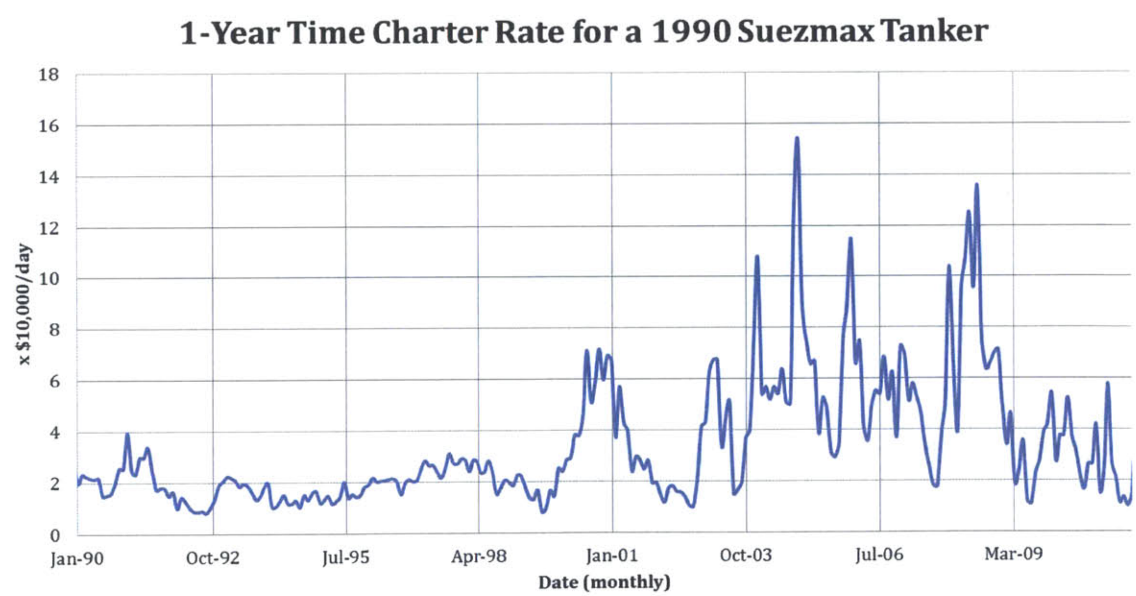


Figure 3-1. 1-Year TCE rates for a 1990 Suezmax tanker.

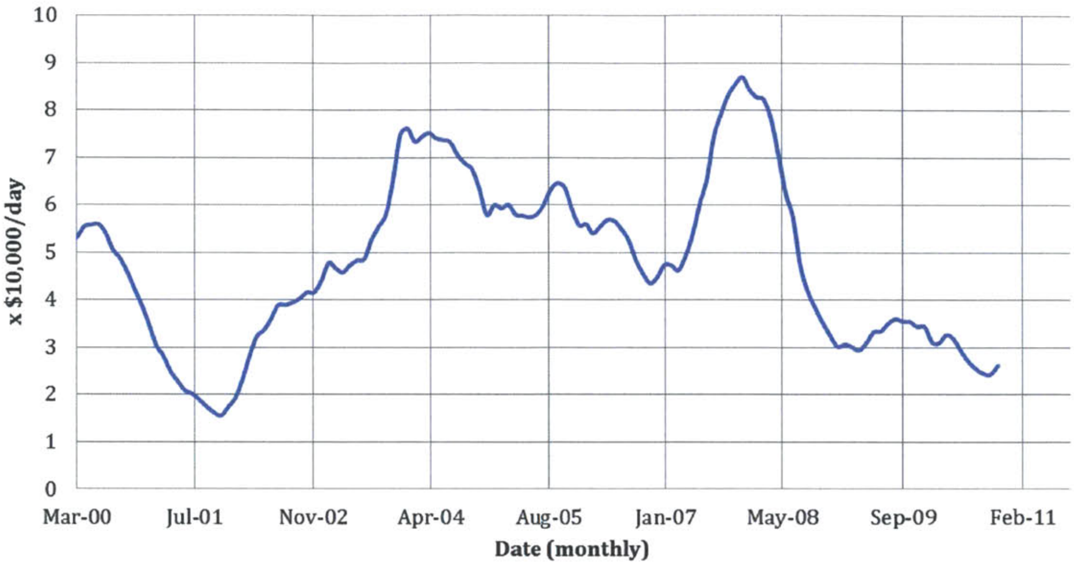


Figure 3-2. 1-Year rolling average of TCE rates for a 1990 Suezmax tanker. Average taken over 12 consecutive months.

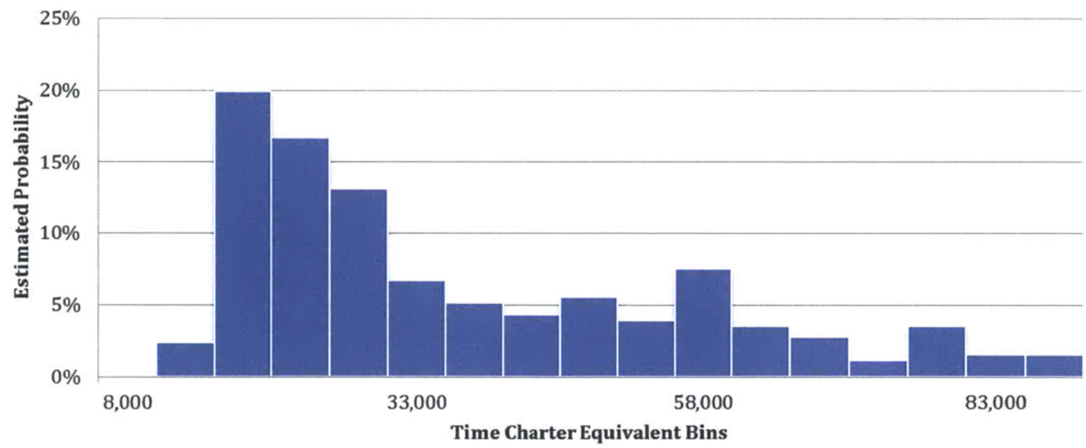


Figure 3-3. Probability density function histogram of one-year rolling average TCE rates calculated for a 1990 Suezmax tanker.

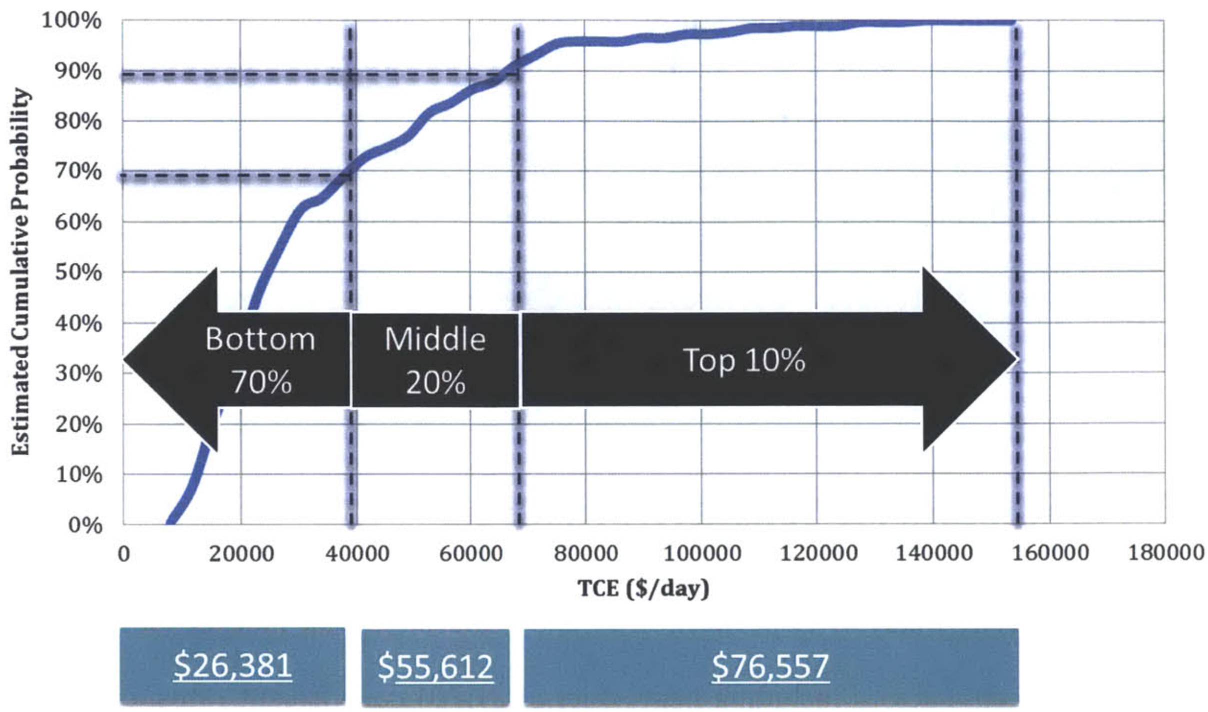


Figure 3-4. Cumulative distribution function estimated from rolling averages for a 1990 Suezmax tanker with representative rates for each market freight rate segment.

If this Suezmax tanker were to be designed today, a traditional approach might use the capital cost in determining the vessel's design speed and other related parameters. The new build price of a 156-158K Suezmax tanker was $66 million in 2010 (Clarksons, October 2011). If the new build price is converted to a price per day with the net present value accounted for, the daily incurred capital cost would be $18,082. Table 3-1 shows the comparison of costs and TCE rates for each vessel size. In Chapter 4, the higher market freight rate segments for the bottom 70%, middle 20% and top 10% will be used as opportunity costs for the equivalent capital cost.

Tanker Size/Type	Cargo Tonnes	Newbuild Cost ($m)	Equiv. Daily +OPEX	TCE Time Period	Top 10% TCE	Top 30% TCE	Average TCE
VLCC (Crude)	265,000	103.1	$28,247+ $13,265	2000-2011	$68,845	$63,886	$49,148
Suezmax (Crude)	130,000	66.0	$18,082+ $11,758	1990-2011	$76,557	$63,111	$38,234
Aframax (Crude)	70,000	55.3	$15,151+ $10,575	1990-2011	$33,745	$31,144	$21,697

Table 3-1. Ship costs and TCE rates by tanker size.

3.3. Parameters for Sensitivity Analysis

A sensitivity analysis is performed to show the impact of market factors on the selection of speed. Factors including heavy fuel oil (HFO) cost, freight rates, capital cost, voyage length, and value of cargo are varied to determine their impact. The market freight rate segments calculated in the last Section are then compared with the sum of the equivalent daily capital & operating cost as well as the current charter rate as of January 2012 in the analysis.

While the equivalent daily capital cost changes with each design speed and corresponding engine selection, the market freight rate segment is the same for each ship size category, as shown below in Table 3-2. Note that the current TCE is lower than the bottom 70% TCE for all three tanker sizes.

Daily Cost Input	Aframax	Suezmax	VLCC
Current TCE (Clarksons, 2011)	$15,050	$20,436	$21,000
Bottom 70% TCE	$17,288	$26,381	$40,597
Middle 20% TCE	$27,677	$55,612	$60,213
Top 10% TCE	$33,745	$76,557	$68,845

Table 3-2. Representative TCE rates of market freight rate segment breakdown.

It should be noted that using the top 10% historic TCE value is a conservative indicator of a boom. In reality, spot rates may be more than twice as high as the rolling average of 1-year charter rates, but for the purpose of this study, the top 10% of TCE's only is grouped together as the target boom condition.

A modern Suezmax tanker with a design speed of 15 knots is chosen as the benchmark case from the representative tankers detailed in Clarksons' *Sources and Methods for Shipping Intelligence Weekly*. Speeds are varied from 11 to 18 knots with vessel scantlings held constant and with an engine selection process performed for each new speed. HEC's ship design tools assist in these calculations. Only integer values of speed are considered, and it is assumed that operating speed is the same as design speed. For example, a vessel with a design speed of 15 knots would always travel at 15 knots for both its laden and ballast voyages.

Four fuel projections for HFO are considered at $300, $600, $900, and $1200 per metric ton. The value of cargo is not changed with the price of fuel, though its effect on RFR is examined. The sensitivity study is conducted for Aframax, Suezmax, and VLCC sizes, all the ship sizes where historical TCE data were available. In this Section, an analysis is stepped through of the HEC-designed Suezmax tanker with the parameters listed below in Table 3-3. All parameters of the ship remain the same throughout this example, as shown below, with the exception of design speed.

Vessel Particulars	HEC Suezmax Design
100% Cargo Capacity (MT)	180000
Length Overall	280
LBP	270
Beam	48
Depth	24
Design Draft	15.9
Summer Loadline Draft	17.41
Lightship	25819
Design Block Coefficient	0.825
Deadweight at Design Draft	148869
Deadweight at Loadline draft	166576
Number of Screws	1
Design Speed: 15% SM at 90% MCR	15.2
Required Engine Power (MCR)	17185

Table 3-3. HEC Suezmax vessel particulars.

Below is Table 3-4 which contains the three key Suezmax trade routes included in the sensitivity analysis. The base case Suezmax trade route assumed in this study is the port pair Bonny Offshore, Nigeria to Lavera, France with an assumed fuel projection of \$600/MT.

Origin	Destination	Trade Route Length (nm)
Sidi Kerir	Lavera	1,420
Bonny Offshore	Lavera	4,070
Ras Tanura	Huizhou	5,159

Table 3-4. Suezmax trade routes.

3.4. Engine Selection

For each design speed considered in the sensitivity analysis, a different engine must be selected. MAN B&W's electronically-controlled low speed diesel engines are chosen for every ship size across speeds 11 through 18 knots. Selections are limited to the same stroke class, the "S" class, ensuring that the engines are as similar as possible to provide a continuous metric for comparing speed-dependent properties and understanding the relationship between RFR and speed. Within the S class, only the most efficient engines are chosen for the design. In addition, engine RPM is maintained where possible. In some cases, the same engine is selected for two sequential design speeds to keep engine types as similar as possible. For the 18-knot ship, there is less availability of the "S" class to choose from. To address inconsistencies in engine selection, theoretical fixed engine RPM values were assumed. RFR is sensitive to the engine selected for a ship, and both engine RPM and SFOC can cause significant steps in an RFR curve. Assuming a theoretical engine minimizes this effect. HEC was consulted in engine selection, and their tools were used to determine required power for the ship size parameters.

3.5. Variation of Ship Design Speed

As ship design speed increases, the distribution of costs evolves to reflect the larger engine size, higher fuel cost, and lower inventory carrying cost (ICC), which is the cost to the cargo owner, who may also be the charterer, for having money tied up in inventory being carried on the ship. The cost trends are illustrated in Figure 3-5 using a fuel projection of \$600/MT. Daily operating costs remain the same for all speeds. Inventory carrying cost is significant but does not vary much. In order to convert from construction costs to daily equivalent capital costs, the approach used by Drewry in their publications of taking the annual equivalent as 10% is followed.

Table 3-5 provides a breakdown of ship costs and voyage characteristics for each ship speed. For each speed, a different engine is selected to provide the required power, resulting in capital costs that increase with ship speed by a multiple of the power differential to account for the cost of the new engine, supporting machinery systems, and engine room labor and equipment. Operating costs are taken from Drewry and include crew costs, stores, supplies, lube oil, spare parts, maintenance and repairs, drydocking costs, insurance, and management fees. Since the ship parameters are exactly the same for each speed, the throughput for each voyage does not change, but the annual throughput is greater for higher speeds. Port fees are included and hotel loads excluded from the calculations.

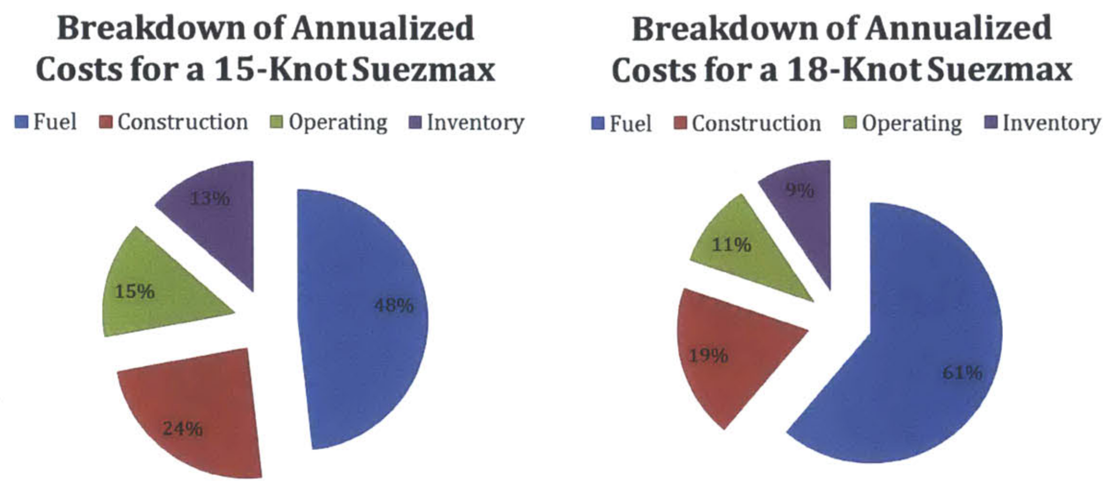


Figure 3-5. Comparison of breakdown of annualized costs for a typical 15-knot and 18-knot Suezmax tanker with the price of fuel projected at $600/MT.

Speed (knots)	15	16	17	18
Capital Cost	$68,447,871	$70,249,674	$72,809,164	$75,972,231
Daily Operating Cost	$11,758	$11,758	$11,758	$11,758
Daily Fuel Cost ($600/MT)	$39,010	$46,200	$55,724	$68,812
Average Daily Inventory Cost	$10,821	$10,689	$10,562	$10,440
Annual Throughput	2,147,773	2,263,081	2,376,057	2,486,773
Voyage Duration (days)	26	25	24	23

Table 3-5. Ship costs and voyage characteristics for unique design speeds.

4. Chapter 4

Impact of Market Rate Variability on Ship Design

4.1. Overview

Purchasing a crude oil tanker can be a high risk gamble. Chapter 4 addresses the question of whether or not a shipowner should purchase a new oil tanker, and, if so, what the design speed should be. The sensitivity analysis detailed in Chapter 3 is applied in this chapter's scenarios. First, a basic RFR study is conducted from the shipowner's perspective in Section 4.2. Inventory carrying cost is then added to the model in Section 4.3. In Section 4.4, the "market approach" of replacing capital costs with opportunity costs in the RFR calculation is introduced. This market model is calibrated with historical freight data provided in Chapter 3. Section 4.5 discusses the role of inventory rate, and Section 4.6 analyzes the sensitivity of traditional RFR to capital cost. Lastly, Section 4.7 provides a matrix of recommendations that fulfill the RFR minimization objective function, and the relationship between RFR and design speed is demonstrated.

4.2. The Shipowner's Perspective: Ship Financing RFR Study

Before purchasing a ship, a shipowner may theoretically consider a minimum required freight rate (RFR) when selecting a design speed for the new build. In this first case, the shipowner would consider the ship financing costs, and RFR would be calculated on a per metric ton basis as a function of CAPEX, OPEX, voyage costs, and the tonnage of cargo:

$$RFR = \frac{CAPEX + OPEX + Voyage\ Costs}{Cargo\ Tonnage\ Moved}$$

In Figure 4-1, circles mark the minimum RFR values for each fuel cost projection. The daily equivalent capital cost for the Suezmax tanker ranges from $17,202 to $20,814 depending on the engine size selected for each design speed. According to the RFR curves, the shipowner would initially consider speeds at the lower end of the speed range.

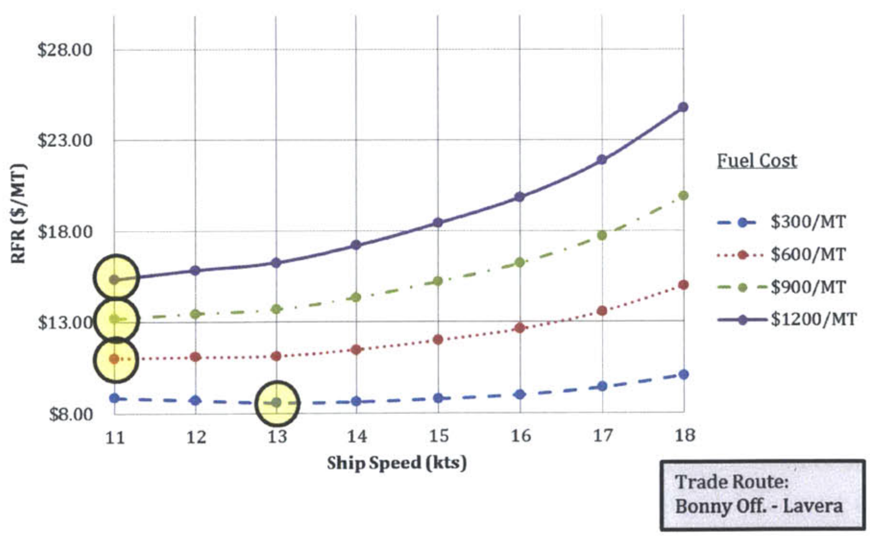


Figure 4-1. Suezmax RFR values with equivalent capital and OPEX cost input and no inventory carrying cost. Trade route: Bonny Offshore, Nigeria to Lavera, France.

4.3. Inventory Carrying Cost

If the shipowner considers ICC, the RFR equation is modified to factor in the inventory cost:

$$RFR = \frac{CAPEX + OPEX + Voyage\ Costs + Inventory\ Carrying\ Cost}{Cargo\ Tonnage\ Moved}$$

The resulting RFR values are higher by up to $6.00, as shown in Figure 4-2. The speed corresponding to minimum RFR has also been shifted upward. For instance, assuming a fuel projection of $300/MT, the speed that yields the minimum RFR has increased from 13 knots to 14 knots. In this calculation, the cost of the cargo is tied to the cost of the fuel. The shipowner "borrows" money at 10% per year in order to own the cargo as soon as it is being loaded on the ship. Note that the spread of RFR values for different fuel projections increases in such a way that the RFR is even more sensitive to the price of fuel when ICC is included. All further calculations will include ICC.

