Economic Analysis of Assembly Systems

• Goals of this class
  – understand the basics of economic analysis
  – unit cost of assembly by different resources
  – return on investment
  – particular properties of assembly systems
Cost and Price Considerations

Development cost
Unit mfr cost: materials, labor, depreciation, waste, scrap, rework
Production ramp-up
Marketing
Ongoing support

Unit cost
Prod’n volume/yr

Cost
Price
Sales volume/yr

Price
Sales volume/yr

“Supply curve”
“Demand curve”

Value>Price>Cost

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Cost Analysis is a Murky Area

• Engineers need to know the basics of cost analysis for three reasons
  – so they can make sound technological choices
  – so they can judge the suitability of a supplier’s bid
  – so they can argue effectively with accountants

• “Don’t ask us how we do investment justification. We just fill out a form and after a while an answer comes back Yes or No.”

• “MAPI means ‘makes a project impossible’””
  – MAPI = Manufacturing and Allied Processes Institute

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Kinds of Cost Categories

• Fixed cost = what you pay to set up (usually investment in facilities)

• Variable cost = what you pay that depends on how many you make per unit time
  – Labor, both direct and indirect (maintenance, supervisors)
  – Materials cost: what you buy that you add value to
  – Expendables: energy, lubricants, tool bits, etc
  – Scrap, rework

• Institutional cost = all other costs of doing business
Cost Distribution in Engine Plants

- Materials: 75%
- Labor: 9%
- Capital: 8%
- Others: 9%

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Sources of Cost in the Supply Chain

Source: Daimler Chrysler via Munro and Associates

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A Small Problem

• Fixed costs are usually expended all at once, usually before production starts
• Variable costs are incurred as production runs
• How should these two kinds of costs be combined to provide a true picture of the cost per unit?
• The usual method is to allocate the fixed costs to the units by choosing a time period during which the investment is “recovered”
• unit cost = variable cost
  + Some_Fct (fixed cost, # of units made in some time period)
Cash Flows Over Time

- **INCOME**
  - **BUY EXPENSE**
  - **SELL PRODUCTS**
  - **PAY ONGOING EXPENSES**

- **TIME**
  - **SELL EQUIPMENT FOR SCRAP**

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Payback Period Method

• A payback period $P$ is selected (arbitrarily?)
• The fixed cost is allocated equally to each unit made during $P$:
• unit cost $= \text{variable cost} + \frac{\text{fixed cost}}{(P\,Q)}$

where $Q = \text{quantity made per year}$
$P = \text{a number of years}$
Internal Rate of Return Method

- The payback period is replaced by an investment horizon $H$ and an interest rate $r$
- This is equivalent to a mortgage for $H$ years at interest rate $r$
- The annual payment $A$ and the annual cost factor $f_{AC}$ for an initial investment $I_0$ are (for zero salvage value)

$$A = I_0 \left[ \frac{r(1 + r^H)}{(1 + r^H) - 1} \right]$$

$$f_{AC} = \frac{A}{I_0} = \left[ \frac{r(1 + r^H)}{(1 + r^H) - 1} \right]$$
Unit Cost Based on IRoR

- unit cost = variable cost
  + $f_{AC}$ fixed cost /Q

where

Q = quantity made per year

$f_{AC}$ = fraction of fixed cost paid per year, based on:

r = IRoR (ranges from 15% to 35%)

H = investment horizon (ranges from 2 to 5 years or more)
Annualized Cost Factor vs $r$

Annualized Cost Factor $fAC$

$\begin{align*}
\text{Investment Horizon } H \\
n & = 1, 2, 3, 4, 5, 6
\end{align*}$

