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

Cost

Unit cost
Prod’n volume/yr
Cost
Loss
Profit
Prod’n volume
Sales volume
Price
“Supply curve”
“Demand curve”

Price
Sales volume/yr
Prod’n volume/yr
Unit cost

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“Price Has Nothing to Do with Cost”

• Price is about value
• Value is often perceived and can be influenced
• Direct value involves functions and ilities
• Perceived value involves or is influenced by
  – Marketing
  – Perceived quality
  – Number of choices available even if most will not be taken
• Value > Price > Cost, otherwise no sales or no profit
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
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

• In many cases, labor is a fixed cost, due to contracts or the inability to lay people off for short periods when business fluctuates
Cost Distribution in Engine Plants

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Sources of Cost in the Supply Chain

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Source:

Source: Daimler Chrysler via Munro and Associates
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

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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 = variable cost 
  + fixed cost / ($P \times Q$)

where $Q =$ quantity made per year  
$P =$ 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
  + $f_{AC} \times \frac{\text{fixed cost}}{Q}$

where  
$Q = \text{quantity made per year}$

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

$r = \text{IRoR (ranges from 15\% to 35\%)}$

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

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Simplified Unit Cost for Manual Assembly

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

\[
\# \ People = \left\lfloor \frac{T \ N \ Q}{2000 \times 3600} \right\rfloor \quad \text{[largest integer]}
\]

- \(Q\) = annual production volume
- \(T\) = assembly time per part, sec
- \(N\) = number of parts per unit
- \(\text{A}\$\) = annual cost of a person
  \[\text{A}\$ = \bar{L}_H \times 2000\]
- \(\bar{L}_H\) = labor cost, $ / hr
- \(2000\) = hours per shift year
- \(3600\) = sec / hr

(assumes no investment required)
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)
where $I =$ total investment in machines and tools

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

$I = \# \text{ MACHINES} \times \frac{\$}{\text{MACHINE}} + \# \text{ TOOLS} \times \frac{\$}{\text{TOOL}}$

\[
\# \text{ MACHINES} = \left\lfloor \frac{TNQ}{2000 \times 3600} \right\rfloor
\]

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

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

where $w =$ number of workers / station

Combining the above yields:

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

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

Unit Cost Example

Unit Assembly Cost by Three Methods

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

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Unit Cost Example - 2

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More Detailed Cost Model

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Source:
Caveats About Examples

• If \( T = 2 \text{ s} \), then \( Q = 3.6 \text{ million} \), 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 \( Q > 7.2 \text{ Million} / T \), 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)

\[
\frac{1}{(1 + DF)^t} = DF = \text{discount factor}
\]

Its value now

Its value if delayed until t

\[e^{-\rho t}\]

\[\rho = DF = \text{discount factor}\]
Two Cash Flow Formulas

Takeaway: The early cash flows contribute the most.

Sum of future cash flows without discounting

present value of sum of future cash flows

\[ \text{DF} = 0.1 \]

present value of future cash flows

\[
\sum \left( \frac{CF}{(1+DF)^i} \right) = \frac{e^\text{DF} - 1}{\text{DF}}
\]

\[
\frac{CF}{1+DF} = \frac{e^\text{DF} - 1}{DF}
\]
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 greater than or equal to 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
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/~roztsocki/abc/abc.htm
• See Econ DEMO-Stanley Hammer.xls on MIT Server.
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 MIT Server finds the discount rate that gives $NPV = 0$

• Can be used to find $NPV$ for any discount rate
# Zero Present Value Analysis

## ZERO PRESENT WORTH CASH FLOW ANALYSIS

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<th>YEAR</th>
<th>EXPENSE FORECAST</th>
<th>INCOME FORECAST</th>
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<td>RATIO</td>
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TOTAL INVESTMENT $400
DEPRECIABLE INVESTMENT $267
INTERNAL RATE OF RETURN 18.41%
RESULT OF GOAL SEEK ON CELL G38 = 0

## PRO FORMA CASH FLOW

<table>
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<th>DEPRECIATION</th>
<th>TAXES</th>
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</tbody>
</table>

SALVAGE VALUE IN YEAR 4 $83
GROSS INCOME $713 $183 $152 $0 $561 $355
NET INCOME $313 $183 $106 $0 $206 ($0)
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
Aircraft Development Cost Quandry

Aircraft Product Development Cost Recovery

IRoR = 7.11%

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

Undiscounted Cumulative Income After Taxes and Depreciation
Discounted Cumulative Income After Taxes and Depreciation
Annual Gross Income Before Taxes and Depreciation
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%

Net Income Before Depreciation and Taxes
Net Income After Taxes and Depreciation
Sum of Undiscounted Net Cash Flows
Sum of Discounted Net Cash Flows
NPV vs Discount Rate for A380

NPV VS DISC RATE
FOR A380

DISC RATE, %

NPV, $M

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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!
Summary of Economic-Technical Analysis

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