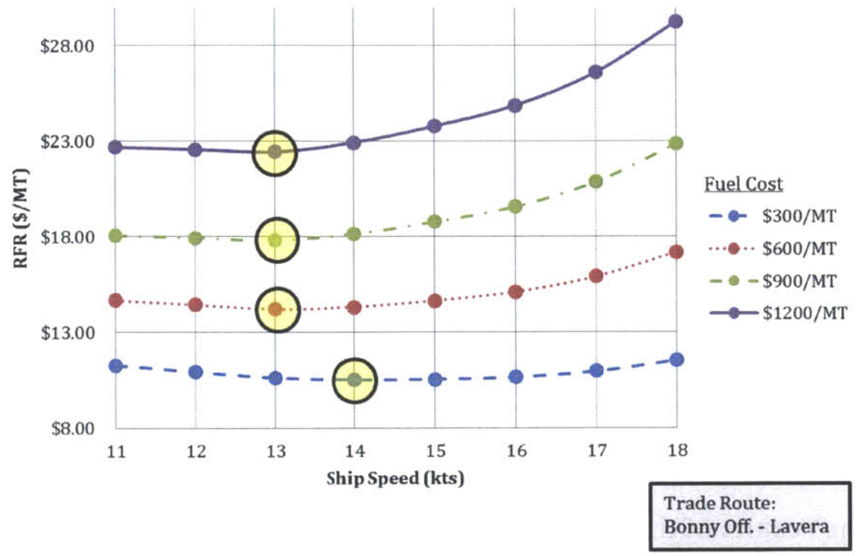


Figure 4-2. Suezmax RFR values with equivalent capital and OPEX cost input and inventory carrying cost. Trade route: Bonny Offshore, Nigeria to Lavera, France.

4.4. Market Approach

Another approach would be to design for market rates, particularly during a boom, before the ship is built by taking into account historical charter rates, market projections, operations data, and key indicators of profitability. In this case, the charter rate is treated as the opportunity cost for the annualized capital cost and OPEX, and the design speed is selected based on the desired reserve power for speeding up at market peaks.

To investigate the relationship between market variability and tanker design speed for a traditional Suezmax tanker, time charter rates representing different Sections of the market freight rate structure are substituted as opportunity costs for capital and operating costs and are then used to calculate RFR. A potential ship owner might be interested in performing a required freight rate (RFR) analysis to determine whether existing freight rates would result in a desired return on the investment of building a new tanker.

In the market approach, RFR is calculated in the following manner with TCE market freight rate segments replacing the operating and equivalent capital costs:

$$RFR = \frac{TCE \frac{Rate}{Voyage} + Voyage\ Costs + Inventory\ Carrying\ Cost}{Cargo\ Tonnage\ Moved}$$

When the results of this calculation are compared with the expected freight rates, it can be determined whether or not the desired financial return with this investment will be made.

Figure 4-3 presents the RFR curve for the top 10% of the market when the price of fuel is projected at $600/MT for a Suezmax tanker. The curve is continuous since the engines are selected from the same class. All fuel projections are considered for the top 10% in Figure 4-4 to show the impact of fuel rate in addition to market rates when selecting design speed. While the daily equivalent capital and operating cost input for RFR are below $33,000, the substituted boom TCE rate representing the top 10% of historic rates for Suezmax tankers is $76,577. The RFR trends are therefore further shifted to the right when charter rates replace the sum of the annual equivalent capital & operating costs to calculate the new speed corresponding to minimum RFR at 17 knots, up from 14 knots with a fuel cost of $300/MT.

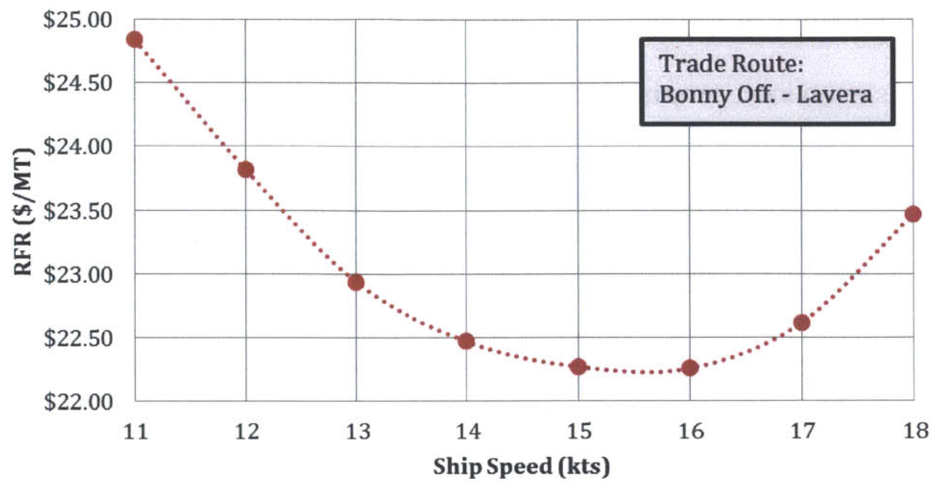


Figure 4-3. Suezmax RFR values with top 10% TCE cost input at projected fuel price of $600/MT. Trade route: Bonny Offshore, Nigeria to Lavera, France.

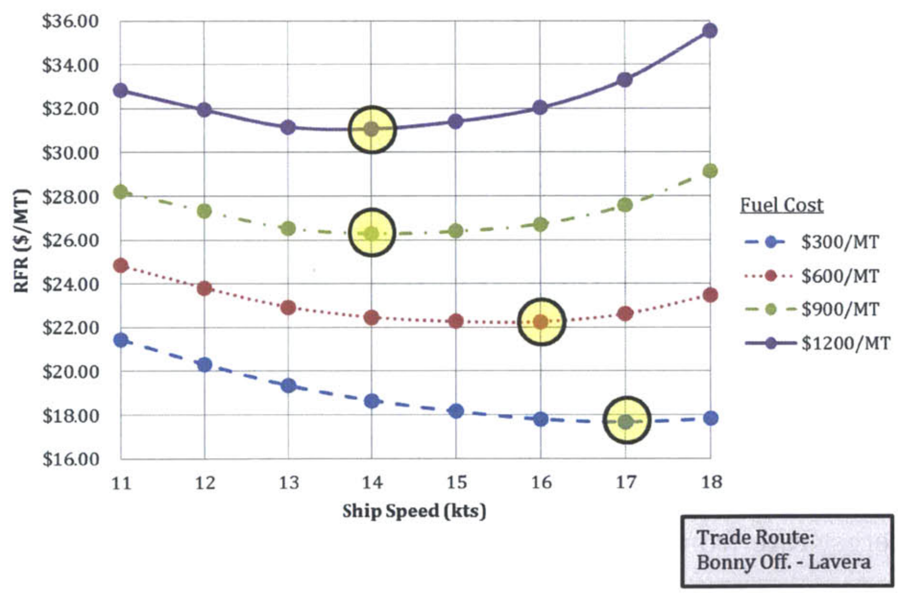


Figure 4-4. Suezmax RFR values with top 10% TCE cost input. Trade route: Bonny Offshore, Nigeria to Lavera, France.

In Figure 4-5, a comparison of RFR for various charter rates, it makes sense that the higher the freight rate, the higher the annual RFR. Note that the bottom 70% curve is lower than the equivalent capital and OPEX curve and does not fully cover allocated costs. The current TCE rate is even lower than the bottom 70% rate and also does not fully cover allocated costs.

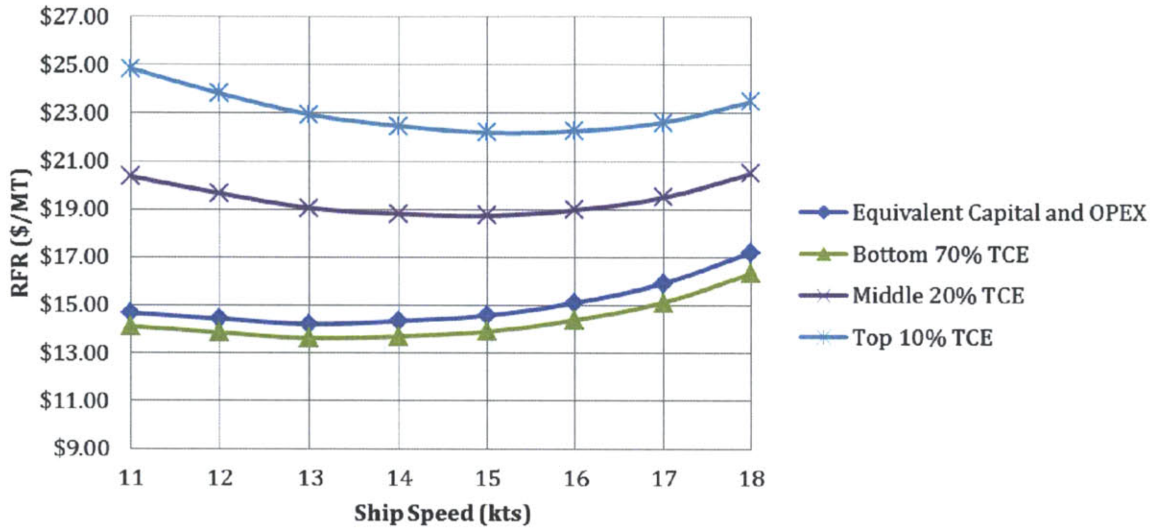


Figure 4-5. Suezmax RFR values for market freight rate segments at projected fuel price of $600/MT. Trade route: Bonny Offshore, Nigeria to Lavera, France.

4.5. The Role of Inventory Carrying Cost

To determine the impact of the value of cargo on RFR, the ICC is doubled. This effect can be achieved in more than one manner, but one example is to double the related inventory interest rate from 10% to 20%. This alteration results in RFR values 10-25% greater than those in the base case. The lower the TCE, the greater the resulting change is in RFR. For the Top 10% market freight rate segment, illustrated in Figure 4-6, the change in ICC is not sufficient to change the recommended speed. However, speed recommendations do change for the higher fuel projections of $900/MT and $1200/MT, as shown in Figure 4-7. When compared with Figure 4-4, which has an ICC of 10%, the speed recommendations increase from 15 to 16 knots for the two upper fuel projections.

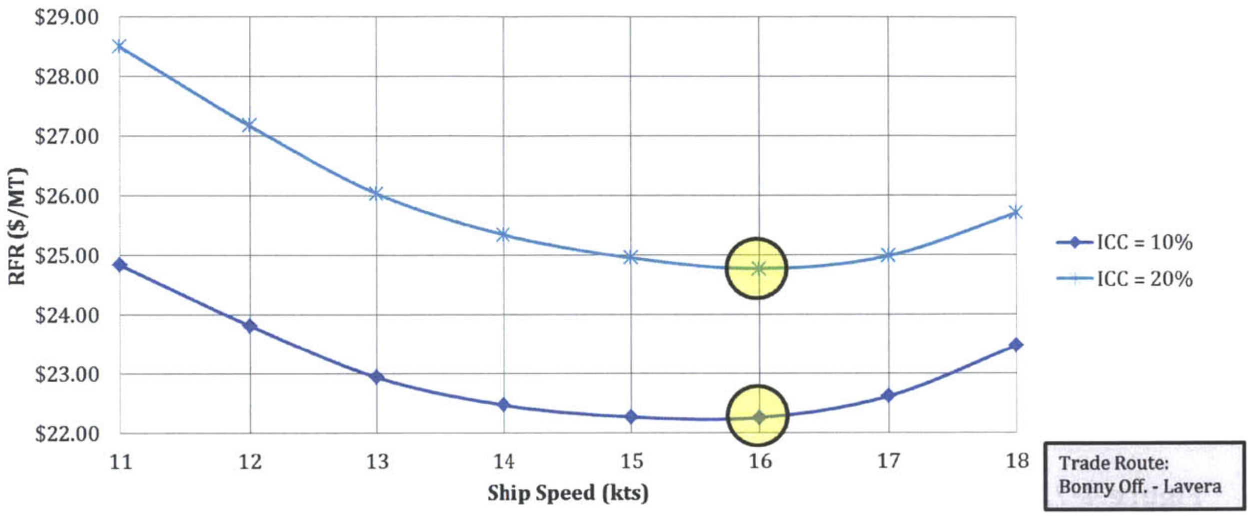


Figure 4-6. Impact of varying ICC from 10% to 20% on Suezmax RFR values for top 10% TCE at projected fuel price of $600/MT. Trade route: Bonny Offshore, Nigeria to Lavera, France.

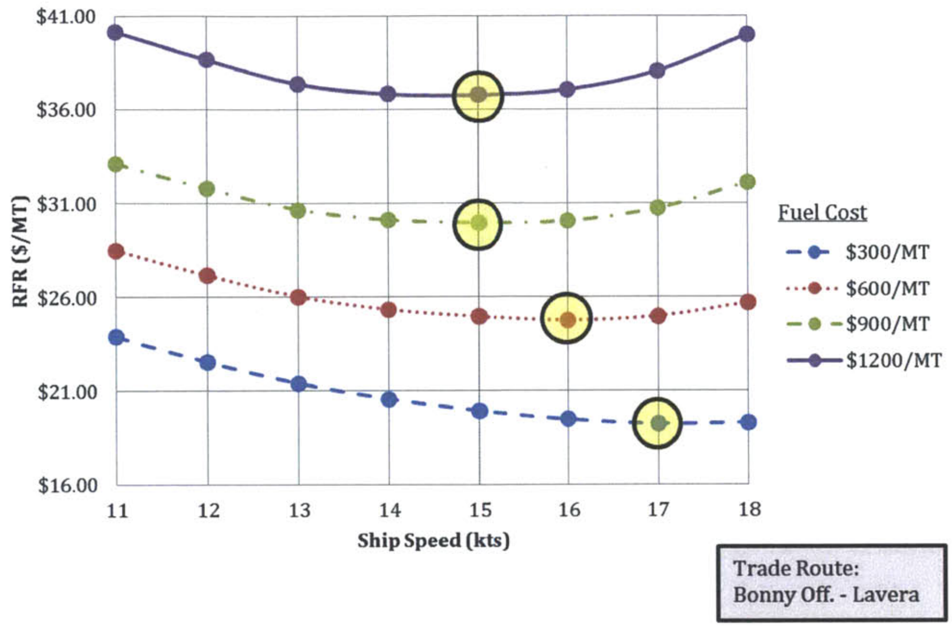


Figure 4-7. Suezmax RFR values for top 10% TCE cost input and 20% ICC. Trade route: Bonny Offshore, Nigeria to Lavera, France.

4.6. Sensitivity to Capital Cost

To test the sensitivity of RFR and speed selection to capital cost, the engine cost is varied in respect to the 15-knot Suezmax benchmark. Table 4-1 presents engines selected for Suezmax tankers over a wide range of design speeds. Note that installed maximum continuous rating (MCR) power is the same for some consecutive speeds. The RPM for the 18-knot ship is artificially adjusted to match the other engine RPM's for continuity.

Speed (knots)	MAN Engine	MCR (kW)	RPM	SFC (g/kWh)
11	5S60ME-C8	11900	105	167
12	5S60ME-C8	11900	105	167
13	5S65ME-C8	14350	95	167
14	5S65ME-C8	14350	95	167
15	6S70ME-C8	19620	91	167
16	7S70ME-C8	22890	91	167
17	8S70ME-C8	26160	91	167
18	8S70ME-C8	34380	91*	167

Table 4-1. Table of selected Suezmax engines.

Capital cost is calculated using HEC's ship design software tools. The following quantities are included in the calculation of construction/capital cost:

- Hull Steel
- Coatings
- Accommodation Outfit
- Hull Outfit
- Cargo Gear and Piping
- Machinery
- Engineering and Fees
- Shipyard Profit

Capital cost increases consistently with speed, while the installed MCR is a step function of power ratings corresponded to engines handpicked for each speed (Figure 4-8). If theoretical engine power values were chosen instead, the MCR curve would have more resemblance to the capital cost curve (i.e. a smoother curve).

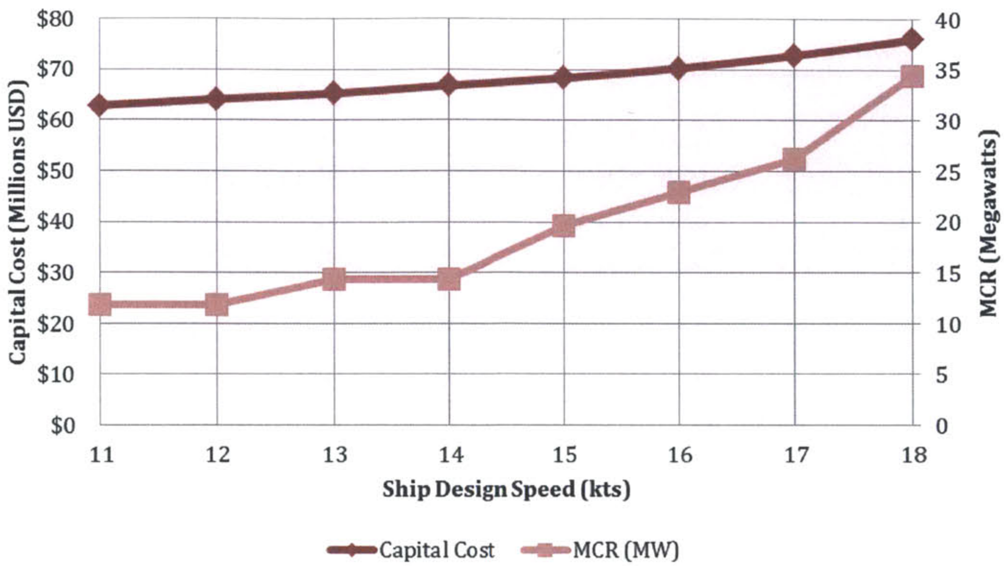


Figure 4-8. Rising capital cost and MCR over design speed for a Suezmax tanker.

The incremental capital cost with respect to MCR varies from $300/kW to $800/kW depending on the relationship between installed MCR and the increase in required MCR needed to power the ship at a given speed, as shown in Figure 4-9. Only increments in which a new engine is selected are included.

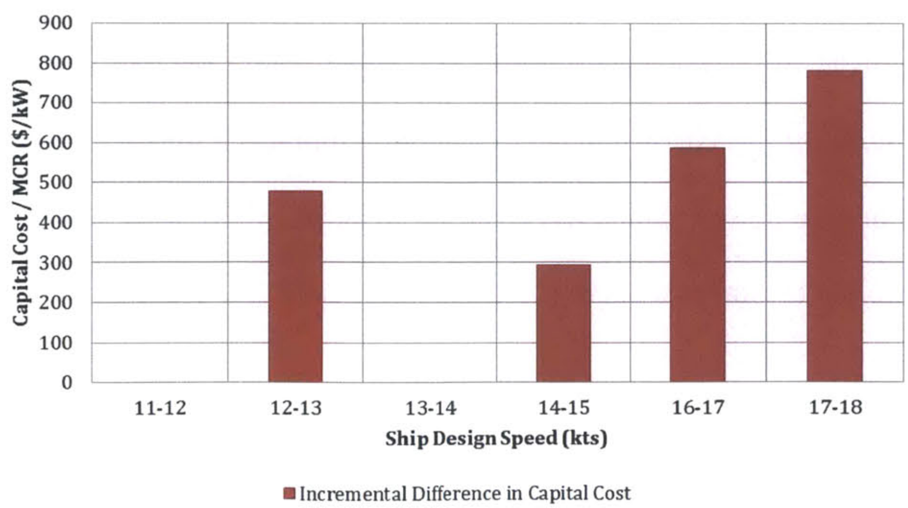


Figure 4-9. Incremental capital cost with respect to MCR for a Suezmax tanker.

When the capital cost increment is removed such that capital costs for all speeds are set to the 15-knot benchmark capital cost, RFR logically increases below 15 knots and decreases above 15 knots, as shown in Figure 4-10. Doubling the cost increment has the inverse effect. In other words, RFR increases with engine size and capital cost. The impact of doubling or removing the capital cost increment on the extremes of the analyzed speed spectrum at 11 and 18 knots is 2.2% and 1.7%, respectively. The speed corresponding to the minimum RFR, in this case 13 knots, is unchanged. Therefore, capital cost does not significantly affect speed selection.

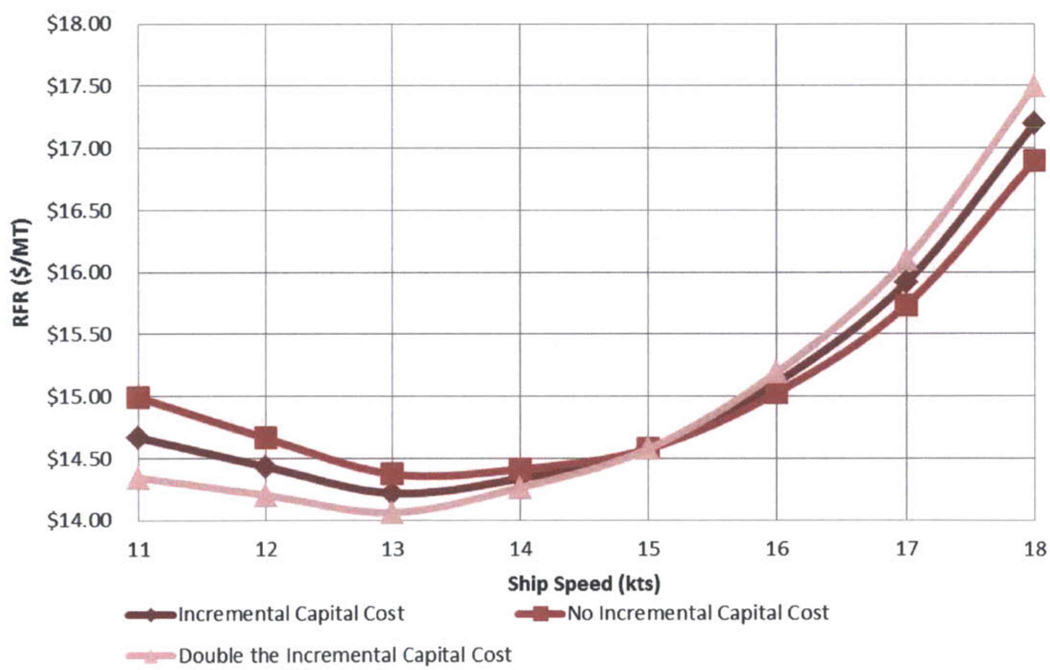


Figure 4-10. Suezmax RFR values with OPEX + ICC + varied capital cost input.

4.7. Minimum RFR Recommendations

For each fuel projection, the minimum RFR is selected from the series of RFR values generated for each design speed. As expected, in Figure 4-11, the trend between fuel cost and minimum RFR is linear with the same rate of change for each TCE. As the market improves, the minimum required freight rate increases directly.

For every charter cost input, there is a speed that yields the minimum RFR. While the calculation for minimum RFR is performed, data on the corresponding speed are collected to determine the most profitable speed at which to run a ship based on the market rate and cost of fuel (Figure 4-12). Note that the speed trend lines for each TCE never cross, though in some cases the speed is the same for different segments of the market. This relationship suggests that a ship should not be run faster than 16 knots except for in the extreme case where there is a market boom and fuel is as cheap as $300/MT. Likewise, ships with the reserve power to operate over 15 knots have an edge when the market is favorable as long as the fuel price does not exceed approximately $750/MT.