Note: ignores depreciation

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Simplified Unit Cost for Manual Assembly

\[
\text{COST}_{\text{UNIT MANUAL}} = \frac{A$ \cdot \# \text{ People}}{Q}
\]

\[
\# \text{ People} = \left\lceil \frac{T N Q}{2000 \cdot 3600} \right\rceil \quad \text{[largest integer]}
\]

\[Q = \text{annual production volume}\]
\[T = \text{assembly time per part, sec}\]
\[N = \text{number of parts per unit}\]
\[A$ = \text{annual cost of a person}\]
\[A$ = L_H \cdot 2000\]
\[L_H = \text{labour cost, } \$ / \text{hr}\]
\[2000 = \text{hours per shift year}\]
\[3600 = \text{sec / hr}\]

(assumes no investment required)

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Simplified Unit Cost for Fixed Automation

\[ C_{UNIT\,FIXED} = \frac{f_{AC} \cdot N \cdot S\$}{Q} \]

where \( Q \) = annual production volume, units / year

\( f_{AC} \) = fraction of machine cost paid for per year

\( S\$ \) = cost of one station in the machine

(assumes one station per part)
(also assumes no people required)

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\[ C_{\text{UNITFLEX}} = \frac{f_{\text{AC}} I}{Q} + \frac{L\$}{Q} \]

where \( I = \) total investment in machines and tools

\( L\$ = \) annual cost of workers associated with the system

\( I = \# \text{MACHINES} \times \$ / \text{MACHINE} + \# \text{TOOLS} \times \$ / \text{TOOL} \)

\[ \# \text{MACHINES} = \left[ \frac{T \times N \times Q}{2000 \times 3600} \right] \]

\[ \# \text{TOOLS} = N \]

\( L\$ = w \bar{L}_H \# \text{MACHINES} \times 2000 \)

where \( w = \) number of workers / station

Combining the above yields:

\[ C_{\text{UNITFLEX}} = \frac{f_{\text{AC}}}{Q} \left[ \# \text{MACHINES} \times \$ / \text{MACHINE} + \# \text{TOOLS} \times \$ / \text{TOOL} \right] + \frac{L\$}{Q} \]

\[ C_{\text{UNITFLEX}} - \frac{f_{\text{AC}} \$ / \text{MACHINE} \times T \times N}{2000 \times 3600} + \frac{f_{\text{AC}} \$ / \text{TOOL} \times N}{Q} + \frac{w \times T \times N \bar{L}_H}{3600} \]

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Conclusions from Unit Cost Models*

- Cost is linearly proportional to number of parts N
  - one reason for fixation on part count reduction
- Cost of flexible automation grows with the “price-time product”: $/machine * T
  - shows that cost and time can be traded
- Other costs grow as part, station, and tool count grow
  - floor space
  - support staff
  - line downtime (see Boothroyd chapter)


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Basic Nominal Capacity Equations

\[
\text{# operations/unit } \times \text{# units/year} = \text{# ops/yr}
\]

\[
\text{# ops/sec} = \text{# ops/yr} \times \left(\frac{1 \text{ shift}}{28800 \text{ sec}}\right) \times \left(\frac{1 \text{ day}}{n \text{ shifts}}\right) \times \left(\frac{1 \text{ yr}}{280 \text{ days}}\right)
\]

\[
\text{cycle time} = \frac{1}{\text{ops/sec}} = \text{required sec/op}
\]

\[
\text{equipment capability} = \text{actual sec/op (including all stops)}
\]

\[
\text{actual sec/op} < \text{required sec/op} \rightarrow \text{happiness}
\]

\[
\text{required sec/op} < \text{actual sec/op} \rightarrow \text{misery (or multiple resources)}
\]

Typical cycle times:
- 3-5 sec manual small parts
- 5-10 sec small robot
- 1-4 sec small fixed automation
- 10-60 sec large robot or manual large parts

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Basic Cycle Time Equation

\[
\text{Cycle time} = \frac{1}{\varepsilon} \left[ \text{assy time} + \frac{\text{in – out time}}{\# \text{ units / pallet}} + \frac{\text{tool ch. time}}{\# \text{ units / tool ch.}} \times \# \text{ ch / unit} \right]
\]

cycle time = net avg time per assembly
in – out time = time to move one pallet out and another in
tool ch. time = time to put away one tool and pick up another
# ch. / unit = number of tool changes needed to make one unit
# units / tool ch. = number of units worked on before tool is changed (cannot be larger than number units / pallet)
\varepsilon = \text{station uptime fraction: } 0 < \varepsilon < 1

