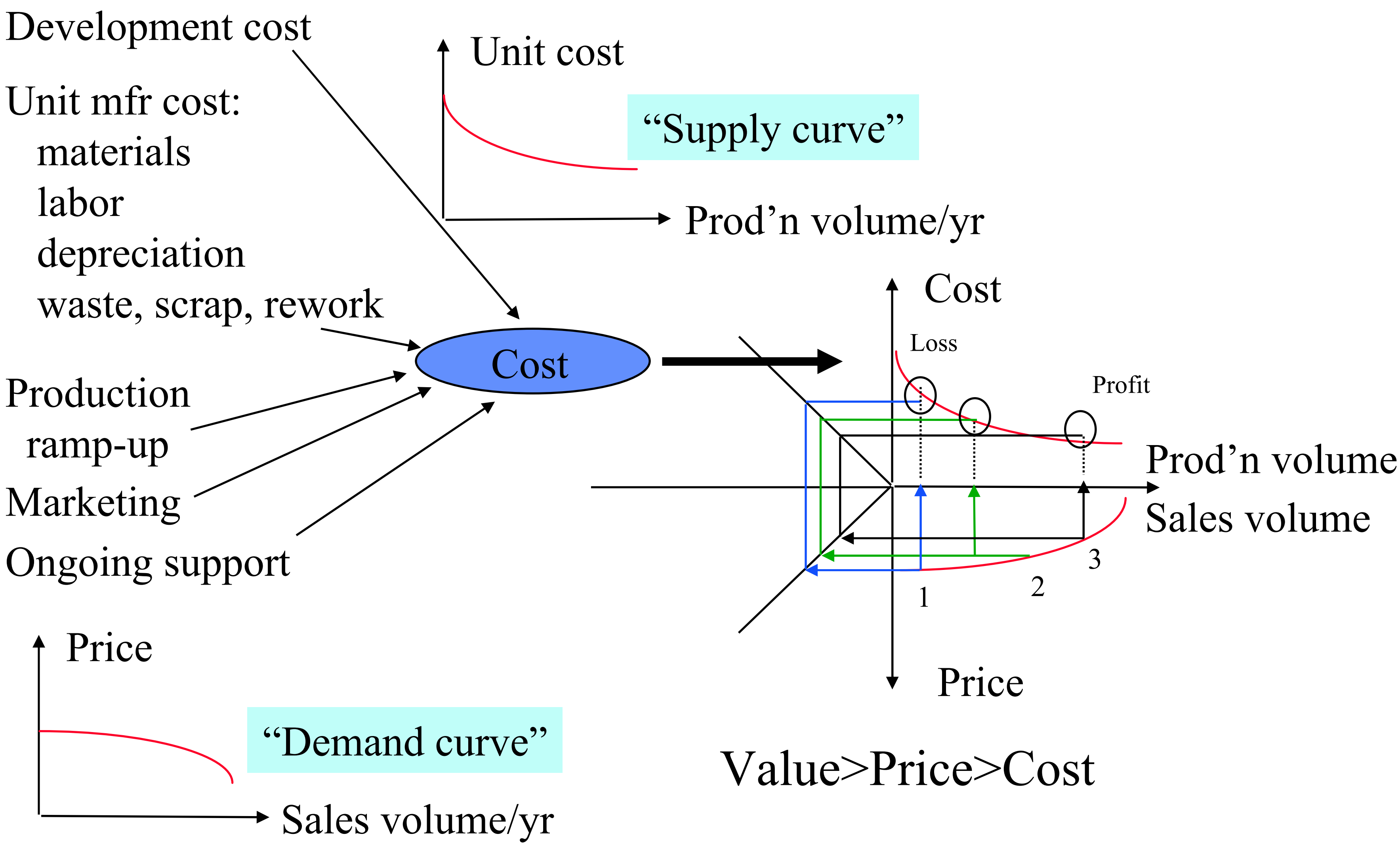
Economic Analysis of Assembly Systems

- 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



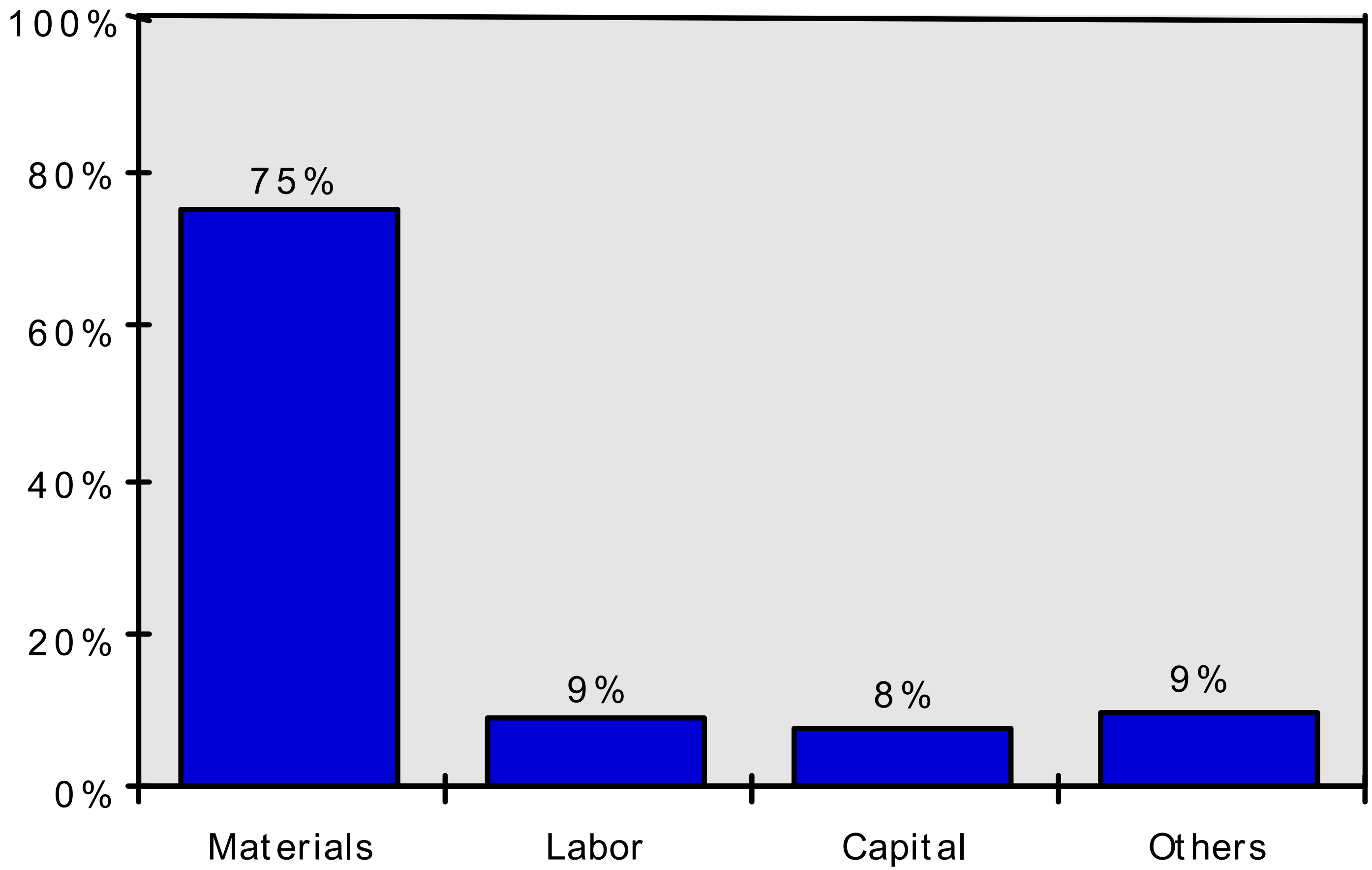
Cost Analysis is a Murky Area