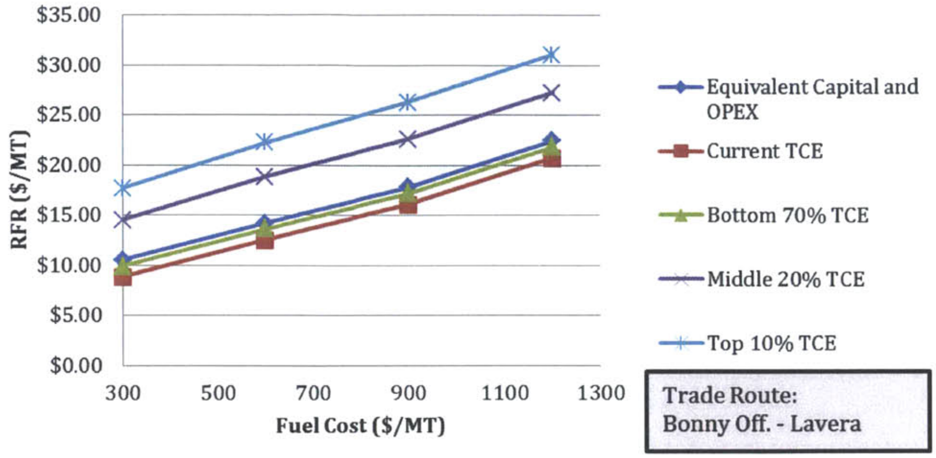


Figure 4-11. Minimum RFR values for a Suezmax tanker across 11 through 18 knots. . Trade route: Bonny Offshore, Nigeria to Lavera, France.

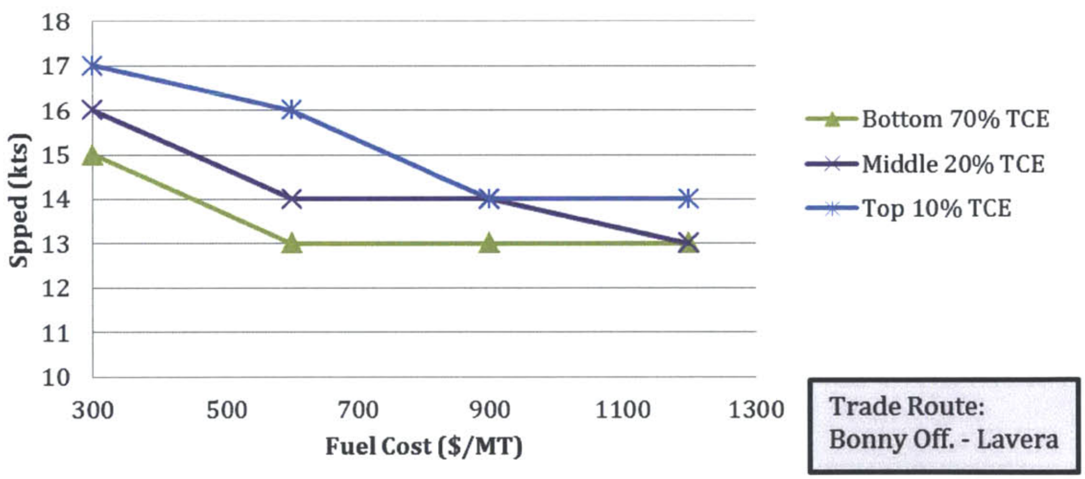


Figure 4-12. Speed corresponding to minimum RFR values for a Suezmax tanker across 11 through 18 knots. Trade route: Bonny Offshore, Nigeria to Lavera, France.

The full range of design speeds that minimize RFR for a Suezmax tanker traveling on a trade route from Bonny Offshore to Lavera is 13 to 17 knots. However, when considering the highest market rate segment, the range is limited to 14 to 17 knots. These extents are therefore chosen as the upper and lower cutoffs for the range of recommended Suezmax design speeds from the RFR metric with charter rate treated as the opportunity cost for sum of CAPEX plus OPEX. The cost of fuel influences this set of recommendations more than any other factor considered in the sensitivity analysis.

5. Chapter 5

Post-Acquisition Ship Management Analysis

5.1. Overview

After a ship has been bought and delivered, a new set of circumstances arises. The relevant question now is which speed the ship should be operated at. At this stage, shipowners have two main options for how to charter their vessel: on the spot market where the owner pays all the costs at a fixed value, or on a time charter where the charterer pays the voyage costs. Even though the charterer pays for fuel in a time charter agreement, it is still in the best interest of the owner to take into account the costs of both the owner and charterer. If the market is considered when setting a design speed, then both stand to gain in savings. CAPEX are already a sunk cost, but OPEX are not. If OPEX, which run at about $12,000 per day for a conventional Suezmax, are not covered by revenue, then the owner should consider selling the ship on the second-hand market or laying it up. If OPEX are covered, however, then the ship operation speed should be selected.

Chapter 5 details the key capabilities of the speed selection model and how they could prove useful to shipowners in scenario planning. In Section 5.2, the tradeoffs between incremental revenue and costs over ship speeds are presented. Next, Section 5.3 defines a metric for selecting speed, "relative joint contribution" (RJC), as the revenue minus the dynamic costs with a maximizing objective function. The full sensitivity analysis is conducted for relative joint contribution, and results are presented in Section 5.3. In order to determine critical TCE rates at which speed selection should be altered, the variation of TCE rates from historical values is analyzed in Section 5.4. The sensitivity of contribution to trade routes is then tested in Section 5.5. Section 5.6 presents speed recommendations for Aframax, Suezmax, and VLCC tankers. Lastly, in Section 5.7, a case study in speed profiles for a low fuel projection introduces speed variation in respect to market rate, which increases a tanker's operational flexibility and allows it to maximize contribution.

5.2. Important Tradeoffs

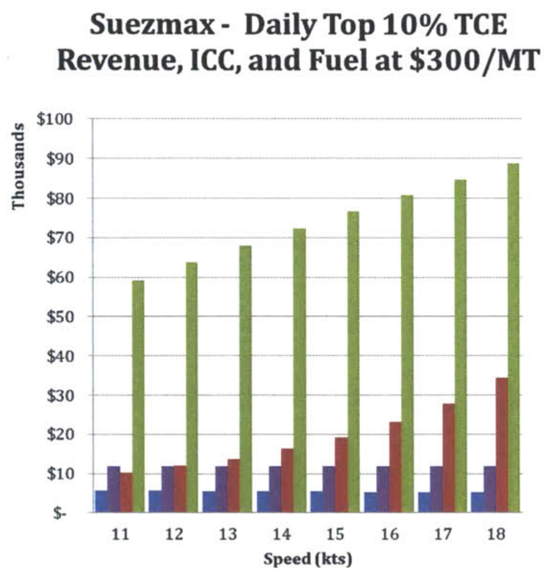
The objective of both the shipowner and charterer should be to maximize the difference between the revenue and costs. In these calculations, the difference between revenue & costs is simply called "relative joint contribution." It is important not to confuse relative joint contribution with profit. The costs of both the shipowner and the charterer are combined, so neither party's profit is reflected by contribution. Oil majors play both roles, and it would theoretically be in their best interest to maximize joint contribution. In other situations, the calculation of contribution is also useful in looking at tradeoffs among the factors involved. For example, if the shipowner is operating at a spot rate in a market boom – different from the top 10% TCE rate – she would pay for the fuel cost. If she wished to speed up the ship and deliver the cargo earlier in order to get an additional day under a new time charter at a rate related to the high TCE rate, she could compare the incremental daily fuel cost of the higher speed involved with the incremental revenue.

The ship's revenue is calculated and studied as a tradeoff with fuel and inventory cost. Time charter rates are used for the determination of revenue in accordance with the percentage of time the market is expected to spend at the bottom 70%, middle 20%, and top 10% of the market.

The number of days it takes to move the 15-knot ship's cargo was referenced as a base time period for comparison in the calculation of revenue for the other speeds. In other words, faster ships will move the same amount of cargo as the benchmark ship in one voyage, and the dollar per ton revenue calculated for the 15-knot ship was also used with faster ships. The construction, operating, and fuel costs were calculated either annually or for the percentage of the year corresponding to the historically-based probability of each charter rate.

The daily revenue is not the same as the time charter equivalent from the probability density functions. Instead, it is weighted by voyage duration based on the TCE for a 15-knot ship so that the revenue per ton is a fixed amount within each size category.

As shown in Figure 5-1, for the highest fuel projection, the fuel costs alone dominate the expected revenue.



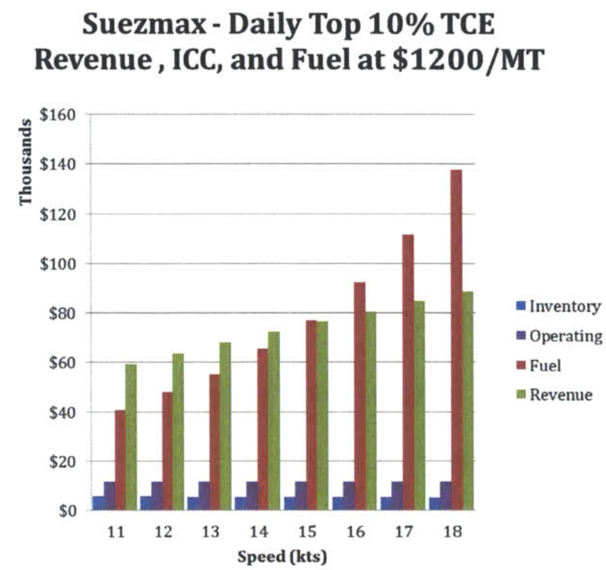


Figure 5-1. Comparison of absolute revenue and dynamic costs for the daily top 10% TCE with the fuel price projected at $300/MT and $1200/MT. Trade route: Bonny Offshore, Nigeria to Lavera, France.

Incremental costs and revenues between ship speeds clearly illustrate the tradeoffs, as shown in Figure 5-2 for the $300/MT low projection. When comparing incremental change as speed increases, inventory cost changes nominally. Daily operating cost remains the same for all ship speeds, and is therefore not accounted for in the tradeoff analysis.

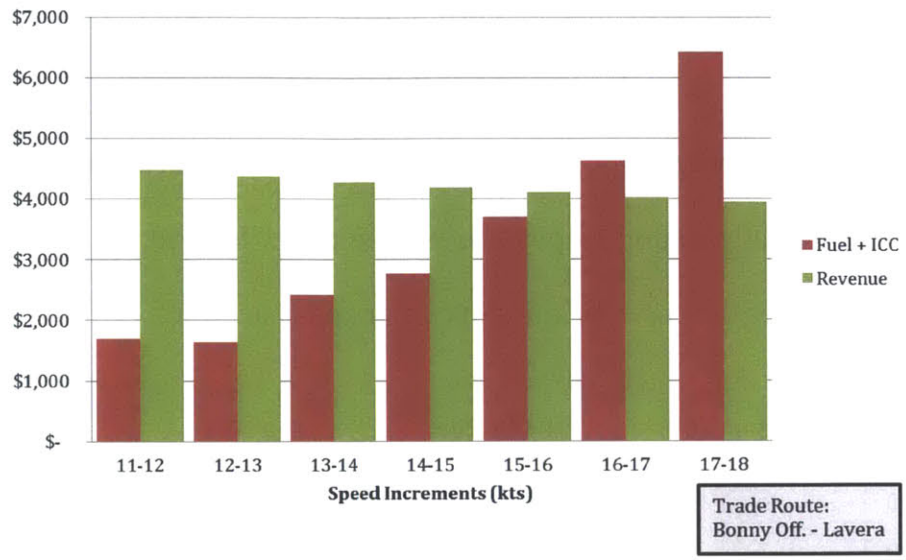


Figure 5-2. Tradeoff of incremental fuel cost and inventory carrying cost with revenue for a Suezmax tanker at the top 10% TCE with fuel price projected at $300/MT. Trade route: Bonny Offshore, Nigeria to Lavera, France.

5.3. Relative Joint Contribution Metric

Though RFR is an important metric, its agreement with a threshold value does not on its own yield the design speed with the maximum profit or provide the ultimate deciding factor for a ship's commerciality. One approach to obtain insight into the choice of design speed is to determine the relative joint contribution (RJC) under different scenarios. RJC is calculated by subtracting all dynamic costs from the revenue, where dynamic costs are defined as those that vary with speed and include fuel and inventory carrying costs. Figure 5-3 compares a set of daily contributions for a 15-knot Suezmax tanker for the three market freight rate segments and four fuel projections.

RJC does not represent the owner's profit, because the owner is not paying the fuel. Also, paying off the ship's capital cost is part of the owner's expense, while market boom charter rates are opportunity costs. Similarly, RJC does not represent the charterer's costs, as the charterer is legally bound to pay the voyage costs. Instead, RJC is a collaborative metric that incorporates the costs for the shipowner and charterer.

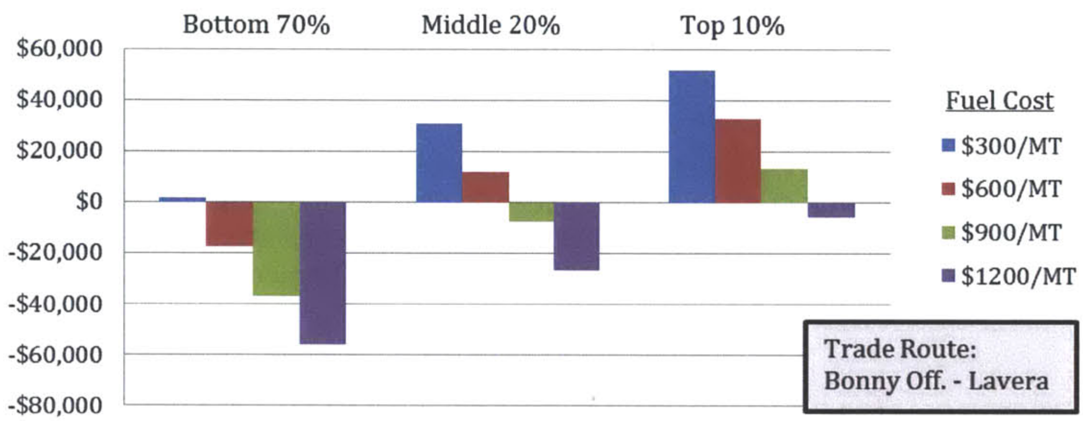


Figure 5-3. Daily contributions for the benchmark 15-knot Suezmax tanker. Trade route: Bonny Offshore, Nigeria to Lavera, France.

The RFR objective function yields a higher speed recommendation than the joint contribution metric. That is to say, RFR is minimized for a higher speed than contribution is maximized for. Refer to Tables 5-1 and 5-2 that show a breakdown of absolute and percent differences, respectively, for a Suezmax case on the Bonny Offshore – Lavera trade route at a low fuel projection of $300/MT. Note that the percent increase in daily fuel + ICC costs is greater than the percent daily decrease in tons carried, and the revenue increases at the same rate as annual throughput, by definition.

	15 knots	16 knots	17 knots	18 knots
Voyage Duration	26.21	24.87	23.69	22.64
Voyage Fuel Cost	$511,209	$574,571	$660,074	$778,801
Voyage ICC Cost	$283,591	$265,867	$250,228	$236,326
Voyage Fuel + ICC	$794,800	$840,438	$910,302	$1,015,127
Top 10% RFR	$18.15	$17.80	$17.66	$17.82
Bottom 70% RFR	$9.86	$9.92	$10.17	$10.65
Daily Fuel + ICC	$30,326	$33,789	$38,425	$44,846
Annual Throughput	2,147,771	2,263,081	2,376,057	2,486,771
Top 10% Daily Revenue	$76,557	$80,667	$84,694	$88,641
Bottom 70% Daily Revenue	$26,381	$27,797	$29,185	$30,545
Top 10 % Daily Relative Joint Contribution	$34,473	$35,120	$34,511	$32,036
Bottom 70% Daily Relative Joint Contribution	-$15,703	-$17,750	-$20,998	-$26,059

Table 5-1. Absolute differences between Suezmax RFR and relative joint contribution quantities across speeds at a projected fuel price of $300/MT. Benchmark trade route.

	15 to 16 knots	16 to 17 knots	17 to 18 knots
Voyage Duration	-5.10%	-4.80%	-4.50%
Voyage Fuel Cost	12.40%	14.90%	18.00%
Voyage ICC Cost	-6.30%	-5.90%	-5.60%
Voyage Fuel + ICC	5.70%	8.30%	11.50%
Top 10% RFR	-2.00%	-0.70%	0.90%
Bottom 70% RFR	0.67%	2.46%	4.78%
Daily Fuel + ICC	11%	14%	17%
Annual Throughput	5.40%	5.00%	4.70%
Top 10% Daily Revenue	5.40%	5.00%	4.70%
Bottom 70% Daily Revenue	5.37%	4.99%	4.66%
Top 10 % Daily Relative Joint Contribution	1.90%	-1.70%	-7.20%
Bottom 70% Daily Relative Joint Contribution	-13.03%	-18.30%	-24.10%

Table 5-2. Percent differences between Suezmax RFR and relative joint contribution quantities across speeds at a projected fuel price of $300/MT. Benchmark trade route.

According to the results, when considering only the capital cost, one should design a ship with a design speed of between 13 and 15 knots, which is within one knot of Suezmax speeds printed in current order books. However, when considering the chartering cost as the opportunity cost for annual capital & operating cost during the top 10% of the market over the next twenty-five years, one should install larger engines so that the design speed is closer to 16 or 17 knots. This recommendation is illustrated in Figure 5-4 below. Preparing for future market peaks instead of considering only the current 25-year-low charter rate will result in the greatest profit margins over the lifetime of the ship. While the amount of the contribution has no specific meaning to the shipowner, a higher contribution will always be preferable to a lower contribution.

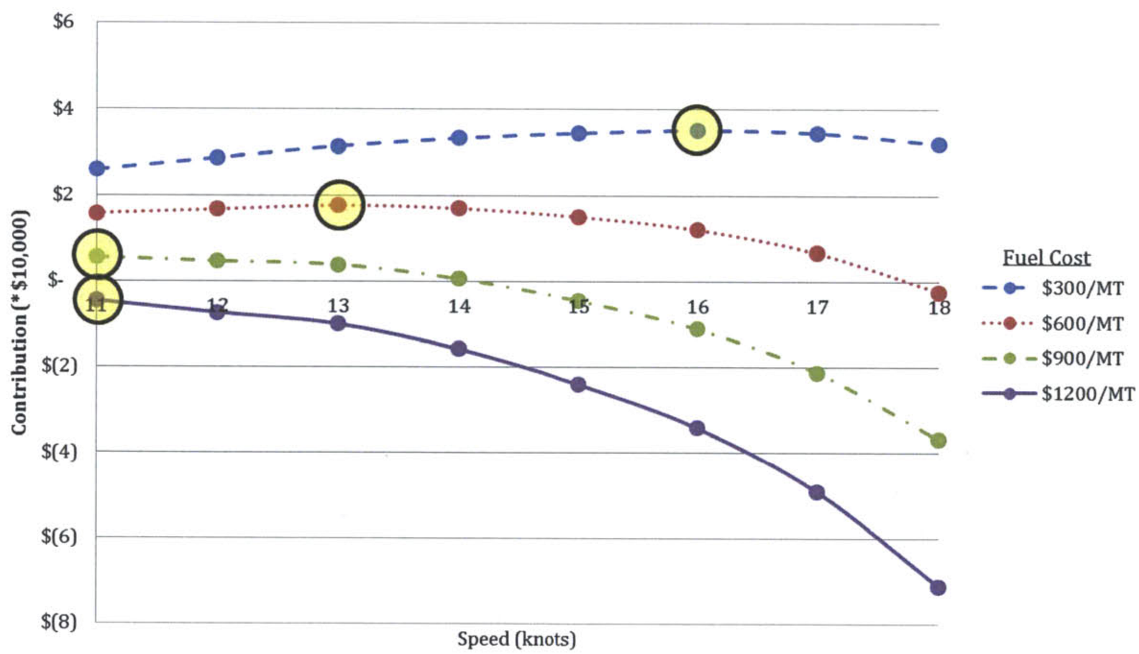


Figure 5-4. Suezmax JRC for the top 10% time charter rate. Trade route: Bonny Offshore, Nigeria to Lavera, France.

5.4. TCE Rate Variability

Future TCE rates will differ from historical market segments. It is therefore imperative to test the sensitivity of RJC to peak market rate values. For the Suezmax high-traffic trade route from Bonny Offshore to Lavera, RJC is maximized at a speed of 16 knots for the $300/MT fuel cost projection. In this case, the historical top 10% TCE of $76,557 daily is used to calculate contribution.

If, for example, the top 10% rate is relaxed in the sensitivity analysis's linear program and varied until the RJC objective function yields 17 knots, the new top 10% rate would be $89,334, a 16.7% increase over the historical value. In other words, to justify installing the reserve power required at 17 knots in a Suezmax tanker, peak rates would need to experience a price hike of at least 15%. Pushing the speed up to 17 knots involves covering an additional $4,762 daily in fuel cost at a fuel price of $300/MT. In order to increment the speed by 1 more knot to 18 knots, an additional $6,543 in fuel cost would need to be covered. This increase in fuel costs decreases the value of reserve power as ship speed increases.

Alternatively, scenarios where the market peak is sustained for longer portions of the year are also considered. Since the top 10% TCE rates being analyzed are daily rates, they will not change with the percentage of the year. However, annual RJC is affected.

The benchmark TCE rates and costs yield an annual RJC of $4,461,183, where the bottom 70% TCE is assumed as the revenue for 70% of the year, etc. Note that the daily inventory carrying cost is halved to account for the ballast voyage.

The following revenues and costs in Table 5-3 apply to the benchmark 15-knot Suezmax tanker on the Bonny Offshore to Lavera trade route at $300/MT:

Revenue/Cost	Daily Rate
Bottom 70% TCE	$ 26,381
Middle 20% TCE	$ 55,612
Top 10% TCE	$ 76,557
Fuel Cost	$ 19,268
Inventory Cost	$ 5,410

Table 5-3. Market-segmented revenues and costs for a Suezmax tanker with fuel price projected at $300/MT. Trade Route: Bonny Offshore, Nigeria to Lavera, France.

If a market peak is sustained, and the time duration of the top 10% market segment is doubled to 20% by cutting into the bottom 70%, the new TCE rates remain the same while the market segmentation changes from 10-20-70 to 20-20-60. The resulting annual RJC is $6,242,431, a remarkable 40% increase over the original RJC. A mere extra 35 days a year of the top 10% rate brings in almost $2,000,000 more RJC. Contribution is therefore extremely sensitive to both market rates and cycles.