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Unit Cost Example

Unit Assembly Cost by Three Methods

- $f_{AC} = 0.38$
- $T = 5s$
- $L_H = $15/hr
- $S_S = 50000$
- $$/\text{tool} = $10000$
- $N = 10$ parts/unit
- $w = 0.25$ workers/sta

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Unit Cost Example - 2

Unit Assembly Cost by Three Methods

\[ f_{AC} = 0.38 \]
\[ T = 2s \]
\[ L_H = $15/hr \]
\[ S = 50000 \]
\[ $/tool = $10000 \]
\[ N = 10 \text{ parts/unit} \]
\[ w = 0.25 \text{ workers/sta} \]
More Detailed Cost Model

Three Kinds of Assembly Resource

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Caveats About Examples

• If $T = 2$ s, then $Q = 3.6$ million, or else the line runs only part of one shift
• If $\# \text{people} > \# \text{of parts or operations}$, then extra people are needed for one shift operation
• If $Q > 7.2$ Million / $T$, then a 2nd or 3rd shift is needed
Discounted Cash Flow Analysis

• AKA net present value calculation
• More detailed and sophisticated than unit cost comparisons
• Seeks to determine if an investment is “good”
• Based on comparing return on investment
  – a base case is compared to an alternate
  – the alternate requires upfront investment
  – it creates a saving stream over time, which is discounted to “present value”
  – do the savings justify the investment?
Discounting Future Cash Flows

Money is a two-dimensional quantity (\(\$, t\))

- Its value now
- Its value if delayed until \(t\)

\[
\frac{1}{(1 + DF)^i} \quad e^{-\rho t}
\]

\(\rho = DF = \text{discount factor}\)

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Two Cash Flow Formulas

Takaway: The early cash flows contribute the most.

Sum of future cash flows without discounting

present value of sum of future cash flows

present value of future cash flows

DF = 0.1

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Comparison Analysis

• Base case
  – fixed costs
  – labor costs
  – material costs

• Alternate case
  – fixed costs
  – labor costs
  – material costs

Comparison:
What discount rate makes the discounted sum of future savings in labor and material costs equal the difference in fixed cost between base and alternate?

\[ \text{Investment}_{\text{alt}} - \text{Investment}_{\text{base}} = \sum_{i=1}^{H} \frac{\text{Net savings}_i}{(1 + DF)^i}. \]

Alternatively: set discount rate = cost of borrowing
Choose the alternate investment if NPV > 0

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Discounted Cash Flow (DCF) and Economic Value Added (EVA)

- EVA is very similar to DCF. The discount rate used in EVA is the weighted average cost of capital (WACC)
  - Cost of capital includes interest rate on debt plus expected rate of return on stock (not easy to compute)
- EVA is usually used to value the whole company but is being used more and more to value individual investments
- See [http://www.pitt.edu/~roztocki/abc/abc.htm](http://www.pitt.edu/~roztocki/abc/abc.htm)
- See Econ DEMO-Stanley Hammer.xls on SloanSpace

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Aircraft Development Cost Quandry

Aircraft Product Development Cost Recovery

PD Investment = $3.5B all taken in year 0
Depreciated over 7 years MACRS
$1.2B tax credit in year 0
First plane sold in year 2

IRoR = 7.11%

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A380 Business Case

A380
Cost and Income

PD Development cost $10.5B

660 planes sold, price $200M ea
Avg profit/plane = $50M

IROR = 11.5%

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NPV vs Discount Rate for A380

NPV vs DISC RATE FOR A380

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Zero or Net Present Value Calculations