5.5. Trade Route Sensitivity Analysis

A trade route study is conducted for theoretical trade route distances ranging from 500 to 6000 nautical miles at intervals of 500. The study affirms that the effect of trade route length on selecting design speed is minimal. For instance, for the top 10% market freight rate segment at a projected fuel price of $600/MT, the recommended speed at which the RFR is minimized across all 8 speeds is consistently 16 knots for all 12 trade routes. Figure 5-5 shows the linear relationship of RFR and trade route length for the 15-knot benchmark Suezmax vessel.

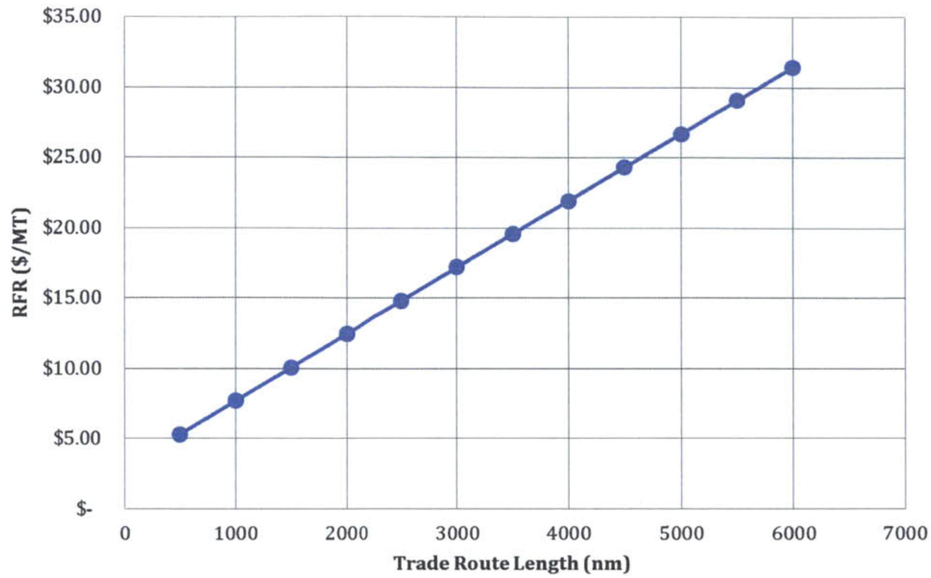


Figure 5-5. Sensitivity of 15-knot Suezmax RFR values to trade route length for the top 10% TCE and fuel price projected at $600/MT.

Figure 5-6 shows RFR curves across the entire speed range. Note how the shape of the RFR curve flattens as the trade route length distance decreases, implying that vessel speed has less of an effect on the RFR for short hauls.

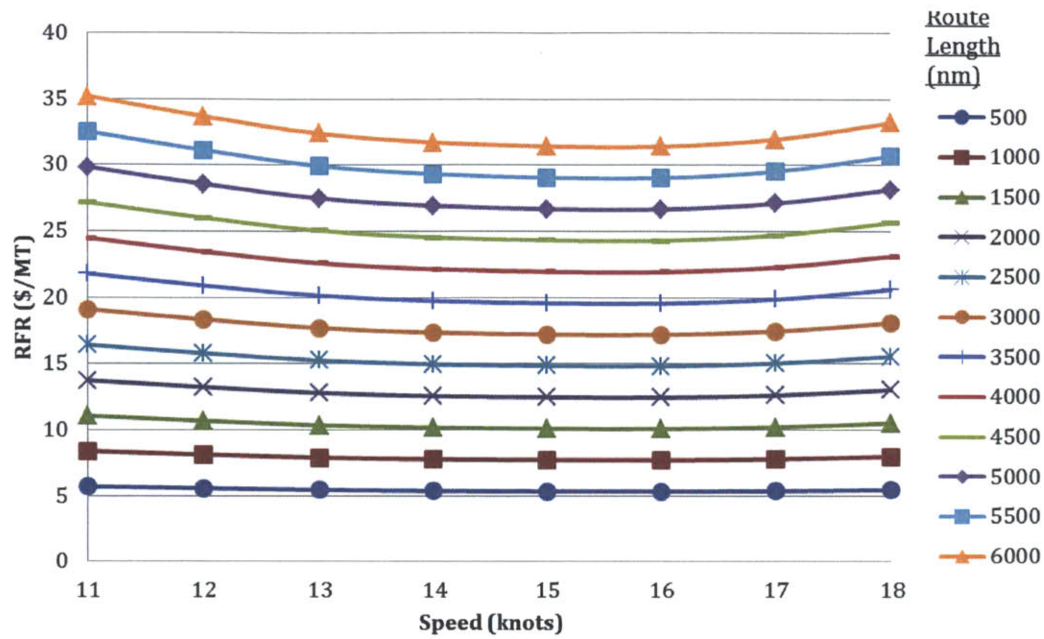


Figure 5-6. Sensitivity of Suezmax RFR values to trade route length for the top 10% TCE and fuel price projected at $600/MT across 11 through 18 knots

Figure 5-7 presents a close-up of three adjacent speed-RFR curves acquired in the study:

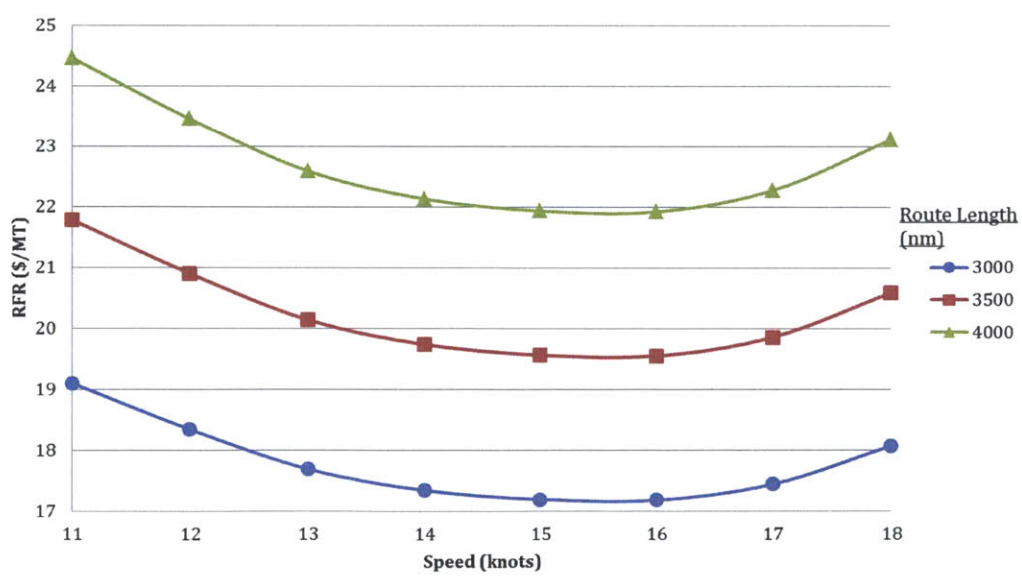


Figure 5-7. Sensitivity of Suezmax RFR values to trade route length at the top 10% TCE with projected fuel price at $600/MT.

5.6. Ship Size RFR Recommendations

The sensitivity analysis is conducted for Aframax, Suezmax, and VLCC tankers. Three representative trade routes are selected for each ship size according to criteria outlined in Chapter 1. The selected trade routes for each size classification are listed in Tables 5-4, 5-5, and 5-6. The resulting RFR curves for each ship size's selected long-haul route are presented in Figures 5-8, 5-9, and 5-10. The recommended speeds for all three sizes fall within 12 to 17 knots and exhibit fairly similar patterns for fuel cost and TCE rate scenarios. It is evident that speed selection is not sensitive to ship size, as it is to fuel cost.

Origin	Destination	Trade Route Length (nm)
Sullom Voe	Wilhelmshaven	531
Curacao	Texas City	1,797
Curacao	Hamburg	4,500

Table 5-4. Selected trade routes for the Aframax tanker study.

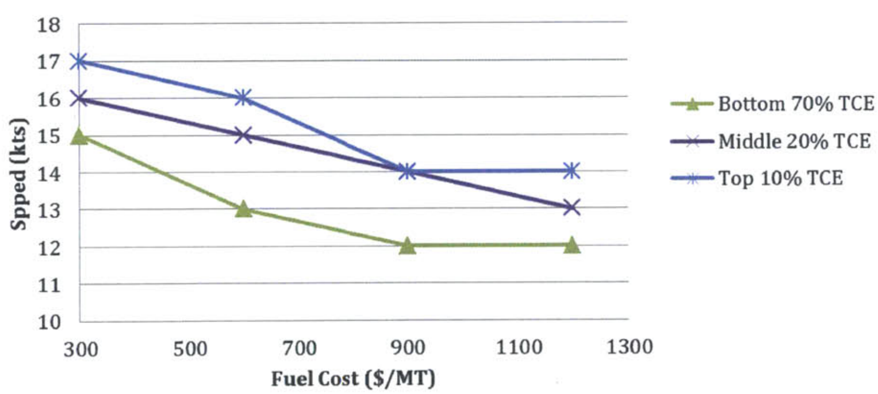


Figure 5-8. Speeds corresponding to minimum RFR values for an Aframax tanker across 11 through 18 knots. Trade route: Curacao to Hamburg, Germany.

Origin	Destination	Trade Route Length (nm)
Sidi Kerir	Lavera	1,420
Bonny Offshore	Lavera	4,070
Bonny Offshore	LOOP	5877

Table 5-5. Selected trade routes for the Suezmax tanker study.

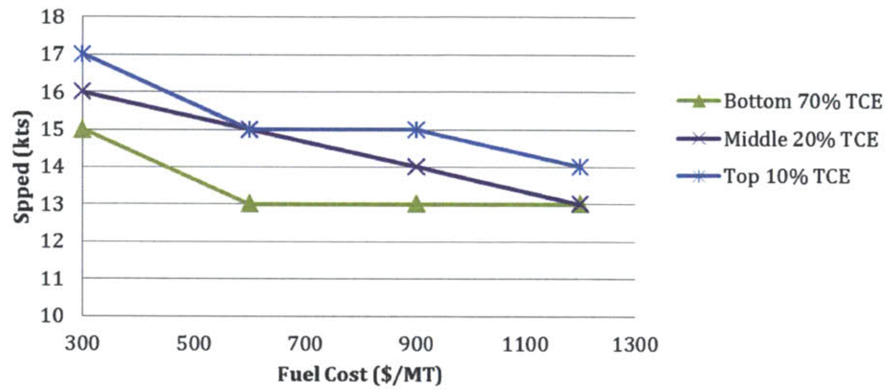


Figure 5-9. Speeds corresponding to minimum RFR values for a Suezmax tanker across 11 through 18 knots. Trade route: Bonny Offshore, Nigeria to LOOP, US.

Origin	Destination	Trade Route Length (nm)
Sidi Kerir	Rotterdam	3,159
Ras Tanura	Chiba	6,605
Ras Tanura	LOOP	12,225

Table 5-6. Selected trade routes for the VLCC tanker study.

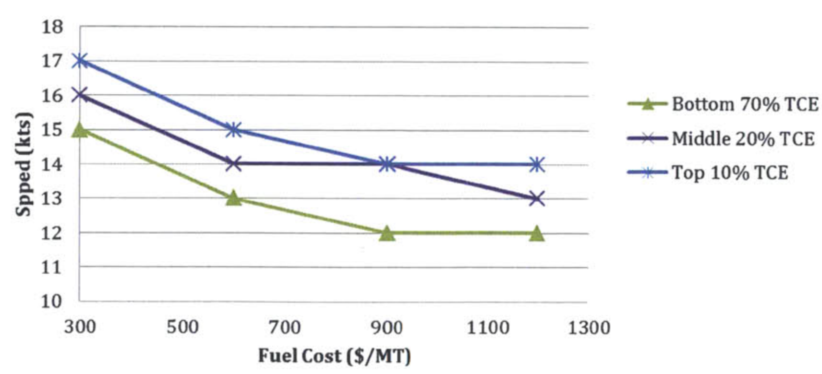


Figure 5-10. Speeds corresponding to minimum RFR values for a VLCC tanker across 11 through 18 knots. Trade route: Ras Tanura, Saudi Arabia to LOOP, US.

5.7. Speed Profile Scenarios

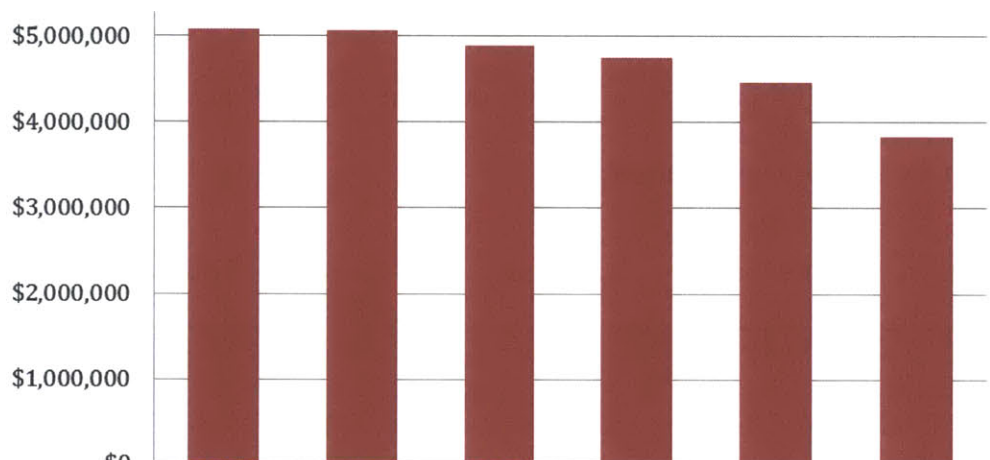
The fuel cost has the greatest influence over speed selection and must be held constant to properly analyze trends across speeds. The following speed profile scenario is performed for Suezmax tankers at the low fuel projection. At the low fuel cost estimate of $300/ton, there is a strong case for running a ship at higher speeds. Refer to Table 5-7, where the contribution is maximized by operating at 16 knots when the market rates are within the top 10%, 15 knots when the market rates are within the middle 20%, and 13 knots when the market rates are within the bottom 70%. If the operating speed is varied throughout the year to properly take into account the market, then the profit will be greater than for any one speed alone.

Time Charter Equivalent	13 knots	15 knots	15 knots - Modified	16 knots	16 knots - Modified
Bottom 70% TCE - Daily (249 days)	$4,119	$1,703	$4,119	-$647	$4,119
Middle 20% TCE - Daily (71 days)	$30,112	$30,934	$30,934	$30,153	$30,934
Top 10% TCE - Daily (35 days)	$48,736	$51,879	$51,879	$52,223	$52,223
Annual Contribution (355 days)	$4,891,640	$4,461,183	$5,061,572	$3,833,944	$5,073,774

Table 5-7. Daily and annual contributions to profit for a Suezmax tanker trading on the Bonny Offshore to Lavera trade route.

The modified 16 knots ship uses the strategic approach of derating its engine or lowering its operating speed by other means in order to maximize annual contribution to profit. When the market is at a peak, it maintains speed at 16 knots; when in a slump, it slow steams to 13 knots. As a result, its annual profit is greater than those for the 13, 15, and 16 knot ships, as shown in Figure 5-11. Therefore, the 16-knot ship clearly has the potential to gain the most contribution.

The calculation of contribution is most price-sensitive to fuel, and if a 17-knot column were added to the chart below, the increase in fuel cost would cause the top 10% contribution to drop. Therefore a 17-knot modified ship would have an identical optimized speed profile to that of the 16-knot modified ship.



	16 knots (Modified)	15 knots (Modified)	13 knots	14 knots	15 knots	16 knots
Contribution	$5,073,774	$5,061,572	$4,891,640	$4,744,751	$4,461,183	$3,833,944

Figure 5-11. Annual relative joint contributions for Suezmax tankers with varying speed profiles at $300/MT. Trade route: Bonny Offshore, Nigeria to Lavera, France.

6. Chapter 6

Conclusions and Recommendations

6.1. General Conclusions

There are several uncertainties that obfuscate the future of the oil tanker market. The current industry perspective is characterized by an almost unanimous belief in slow steaming. There are particular scenarios, however, where it is clearly advantageous to increase ship speed. If ship owners look beyond the initial RFR calculation that relies on capital cost to determine design speed, a more intelligently informed decision on ship investment can be made.

Tanker freight rates are volatile with few opportunities to reap high revenues. A crude oil tanker typically spends almost half its life incurring losses (i.e. not covering fully allocated costs) with high gains to be made during market booms. In the past twenty years, the highest time charter equivalent (TCE) rate for 1990 Suezmax tankers was $158,000 compared to the average value of $38,000. To fully take advantage of such market peaks, ships need to be equipped with reserve power.

In the scenarios both before and after ship acquisition, the charter rate is treated as the opportunity cost for the sum of annual capital cost CAPEX and OPEX. For the benchmark 15-knot Suezmax tanker, the result of this substitution of CAPEX and OPEX of $30,000 for the top 10% TCE of $76,557 results in RFR values up to 70% greater and a higher profitable speed range of 14 to 17 knots. Therefore, when considering market rates instead of simply the capital plus operating costs, more reserve power is needed to sail at higher speeds.

This study's required freight rate and relative joint contribution metrics for comparing vessels with different speeds allows the most profitable design speed for a ship to be determined. While trade route lengths have little effect on the minimization of RFR or maximization of contribution, projected fuel prices and market freight rates clearly have a strong impact on the speed that satisfies both the RFR and RJC objective functions.

6.2. Theory and Reality

6.2.1. Ship Speed

This study makes several assumptions related to tanker speed in order to construct a theoretical approach to speed selection. Consulted references implied that there is an insignificant difference between tanker design speed and maximum operating speed. Therefore, the study assumes that design and operating speed are the same. It also assumes that operating speeds remain the same for both the laden and ballast voyages. In reality, tankers may be able to accelerate beyond their design speed in good weather and may alter operating speed during the ballast voyage. Also, realistically, the speed might be set in a time charter contract with little leeway or incentive to vary speed with charter rate.

6.2.2. Tanker Orderbook and Fuel Cost

The RJC metric yields Suezmax speed recommendations at approximately 16 knots for the preferable market environment of the lowest fuel prices and highest TCE rates. Interestingly enough, this study's set of speed recommendations compares well with design speeds listed in Suezmax orderbooks. Vessels on order for delivery in 2012 and 2013 have speeds that are densely distributed around an average of 15.4 knots with a standard deviation of only 0.14 knots among 78 ships, as shown in Figure 6-1. The reasons for this observed range and its resemblance to the study's speed recommendations are unclear but likely not a product of market impact consideration.

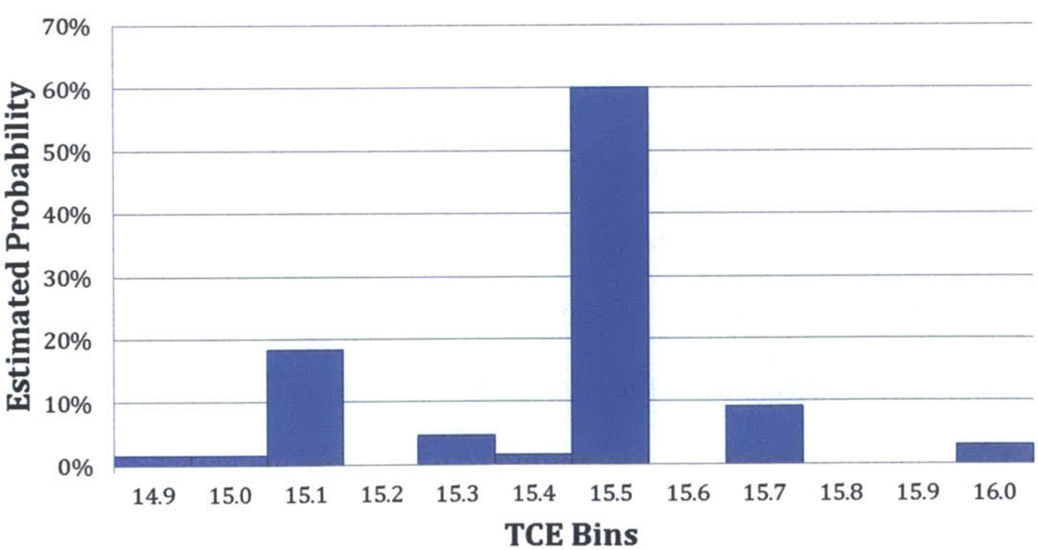


Figure 6-1. Probability density function of 78 Suezmax 2012 & 2013 orderbook speeds. Source: IHS Fairplay.

The sensitivity analysis included fuel cost projections ranging from $300/MT to $1200/MT for HFO. Over the past eleven years, the price of bunker fuel has risen from $100/MT to $700/MT, as shown in Figure 6-2. If these trends continue and sulfurous crude oil is further regulated, our high projection of $1200/MT could become a low projection.

Figure 6-2. Rotterdam bunker fuel price from January 2000 through December 2011. Source: Clarksons, Shipping Intelligence Network Timeseries.

Rising fuel costs have surprisingly not had an effect on design speed selection. Figure 6-3 shows the ratio of Suezmax design speed to horsepower. Overall, the average speed and installed power values for both orderbook and recently built tankers are the same, and the speed-power ratios for future tankers are lower than those of tankers in the existing fleet. Though orderbooks are reputed to have reporting errors, it is clear at a high level that design speed has not evolved over the years in response to fuel costs. One explanation for this trend is that naval architects are designing for reserve power. Another explanation is that high fuel prices are perceived as a temporary phenomenon that can be dealt with by slow steaming and derating engines.

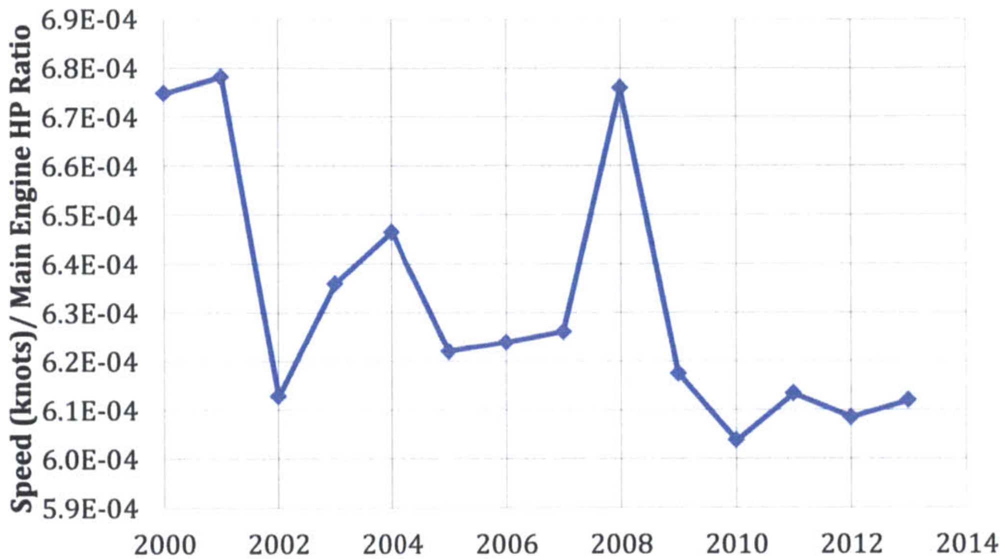


Figure 6-3. Ratio of speed in knots to installed horsepower for 296 150-160k DWT Suezmax tankers.

6.2.3. EEDI

The Energy Efficiency Design Index (EEDI) is an energy efficiency metric for the emission of CO2 per transport work performed by a marine vessel. Vessels built after 2013, 2015, and 2020 must comply with the baseline index curves for each year by obtaining a design index lower than the baseline index for that vessel's deadweight and type category. Since the EEDI is expected to alter future speed and engine trends, a set of sample EEDI calculations are performed and annotated for the benchmark 15-knot Suezmax vessel in Appendix D. Also contained in Appendix D are results from BIMCO's freely available EEDI calculator. The benchmark vessel complies with the 2013 and 2015 baseline EEDI indices.

For 2020, the attained index falls short of the baseline index. Therefore, in reality, engine selection may have to adapt to the EEDI standards by 2020.

6.2.4. Trade Routes

Chapter 2 affirms that oil production & consumption do not factor substantially into future tanker design, and future crude oil trade routes are not subject to major redistribution. However, this study only considers refinery construction, oil production, and changing global demand as the primary factors affecting shipping movements. The international political climate and unexpected events such as the disruption of global chokepoints could force trade routes to evolve. New oil reserves and alternative energy sources may also drastically alter the future tanker operating environment.

6.3. Speed Recommendations

The sensitivity analysis provides an estimate of the impact of key factors on ship profitability in order to determine which future combinations of those factors will lead to specific recommendations on ship speed. The tradeoff of fuel cost and TCE rate is the most important consideration in the selection of speed. For the benchmark Suezmax tanker, revenue is the same as the daily TCE rate. Therefore, for the top 10% market rate and $300/MT fuel projection, the benchmark's daily revenue is $76,557, and its average daily dynamic costs are $19,268 for fuel and $5,410 for ICC. The resulting RJC for the benchmark is $51,879. When the RJC is considered over all ship speeds, the 16-knot Suezmax yields the highest RJC for this scenario.

Future freight rates may not reflect historical rates. If the top 10% rate is relaxed for the benchmark Suezmax tanker such that the RJC objective function yields 17 knots instead of 16 knots, the new top 10% rate would be $89,334, a 16.7% increase over the historical value. In other words, to justify installing the reserve power required at 17 knots in a Suezmax tanker, peak rates would need to experience a price hike of at least 15%. Pushing the speed up to 17 knots involves covering an additional $4,762 daily in fuel cost at a fuel price of $300/MT. This increase in fuel costs decreases the value of reserve power as ship speed increases. If the price of fuel is as high as $1200/MT, fully allocated costs are not covered above 15 knots in any of the scenarios, and additional reserve power provides no advantage.

RFR and RJC speed recommendations for all selected trade routes and tanker size classifications (Aframax, Suezmax, and VLCC tankers) are contained in Appendix C.

6.4. Scenario Planning

Scenario planning is an analytical method commonly used in transportation to create long-term flexible plans and understand the impact of various factors. If shipowners adopt the approach of scenario planning, they may be better prepared for future markets. A shipowner could refer to this study in conjunction with market forecasts to determine what speed a ship should operate at to maximize contribution or return on investment. If fuel costs are rising, a shipowner could use this study's model to determine at which critical fuel cost a vessel should slow steam. Similarly, if the market is expected to be reaching a peak, this study's model can determine how much higher TCE rates need to be than historical values to justify speeding up by a given increment. The substitution of market segmented charter rates as the opportunity costs for capital cost, the foundation of this paper's approach, would allow a ship owner to take into account inevitable market cycles while ordering or operating a ship.

If shipowners wish to differentiate their fleet from their competitors during market peaks, increasing engine size and design speed allows the owners to err on the side of having greater flexibility in operating speed. Refer to the ship profiles discussed in Chapter 6 where a 16-knot Suezmax tanker allowed to vary speed with market rate yields the highest contribution of all speed profiles totaling over $5 million annually, whereas a 16-knot Suezmax tanker that always operates at 16 knots achieves the lowest contribution of below $4 million for a projected low fuel cost of $300/MT. Though slow steaming saves costs when the market is down, to fully take advantage of market peaks and maximize contribution over a ship's lifetime, ships must have sufficient reserve power.

6.5. Future Research

Suggested areas for future research include the following:

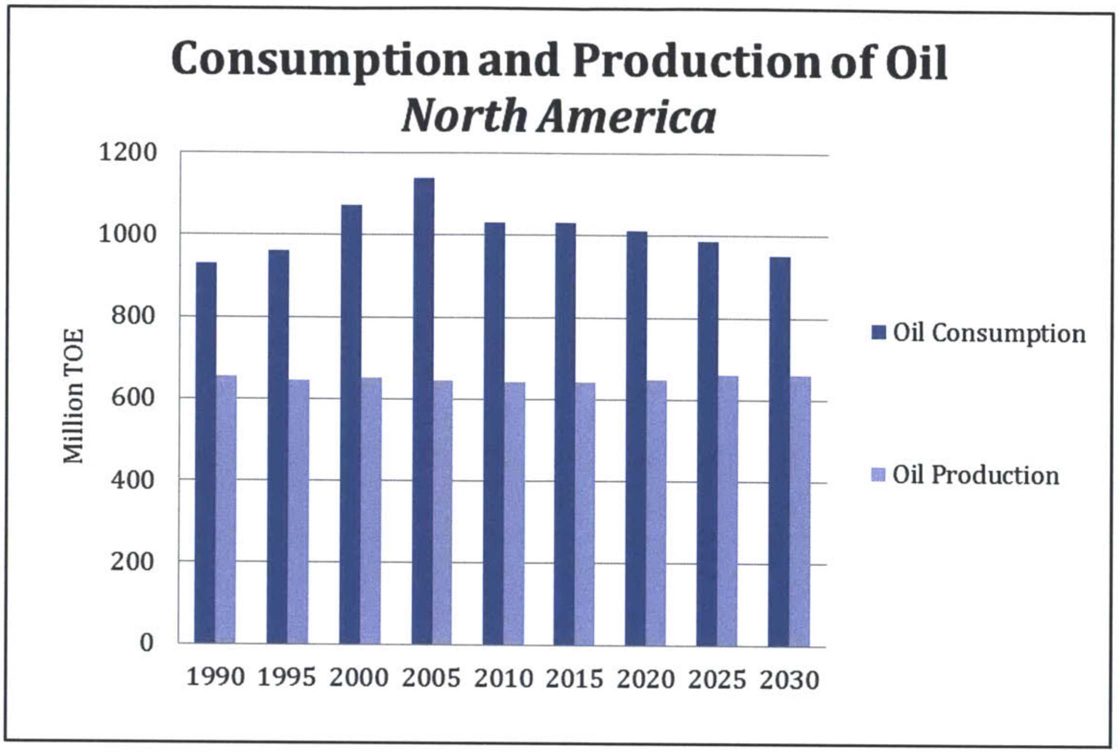
1. Develop a speed optimization program to serve as a scenario planning tool for ship owners and operators. Currently, this study provides a matrix of speed recommendations, but a future program could be developed from this study's analyses and key metrics to determine non-integer speeds with inputs for ship

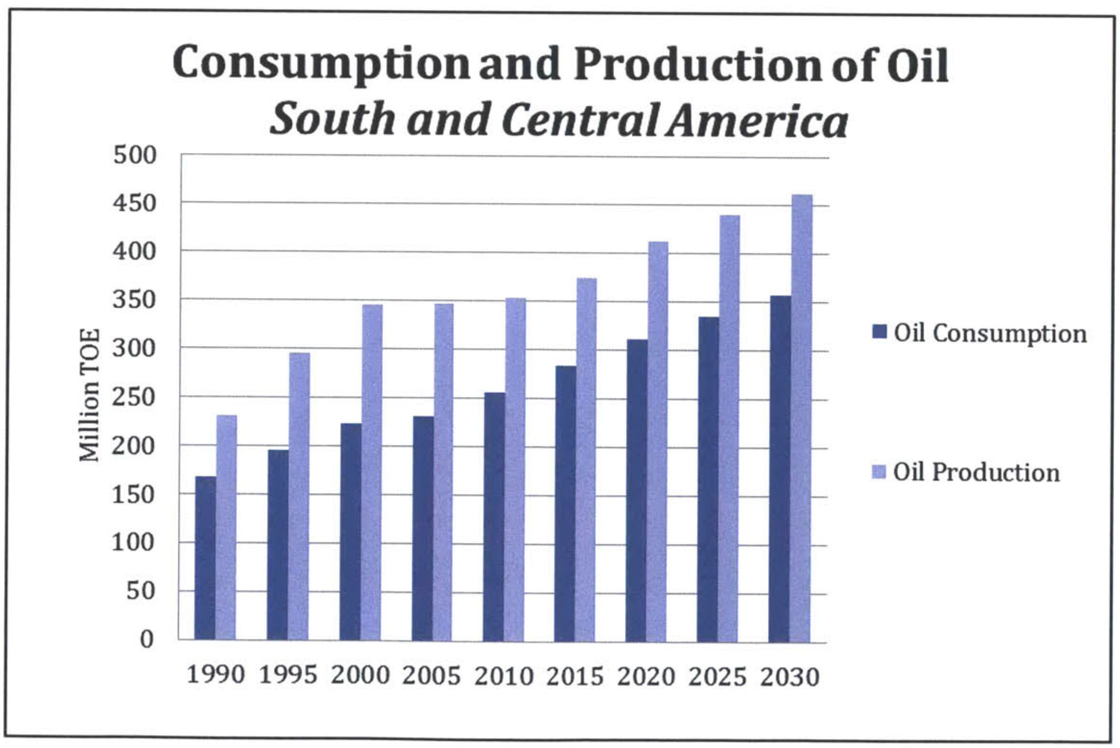
parameters and market forecasts beyond the scope of what is considered in this study. Variable market segmentation would distinguish the program from other ship speed selection tools.

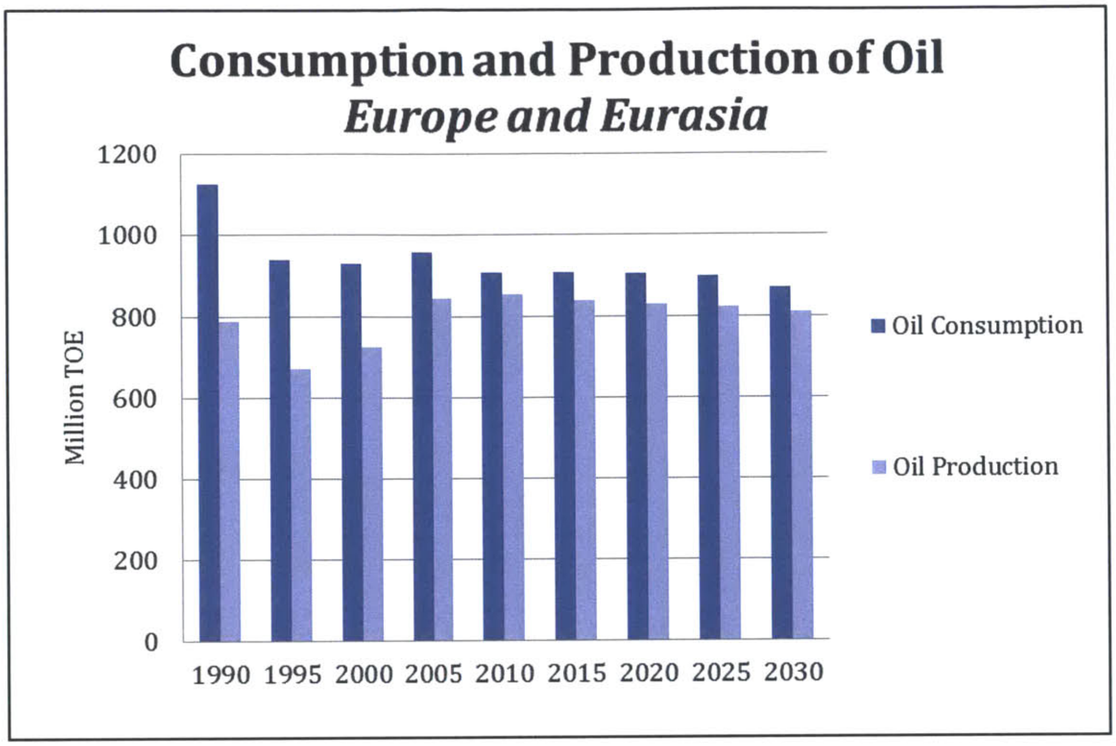
2. Assess the impact of market factors on emissions. The market analysis model could be taken one step further by analyzing the impact of added reserve power on emissions. Impending regulations and emission penalties could be accounted for financially as well. This could take effect in the form of both market prices and amplified fuel costs.
3. Study the advantages of derating engines, where derating is a setting that alters the relationship between the mean and maximum cylinder pressure in such a way that the specific fuel consumption and ship speed would both be reduced. There may be a stronger case for reducing costs over a ship's lifetime by installing larger engines with more reserve power if engines can be conveniently derated in coordination with slumping market cycles.
4. Product tanker routes are expected to evolve in the next quarter century as refineries are constructed closer to oil sources in the Middle East. Drastic increases in product tanker trade route lengths could result in larger size classifications such as Suezmax or even VLCC product tankers. A study based on historical product tanker rates could assess the impact of market factors on future product tanker operations with longer trade routes and larger ship sizes.
5. Evaluate using liquefied natural gas (LNG) as a fuel for tanker vessels with a lifetime cost-benefit analysis and market-based metrics developed in this study.

6. Model a portfolio of ships rather than an individual ship where each ship can operate at its own unique speed. The advantages of reserved power become more complex to quantify as the problem is scaled up to include multiple ships and can be determined by a multi-objective linear program. Shipping fleets resilient to market variability will likely be composed of ships of different sizes and speeds.

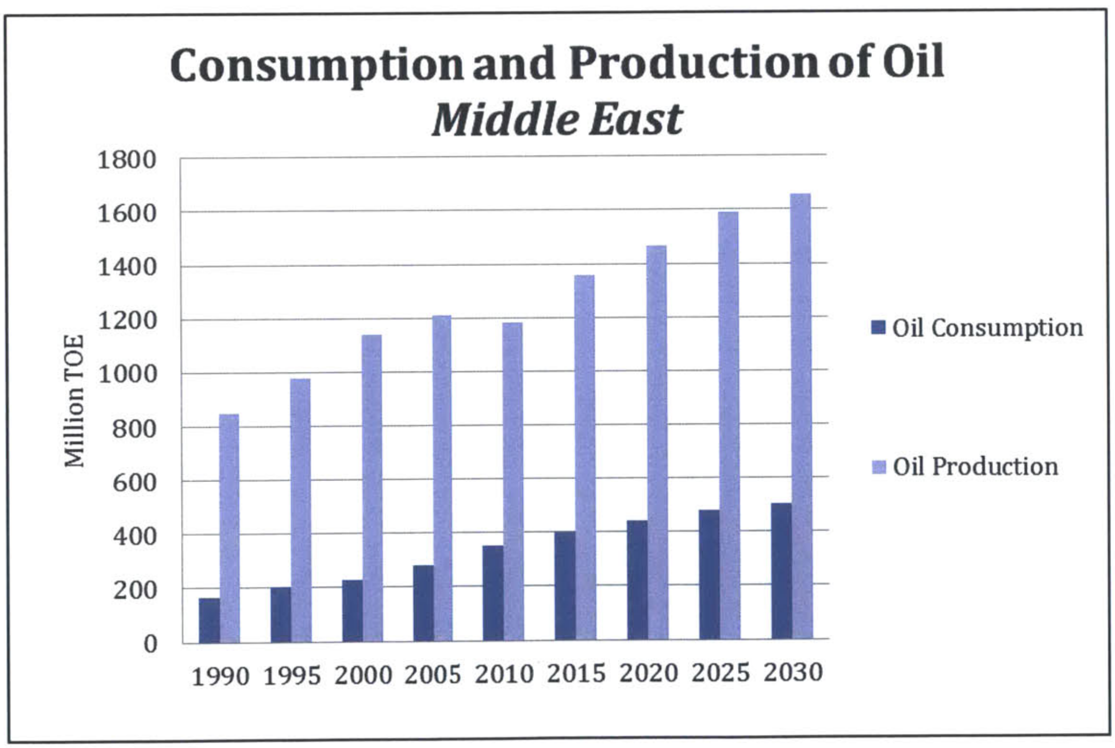
APPENDIX A: Oil Consumption and Production Figures


Consumption and Production of Oil
North America
1200
1000
800
600
400
200
0
Million TOE
1990 1995 2000 2005 2010 2015 2020 2025 2030
Oil Consumption
Oil Production

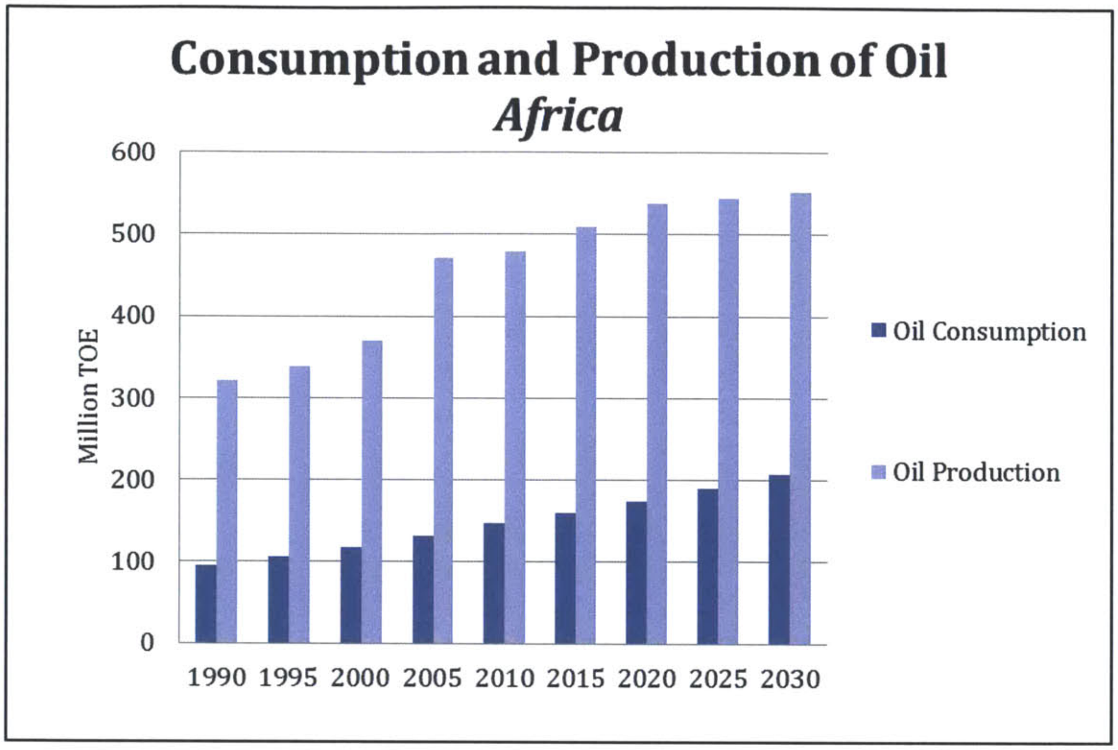

Consumption and Production of Oil
South and Central America
500
450
400
350
300
250
200
150
100
50
0
Million TOE
1990 1995 2000 2005 2010 2015 2020 2025 2030
Oil Consumption
Oil Production



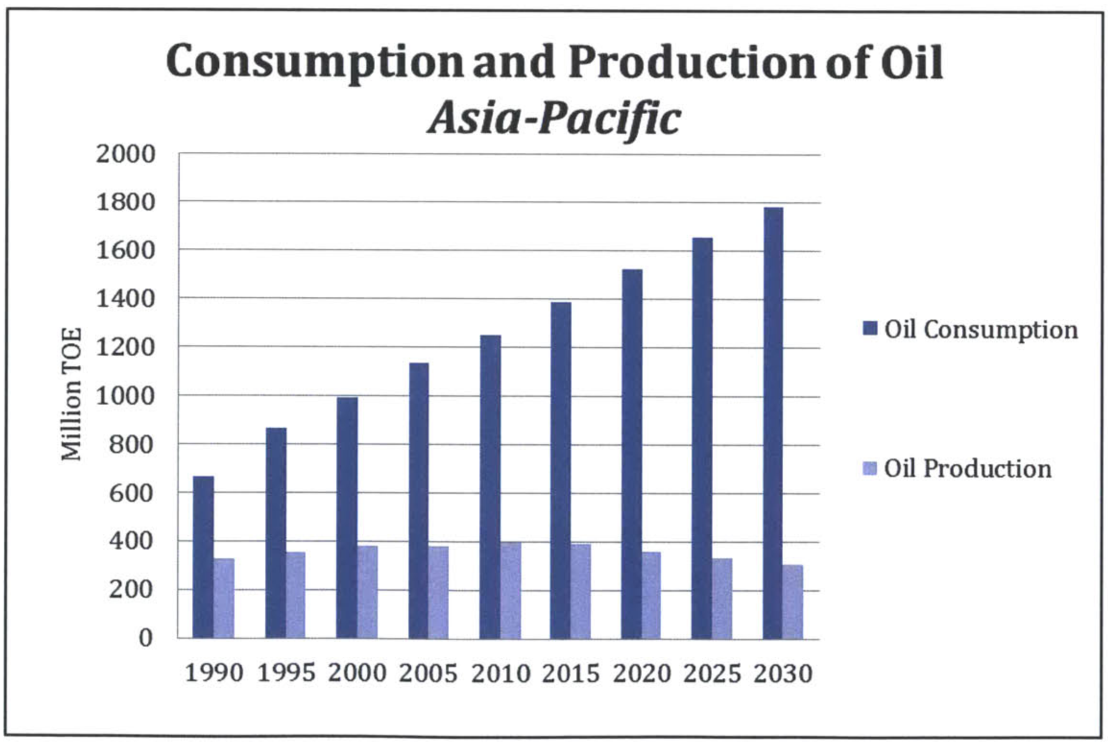
Consumption and Production of Oil
Europe and Eurasia
1200
1000
800
600
400
200
0
Million TOE
1990 1995 2000 2005 2010 2015 2020 2025 2030
Oil Consumption
Oil Production