- Comparing two investments, the savings $S_v$ are considered income
- You pay taxes on the income at tax rate $T_x$, yielding your net income $N_i$
- You can claim depreciation $D_p$ on your investment, decreasing your taxable income and lowering your taxes
- The IRS specifies how much you can claim in depreciation each year
  - the net income is: $N_i = S_v - T_x(S_v - D_p)$
- “present value analysis” spreadsheet on SloanSpace finds the discount rate that gives $NPV = 0$
- Can be used to find $NPV$ for any discount rate
# Zero Present Value Analysis

## Zero Present Value Cash Flow Analysis

### Expense Forecast

<table>
<thead>
<tr>
<th>Year</th>
<th>Ratio</th>
<th>Tax Rate</th>
<th>Depreciable</th>
<th>Savings</th>
<th>Depreciation</th>
<th>Tax Rate</th>
<th>Credit</th>
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<tbody>
<tr>
<td>0</td>
<td>100.00%</td>
<td>34.00%</td>
<td>66.67%</td>
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<td></td>
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<td>1</td>
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<td>14.29%</td>
<td>34.00%</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>$181</td>
<td>24.49%</td>
<td>34.00%</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>3</td>
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<td>17.49%</td>
<td>34.00%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$150</td>
<td>12.49%</td>
<td>34.00%</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td></td>
<td>8.92%</td>
<td>34.00%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>8.92%</td>
<td>SUM OF UNUSED YRS</td>
<td></td>
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<td></td>
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<tr>
<td>7</td>
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<td>8.92%</td>
<td>DEPR= 31.22%</td>
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</tr>
<tr>
<td>8</td>
<td></td>
<td>4.46%</td>
<td>USED FOR SALVAGE VALUE</td>
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</table>

### Income Forecast

- **Total Investment**: $400
- **Tax Credit in Yr 0**: $0

### Depreciable Investment

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<tr>
<th>Year</th>
<th>Income</th>
<th>Depreciable</th>
<th>Taxes</th>
<th>Credits</th>
<th>Net</th>
<th>Disc Net</th>
<th>SUM OF UNDISC INC</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>($400)</td>
<td></td>
<td></td>
<td></td>
<td>($355)</td>
<td>($355)</td>
<td></td>
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<tr>
<td>1</td>
<td>$100</td>
<td>$38</td>
<td>$21</td>
<td>$0</td>
<td>$79</td>
<td>$67</td>
<td>$79</td>
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<td>$147</td>
<td>$88</td>
<td>$368</td>
</tr>
<tr>
<td>4</td>
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<td>$33</td>
<td>$40</td>
<td>$0</td>
<td>$110</td>
<td>$56</td>
<td>$478</td>
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</table>

### Decline in Undepreciated Investment

<table>
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<tr>
<th>Year</th>
<th>Income</th>
<th>Depreciation</th>
<th>Taxes</th>
<th>Credits</th>
<th>Net</th>
<th>Disc Net</th>
<th>SUM OF UNDISC INC</th>
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<td>$0</td>
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<td>$478</td>
</tr>
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</table>

### Salvage Value

- **In Year 4**: $83

### Gross Income

- **$713**

### Net Income

- **$313**

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How to Use this Spreadsheet

- Enter savings, tax rate, depreciation rate
- Goal seek to get zero NPV
- Or
- Put in various discount rates and observe NPV
- NPV > 0 is desired
Critiques of DCF

• Target IROR is arbitrary
• The calculations can be gamed
• “Cost” is a slippery quantity
  – People know their expenditures and assume that they know their costs, but these are different even if they add up to the same amount
  – Overheads are allocated arbitrarily and can distort the calculations
  – Activity-based costing is intended to overcome this
  – Robert Kaplan is an EE!

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Summary of Economic-Technical Analysis

- General Economic Conditions
  - Product Design
    - Assembly Sequence
      - Tasks
        - Costs and Savings
          - New Product Sales - Costs
            - Economic Justification
              - MARR > WACC
                - Annual Cost Factor
                  - Strategic and Tactical Choices
                    - Applicable Resources and Their Costs
                      - MARR > WACC
                        - GOALS MET? (NO -> REVISE, YES)

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