Consumption and Production of Oil
Middle East
1800
1600
1400
1200
1000
800
600
400
200
0
Million TOE
1990 1995 2000 2005 2010 2015 2020 2025 2030
Oil Consumption
Oil Production

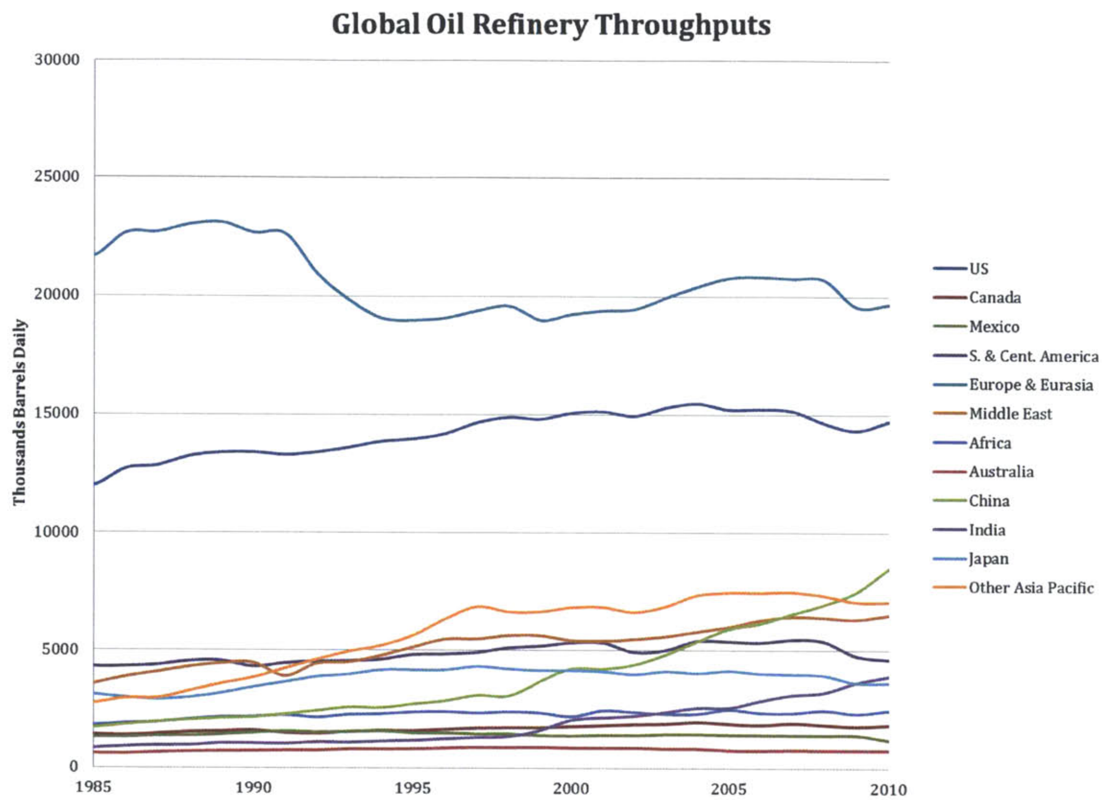


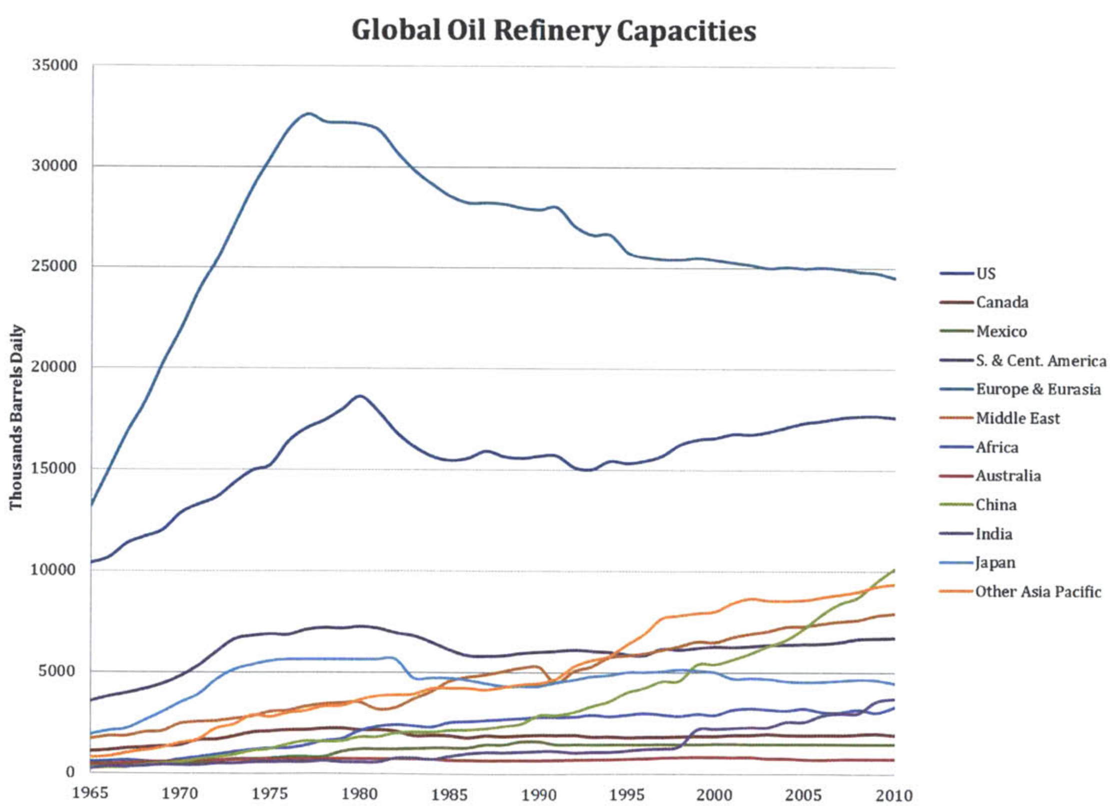
Consumption and Production of Oil
Africa
600
500
400
300
200
100
0
Million TOE
1990 1995 2000 2005 2010 2015 2020 2025 2030
Oil Consumption
Oil Production

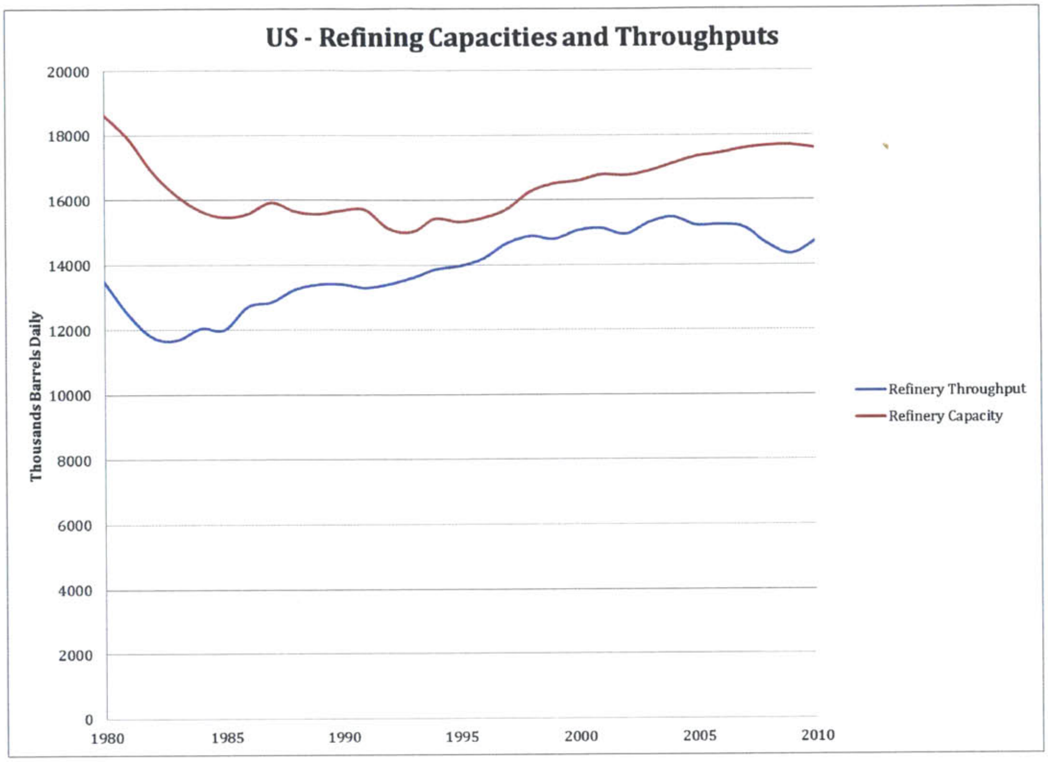


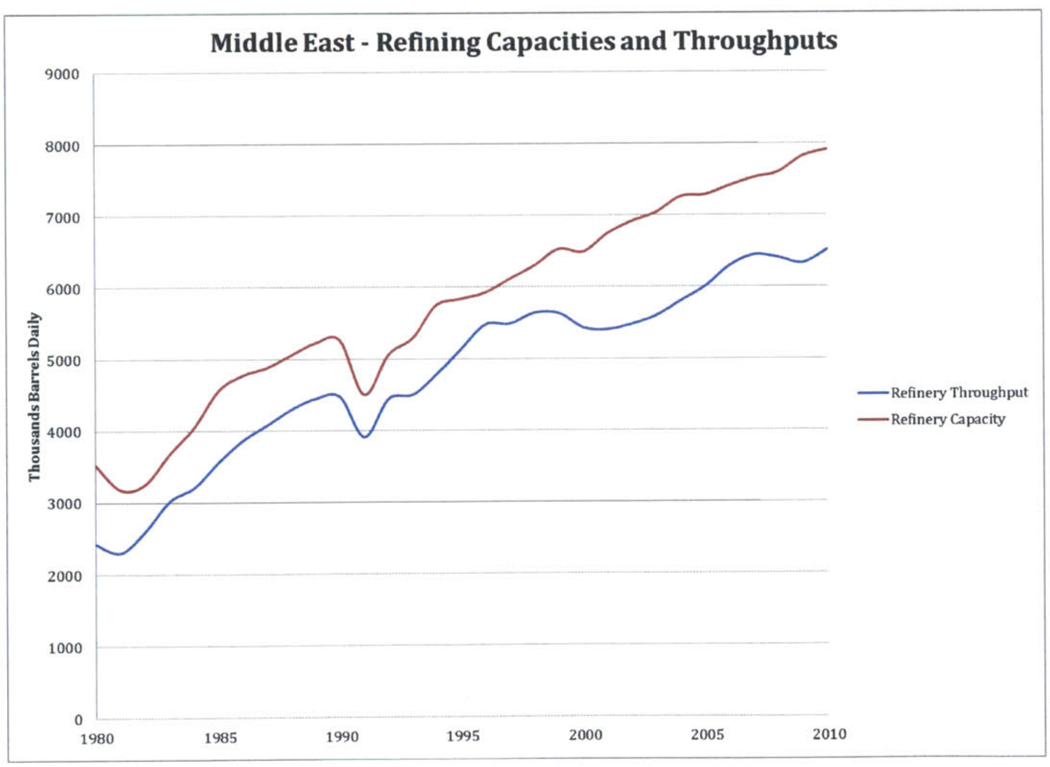
Consumption and Production of Oil
Asia-Pacific
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Million TOE
1990 1995 2000 2005 2010 2015 2020 2025 2030
Oil Consumption
Oil Production

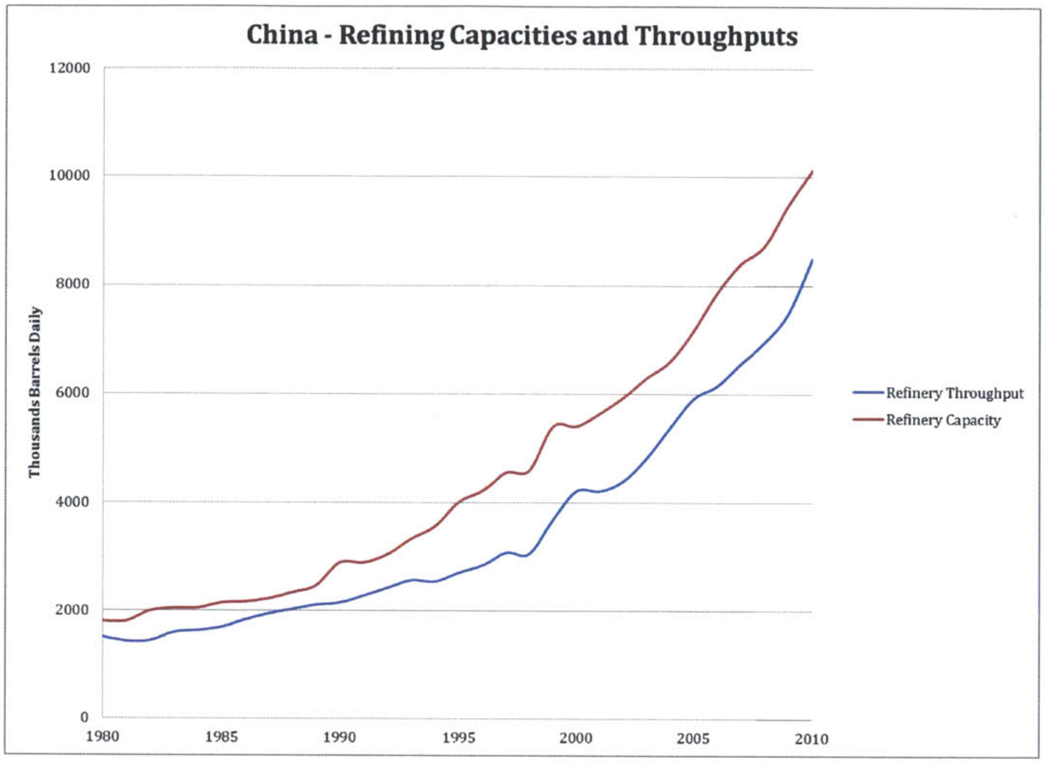
APPENDIX B: Refinery Throughputs and Capacities

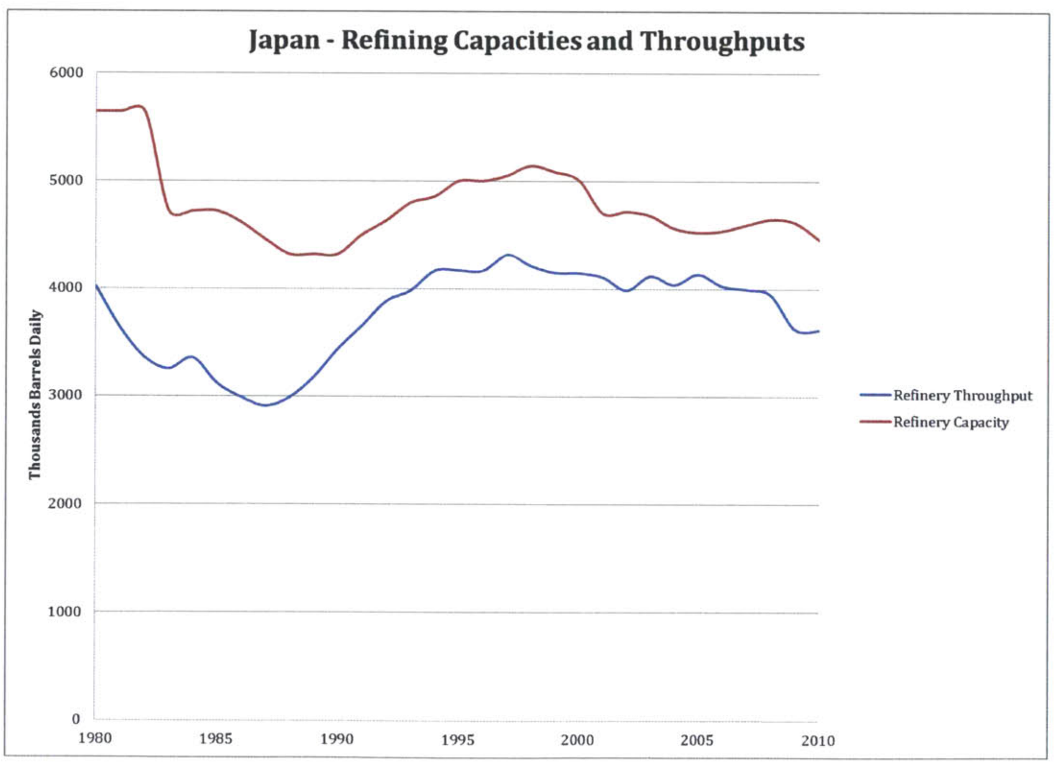

Global Oil Refinery Throughputs
Thousands Barrels Daily
30000
25000
20000
15000
10000
5000
0
1985
1990
1995
2000
2005
2010
US
Canada
Mexico
S. & Cent. America
Europe & Eurasia
Middle East
Africa
Australia
China
India
Japan
Other Asia Pacific

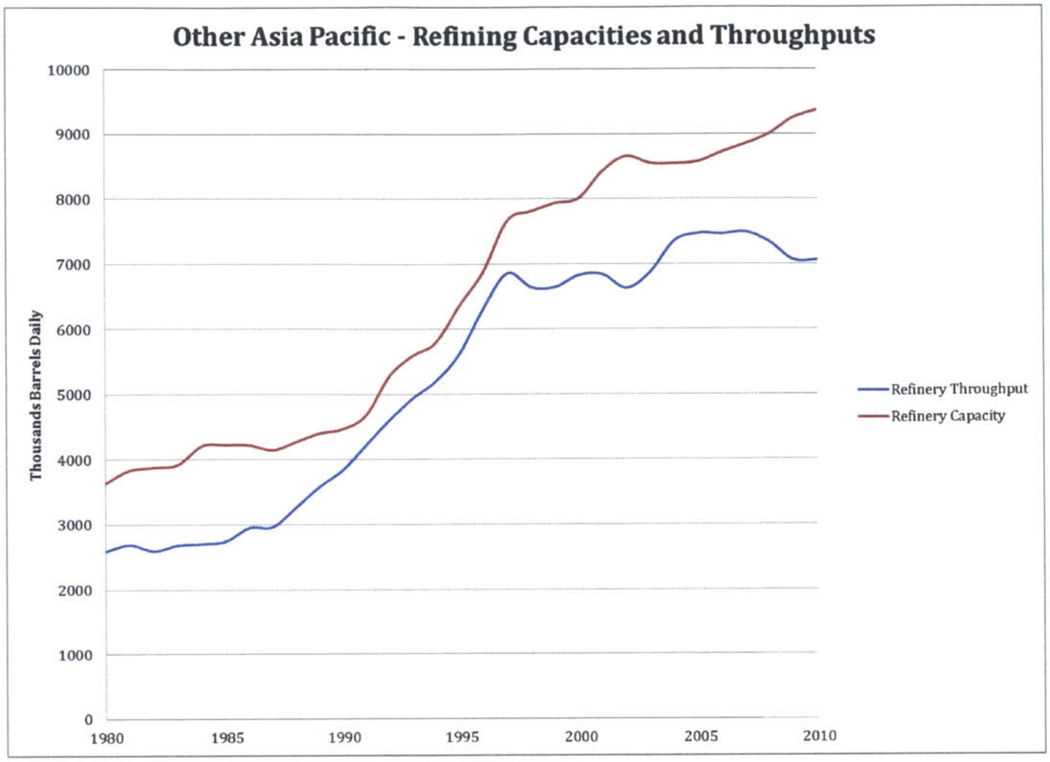

Global Oil Refinery Capacities
Thousands Barrels Daily
35000
30000
25000
20000
15000
10000
5000
0
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
US
Canada
Mexico
S. & Cent. America
Europe & Eurasia
Middle East
Africa
Australia
China
India
Japan
Other Asia Pacific


US - Refining Capacities and Throughputs
Thousands Barrels Daily
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1980
1985
1990
1995
2000
2005
2010
Refinery Throughput
Refinery Capacity


Middle East - Refining Capacities and Throughputs
Thousands Barrels Daily
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1980
1985
1990
1995
2000
2005
2010
Refinery Throughput
Refinery Capacity


China - Refining Capacities and Throughputs
Thousands Barrels Daily
12000
10000
8000
6000
4000
2000
0
1980
1985
1990
1995
2000
2005
2010
Refinery Throughput
Refinery Capacity


Japan - Refining Capacities and Throughputs
Thousands Barrels Daily
6000
5000
4000
3000
2000
1000
0
1980
1985
1990
1995
2000
2005
2010
Refinery Throughput
Refinery Capacity



Other Asia Pacific - Refining Capacities and Throughputs
Thousands Barrels Daily
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1980
1985
1990
1995
2000
2005
2010
Refinery Throughput
Refinery Capacity

Country	Region	Added Capacity (BPD)	Added Capacity (million TPY)	Expected Completion
Libya	Africa	200,000		2014
Morocco	Africa	201,450		2015
Angola	Africa	200,000		2012
Mozambique	Africa	350,000		2014
South Africa	Africa	400,000		NA
China	Asia Pacific	200,000		2013
China	Asia Pacific	(94,785)	20	NA
China	Asia Pacific	300,000		NA
Vietnam	Asia Pacific	200,000		2013
Turkey	Eurasia	214,000		2012
Qatar	Middle East	250,000		2012
Saudi Arabia	Middle East	400,000		2012
Saudi Arabia	Middle East	400,000		2013
Saudi Arabia	Middle East	400,000		2014
UAE	Middle East	417,000		2014
Iraq	Middle East	300,000		NA
Iraq	Middle East	250,000		NA
Saudi Arabia	Middle East	400,000		NA
UAE	Middle East	500,000		NA
US	North America	325,000		2012
Mexico	North America	300,000		2015
Ecuador	South America	300,000		2013
Brazil	South America	530,000		2014
Brazil	South America	300,000		2017
Venezuela	South America	600,000		NA
India	South Asia	(296,089)	15	2012
India	South Asia	(355,306)	18	2014
Pakistan	South Asia	250,000		NA

APPENDIX C: Speed Recommendations

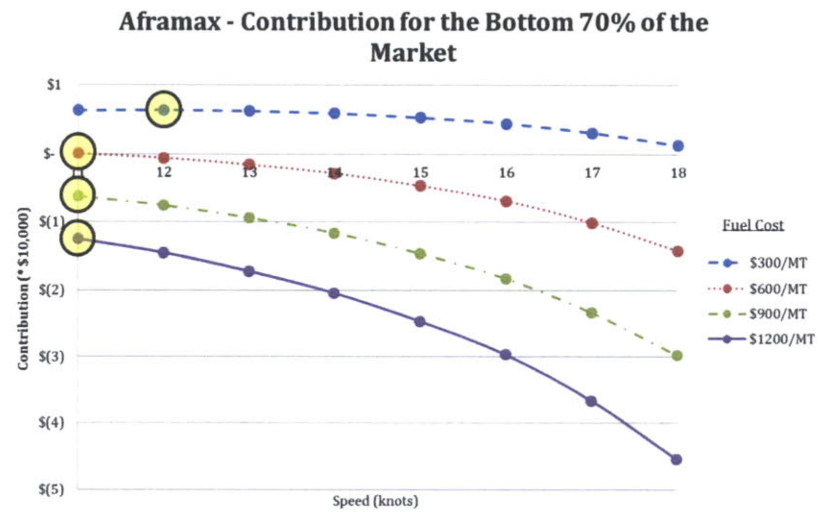
Aframax Crude Oil Tankers

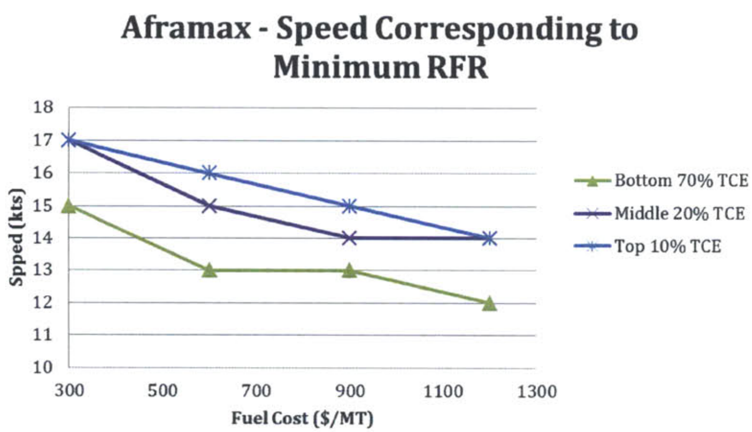
Vessel Particulars	HEC Design
100% Cargo Capacity (m^3)	132,000
Length Overall (m)	249
LBP (m)	239
Beam (m)	44
Depth (m)	21.2
Design Draft (m)	13.6
Summer Loadline Draft (m)	15.06
Lightship (MT)	19,310
Design Block Coefficient	0.825
Deadweight at Design Draft (MT)	101,932
Deadweight at Loadline draft (MT)	116,135
Number of Screws	1
Design Speed: 15% SM at 90% MCR (knots)	14.9
Required Engine Power (MCR) (kW)	13,822

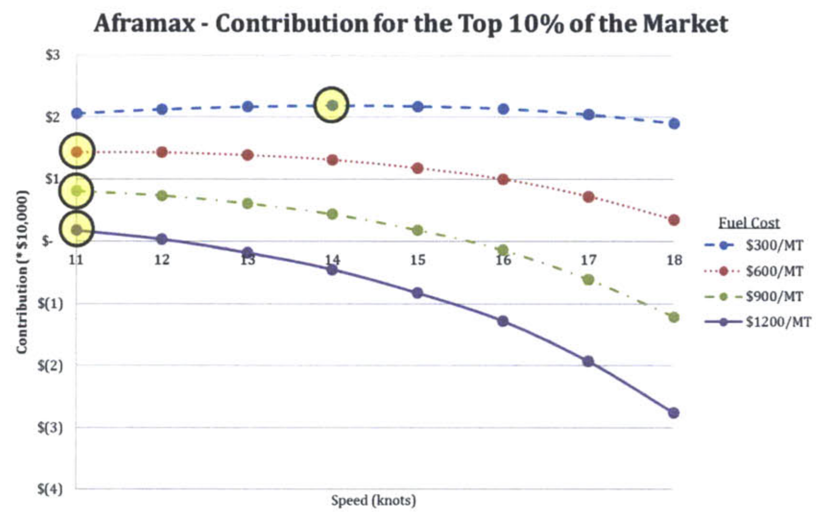
Speed (knots)	MAN Engine	MCR (kW)	RPM	SFC (g/kWh)
11	5S46ME-B8	6900	95*	170
12	5S50ME-C8	8300	95*	168
13	7S50ME-C8	11620	95*	168
14	5S60ME-C8	11900	95*	167
15	5S65ME-C8	14350	95	167
16	6S70ME-C8	19620	91	167
17	7S70ME-C8	22890	91	167
18	7S80ME-C8	29260	91*	166

*Theoretical RPM

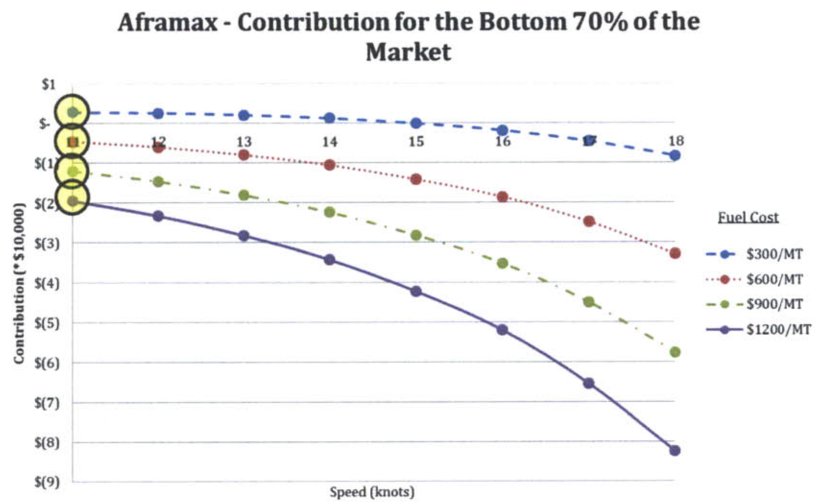
Tanker Size: Aframax
Origin: Sullom Voe
Destination: Wilhelmshaven
Distance (nm): 531

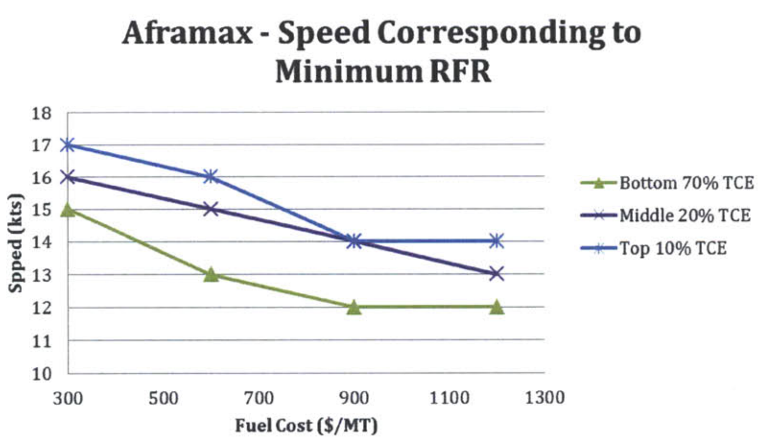


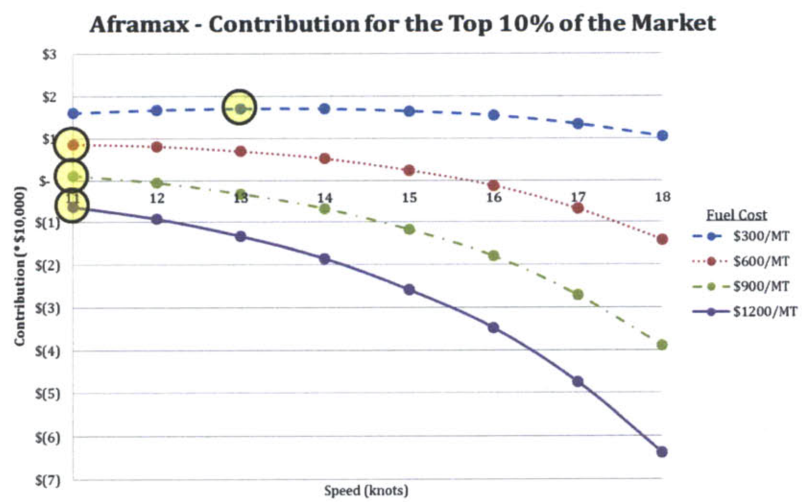




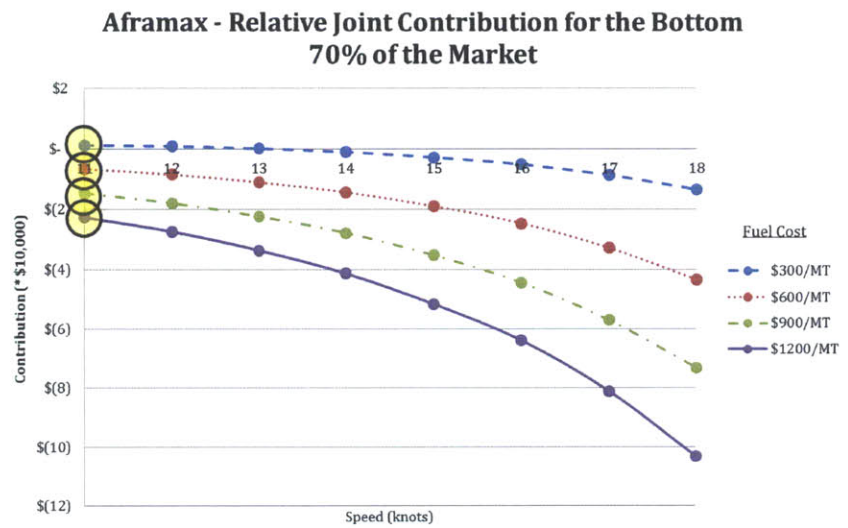
Tanker Size:	Aframax
Origin:	Curacao
Destination:	Texas City
Distance (nm):	1,797

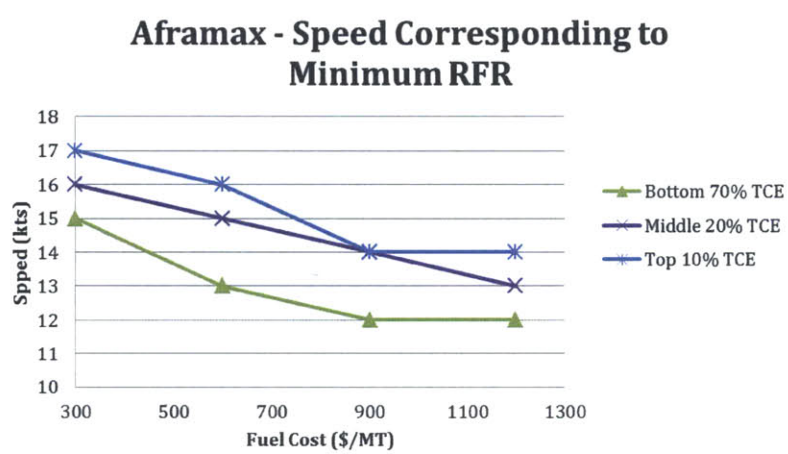


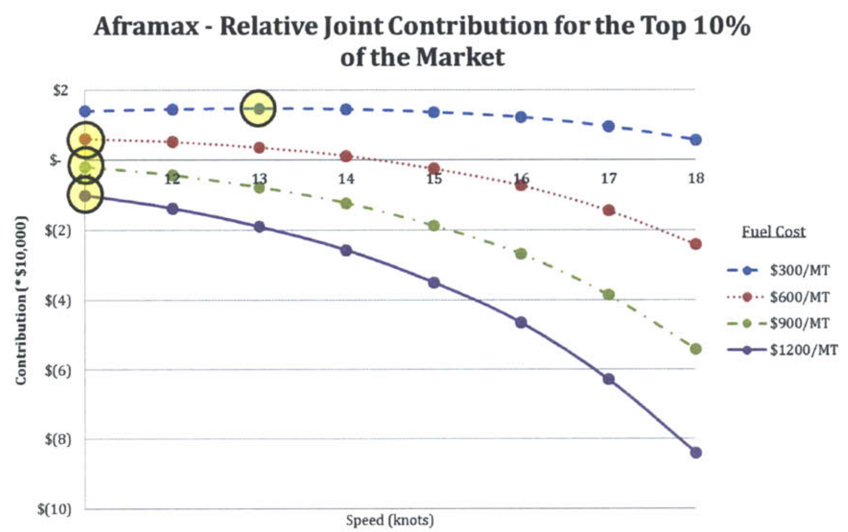




Tanker Size:	Aframax
Origin:	Curacao
Destination:	Hamburg
Distance (nm):	4,500







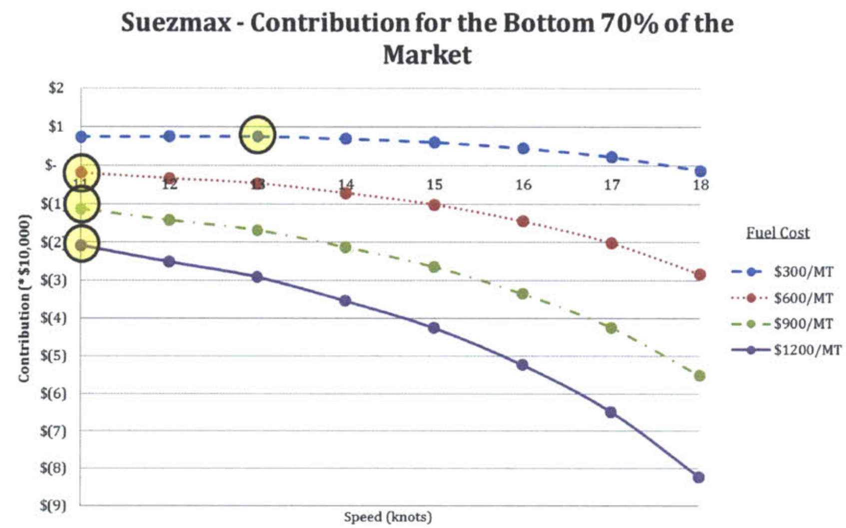
Suezmax Crude Oil Tankers

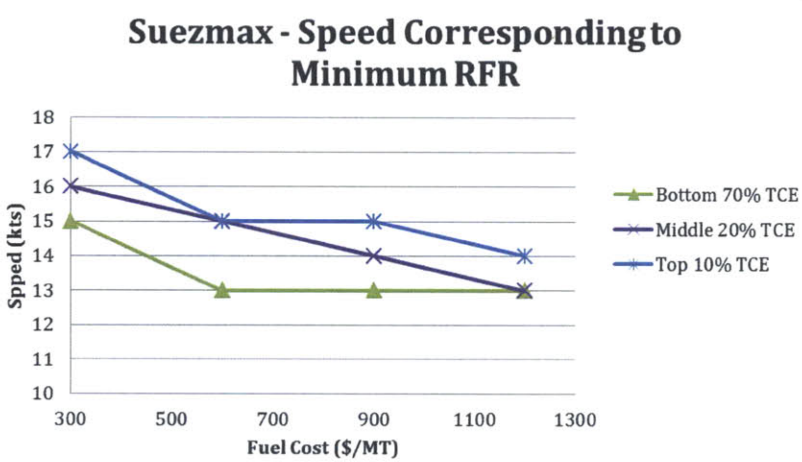
Vessel Particulars	HEC Suezmax Design
100% Cargo Capacity (m^3)	180,000
Length Overall (m)	280
LBP (m)	270
Beam (m)	48
Depth (m)	24
Design Draft (m)	15.9
Summer Loadline Draft (m)	17.41
Lightship (MT)	25819
Design Block Coefficient	0.825
Deadweight at Design Draft (MT)	148869
Deadweight at Loadline draft (MT)	166576
Number of Screws	1
Design Speed: 15% SM at 90% MCR (knots)	15.2
Required Engine Power (MCR) (kW)	17185

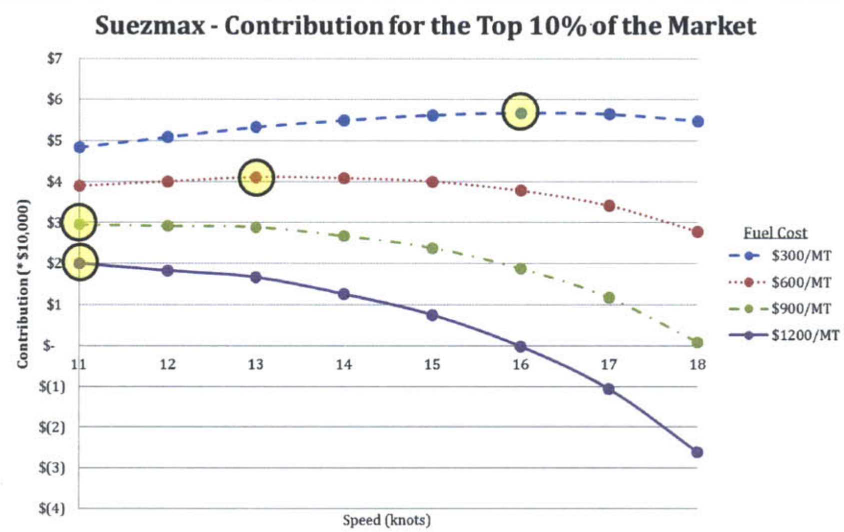
Speed (knots)	MAN Engine	MCR (kW)	RPM	SFC (g/kWh)
11	5S60ME-C8	11900	105	167
12	5S60ME-C8	11900	105	167
13	5S65ME-C8	14350	95	167
14	5S65ME-C8	14350	95	167
15	6S70ME-C8	19620	91	167
16	7S70ME-C8	22890	91	167
17	8S70ME-C8	26160	91	167
18	8S70ME-C8	34380	91*	167

*Theoretical RPM

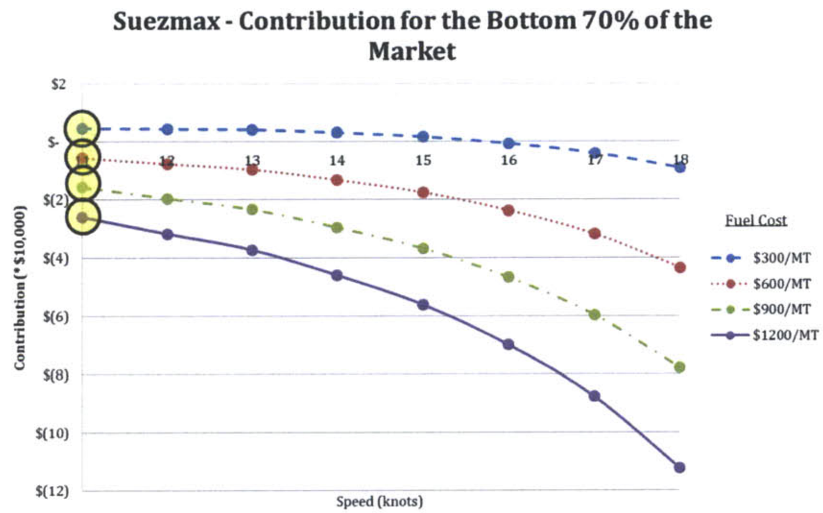
Tanker Size: Suezmax
Origin: Sidi Kerir
Destination: Lavera
Distance (nm): 1,420

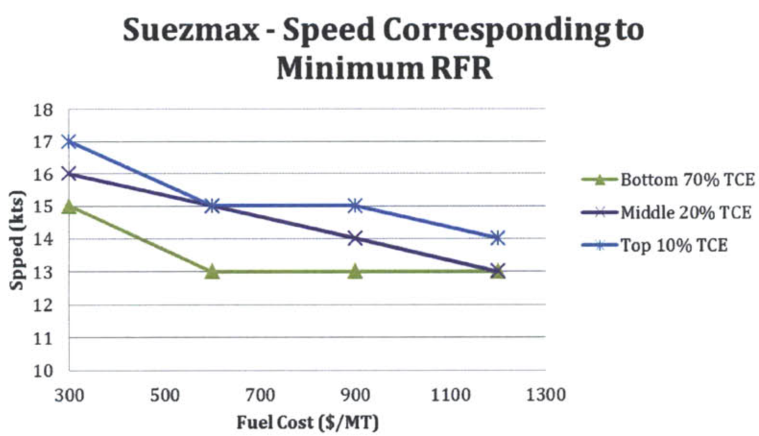


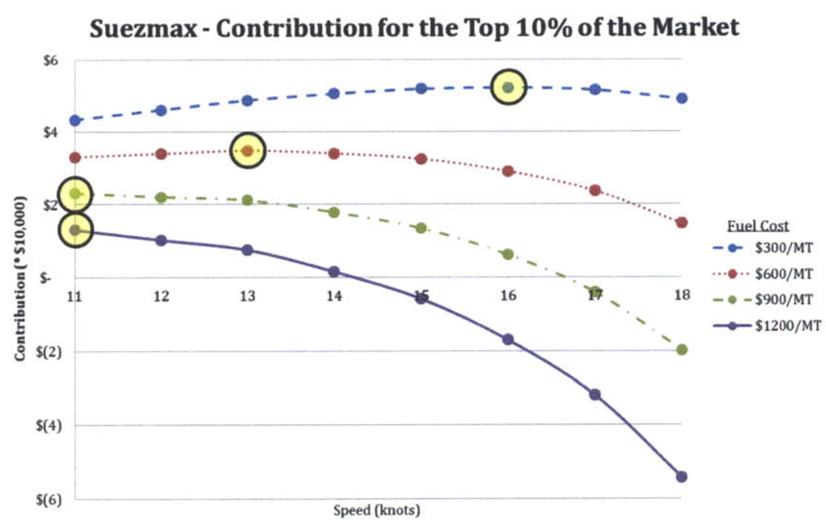




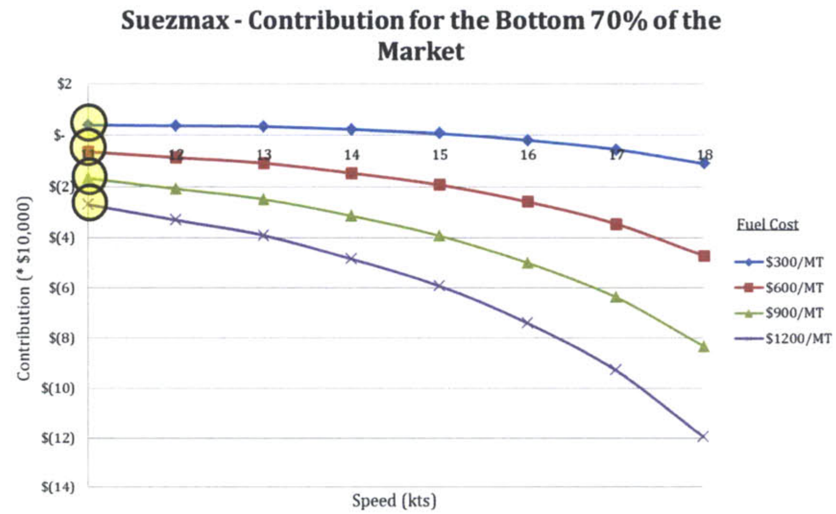
Tanker Size:	Suezmax
Origin:	Bonny Offshore
Destination:	Lavera
Distance (nm):	4,070

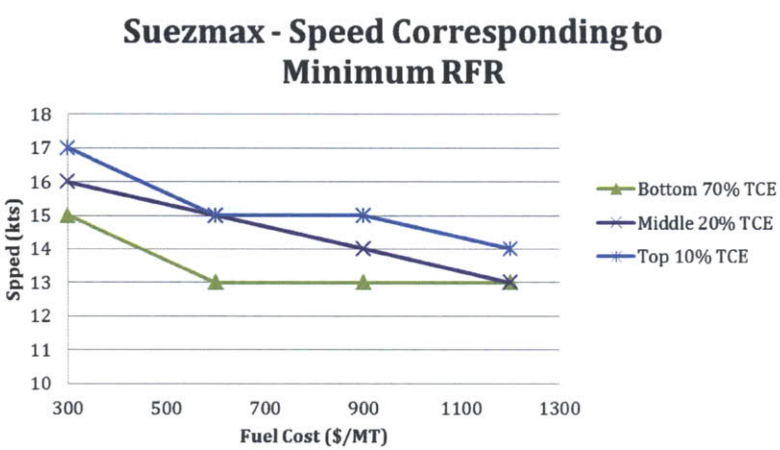


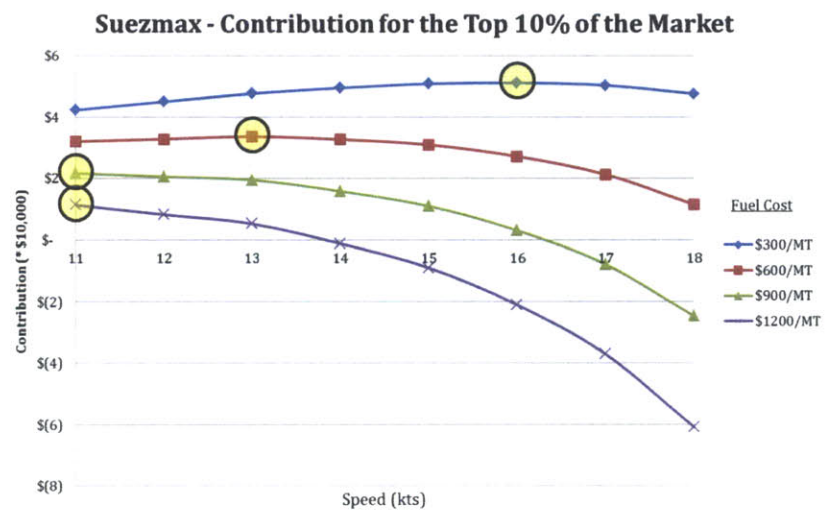




Tanker Size: Suezmax
Origin: Bonny Offshore
Destination: LOOP
Distance (nm): 5,877







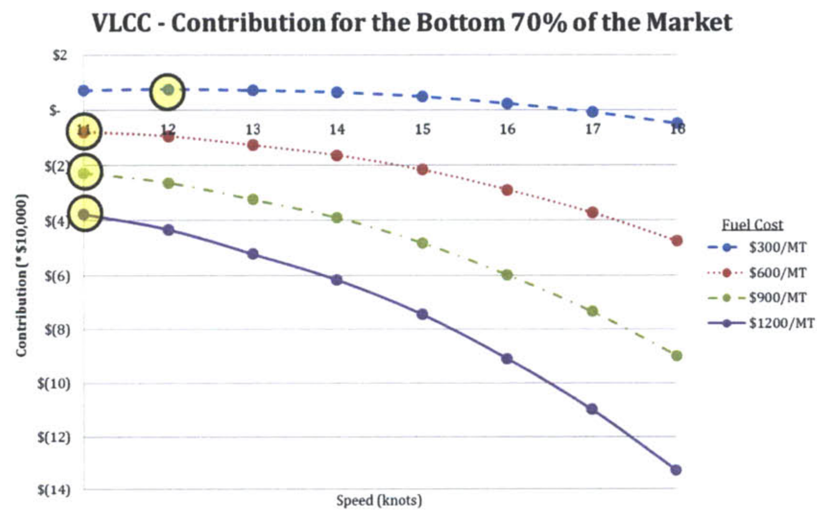
VLCC Crude Oil Tankers

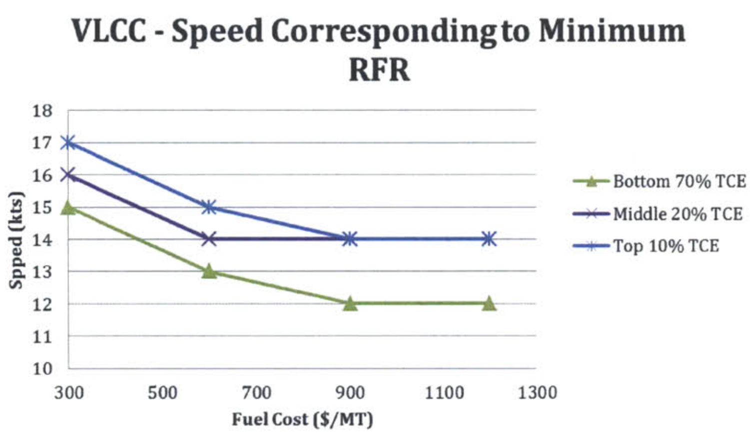
Vessel Particulars	HEC VLCC Design
100% Cargo Capacity (m^3)	360,000
Length Overall (m)	333
LBP (m)	320
Beam (m)	58
Depth (m)	31.2
Design Draft (m)	21
Summer Loadline Draft (m)	22.05
Lightship (MT)	43,258
Design Block Coefficient	0.82
Deadweight at Design Draft (MT)	285,154
Deadweight at Loadline draft (MT)	303,032
Number of Screws	1
Design Speed: 15% SM at 90% MCR (knots)	15.8
Required Engine Power (MCR) (kW)	26,736

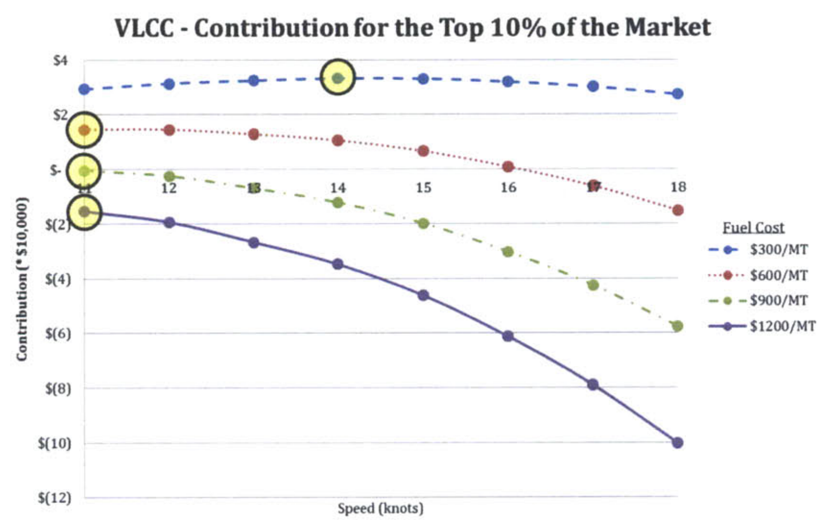
Speed (knots)	MAN Engine	MCR (kW)	RPM	SFC (g/kWh)
11	5S60ME-C8	11900	105	167
12	5S65ME-C8	14350	95	167
13	6S65ME-C8	17220	95	167
14	7S70ME-C8	22890	91	167
15	8S70ME-C8	26160	91	167
16	6S90ME-C8	31620	*95	166
17	7S90ME-C8	36890	*95	166
18	9S90ME-C8	47430	*95	166

*Theoretical RPM

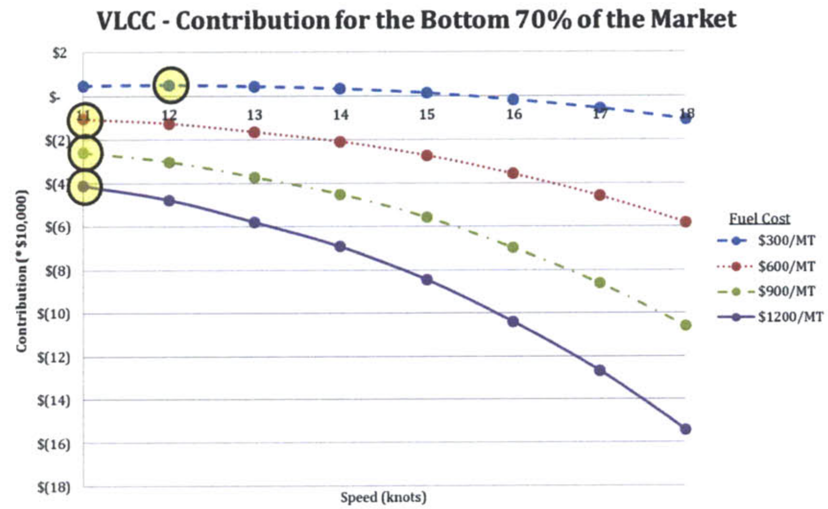
Tanker Size: VLCC
Origin: Sidi Kerir
Destination: Rotterdam
Distance (nm): 3,159

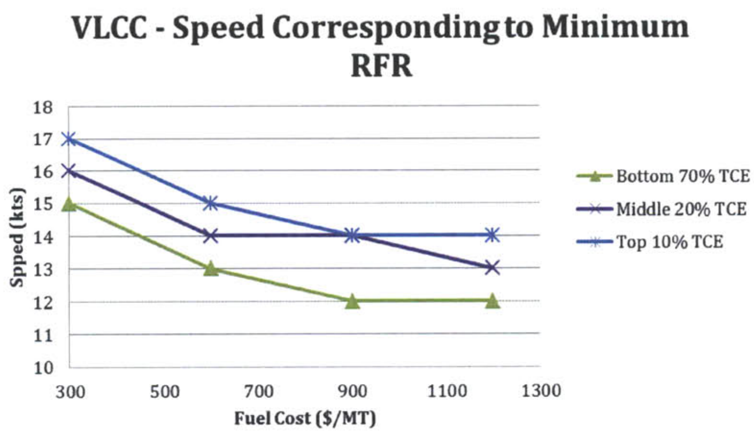


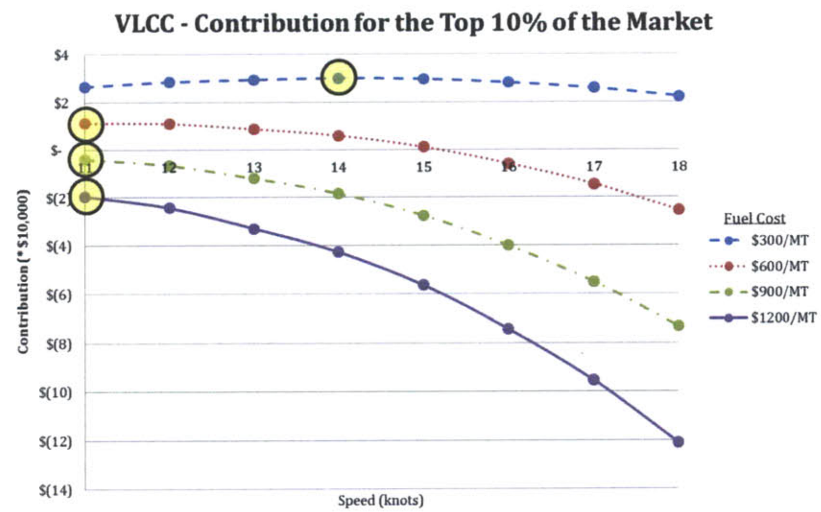




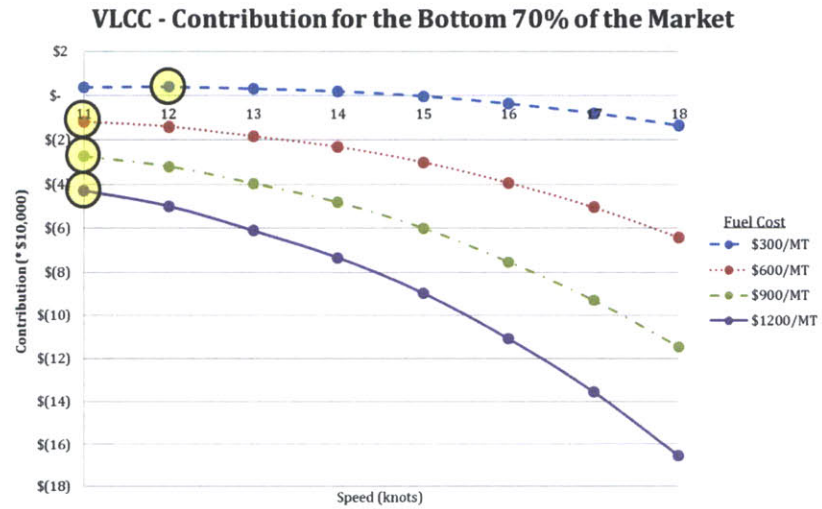
Tanker Size: VLCC
Origin: Ras Tanura
Destination: Chiba
Distance (nm): 6,605

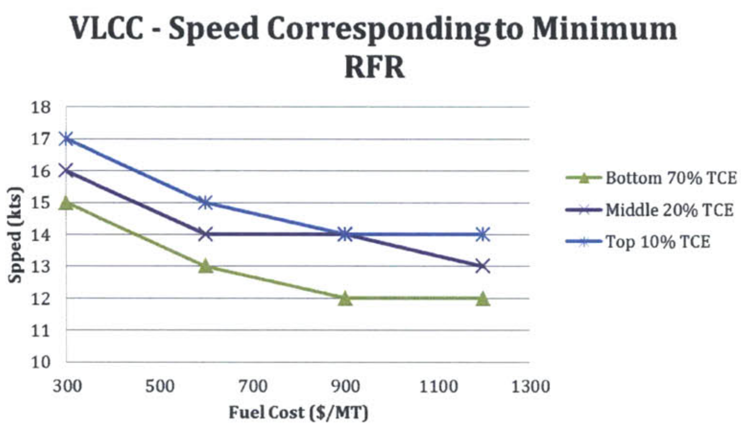


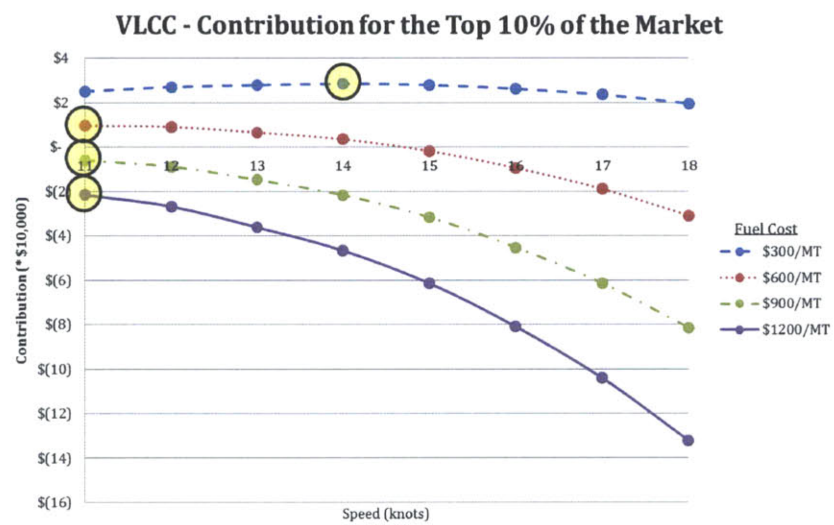




Tanker Size: VLCC
Origin: Ras Tanura
Destination: LOOP
Distance (nm): 12,225







APPENDIX D: EEDI Calculation for the Benchmark 15-Knot Suezmax Tanker

Ship Design Parameters

Ship design speed at which the required power is 75% of required MCR:

$$V_{ref} = 14.75\ knots$$

Capacity for tankers is the DWT rating:

$$Capacity = Deadweight$$

$$= Disp\ at\ SLL\ Draft - Lightship$$

$$= 193{,}728MT - 25{,}981MT$$

$$= 167{,}747MT$$

Engine Power

Main engine power reduction due to individual technologies for mechanical energy efficiency:

$$P_{eff} = 0$$

Auxiliary engine power reduction due to individual technologies for electrical energy efficiency:

$$P_{AEff} = 0$$

Power of individual shaft motors divided by the efficiency of shaft generators, calculated as 75% of the rated power consumption of each shaft motor divided by the weighted averaged efficiency of the generator(s):

$$P_{PTI} = 0$$

Combined installed power of auxiliary engines is the required auxiliary engine power to supply normal maximum sea load including necessary power for propulsion machinery/systems and accommodation. For cargo ships with a main engine power of 10000 kW or above:

$$P_{AE} = 0.025 * \sum_{i=1}^{nME} MCR(i) + 250$$

$$= 0.025 * 17{,}131\ kW + 250$$

$$= 678kW$$

Individual power of main engine at 75% of required MCR:

$$P_{ME} = 75\% * MCR$$

$$= 75\% * 17{,}131\ kW$$

$$= 12{,}848 kW$$

CO2 Emissions

For diesel /gas oil, ISO 8217 Grades DMX through DMC, the main engine composite fuel factor is:

$$C_{FME} = 3.206 \frac{tonnes\ CO_2}{tonne\ of\ fuel}$$

$$= 3.206$$

Auxiliary engine fuel factor is the same as the main engine's:

$$C_{FAE} = 3.206$$

Specific Fuel Consumption

Main engine with MDO:

$$SFC_{ME} = SFOC@75\% * 1.03$$

$$= 167.2 \frac{g}{kWhr} * 1.03$$

$$= 172 \frac{g}{kWhr}$$

Auxiliary engine with HFO:

$$\frac{Basic\ SFOC\ at\ 50\%\ MCR}{Engine} = 189.5 \frac{g}{kWhr}$$

$$Pump\ Correction\ (PC) = 2.6 * \left(\frac{110 * 100}{50\% * 100 + 10}\right)$$

$$= 4.8\%$$

$$\frac{Corrected\ SFOC\ @\ 50\%\ MCR}{Engine} = Basic\ SFOC * (1 + PC)$$

$$= 189.5 \frac{g}{kWhr} * (1 + 4.8\%)$$

$$= 198.5 \frac{g}{kWhr}$$

$$\frac{SFC\ AUX}{Engine} = (Corrected\ SFOC\ @\ 50\%) * 1.03$$

$$= 98.5 \frac{g}{kWhr} * 1.03$$

$$= 204.5 \frac{g}{kWhr}$$

$$SFC_{AE} = \frac{\sum_{i=1}^{nAUX} \frac{SFC\ AUX}{Engine}}{nAUX}$$

$$= \frac{204.5 + 204.5 + 204.5}{3} \frac{g}{kWhr}$$

$$= 204.5 \frac{g}{kWhr}$$

Correction and Adjustment Factors

Availability factor of individual energy efficiency technologies:

$$f_{eff} = 1.0$$

Correction factor for ship specific design elements:

$$f_j = 1.0$$

Coefficient indicating the decrease in ship speed due to weather and environmental conditions:

$$f_w = 1.0$$

Capacity adjustment factor for any technical/regulatory limitation on capacity:

$$f_i = 1.0$$

Calculation of Design Index

Main Engine Emissions:

$$MEE = P_{ME} * C_{FME} * SFC_{ME}$$

$$= 7{,}095{,}731$$

Auxiliary Engine Emissions:

$$AEE = P_{AE} * C_{FAE} * SFC_{AE}$$

$$= 444{,}679$$

Shaft Generators / Motors Emissions:

$$SGME = 0$$

Efficiency Technologies:

$$ET = 0$$

Transport Work:

$$TW = f_i * Capacity * V_{ref} * f_w$$

$$= 2{,}474{,}264$$

Design EEDI Index for Benchmark Ship:

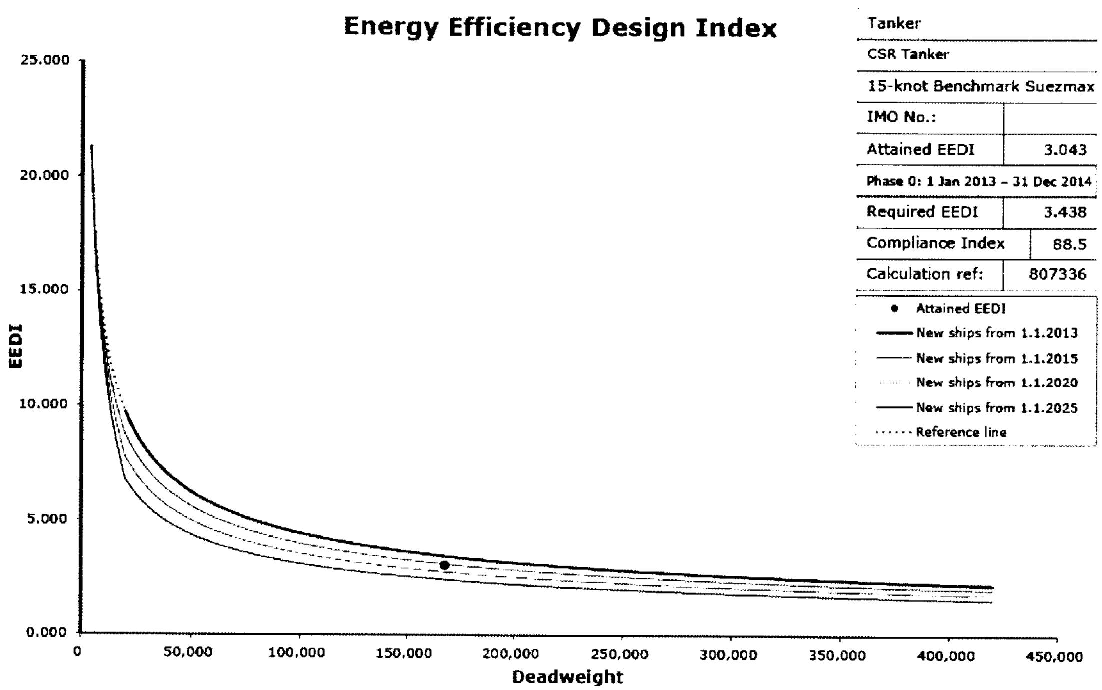
$$EEDI_{bench} = \frac{MEE + AEE}{TW} = 3.05$$

Baseline EEDI Index:

$$EEDI_{BL} = 1218.8 * (SLL\ Deadweight)^{-0.488} = 3.44$$

Note: Both the Design and Baseline EEDI Index match the BIMCO calculator's values.

BIMCO's Calculation



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