- 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

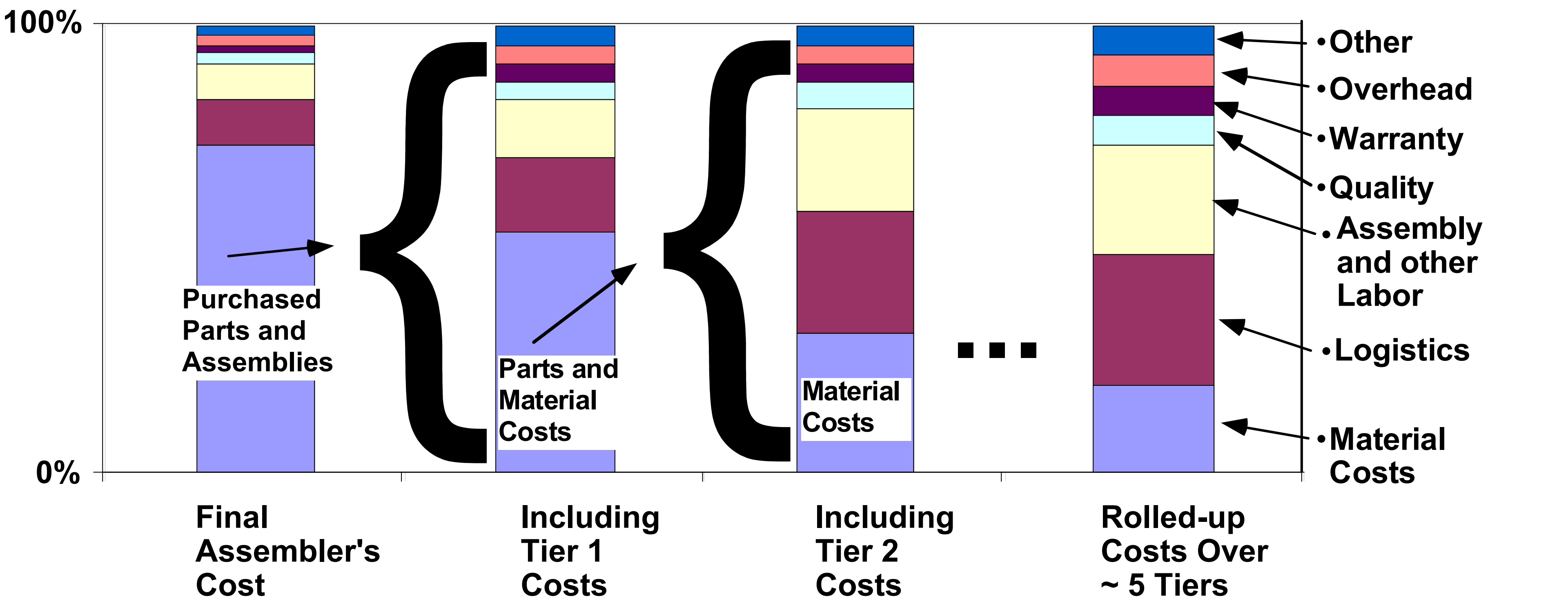
Kinds of Cost Categories

- 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

Cost Distribution in Engine Plants



Sources of Cost in the Supply Chain



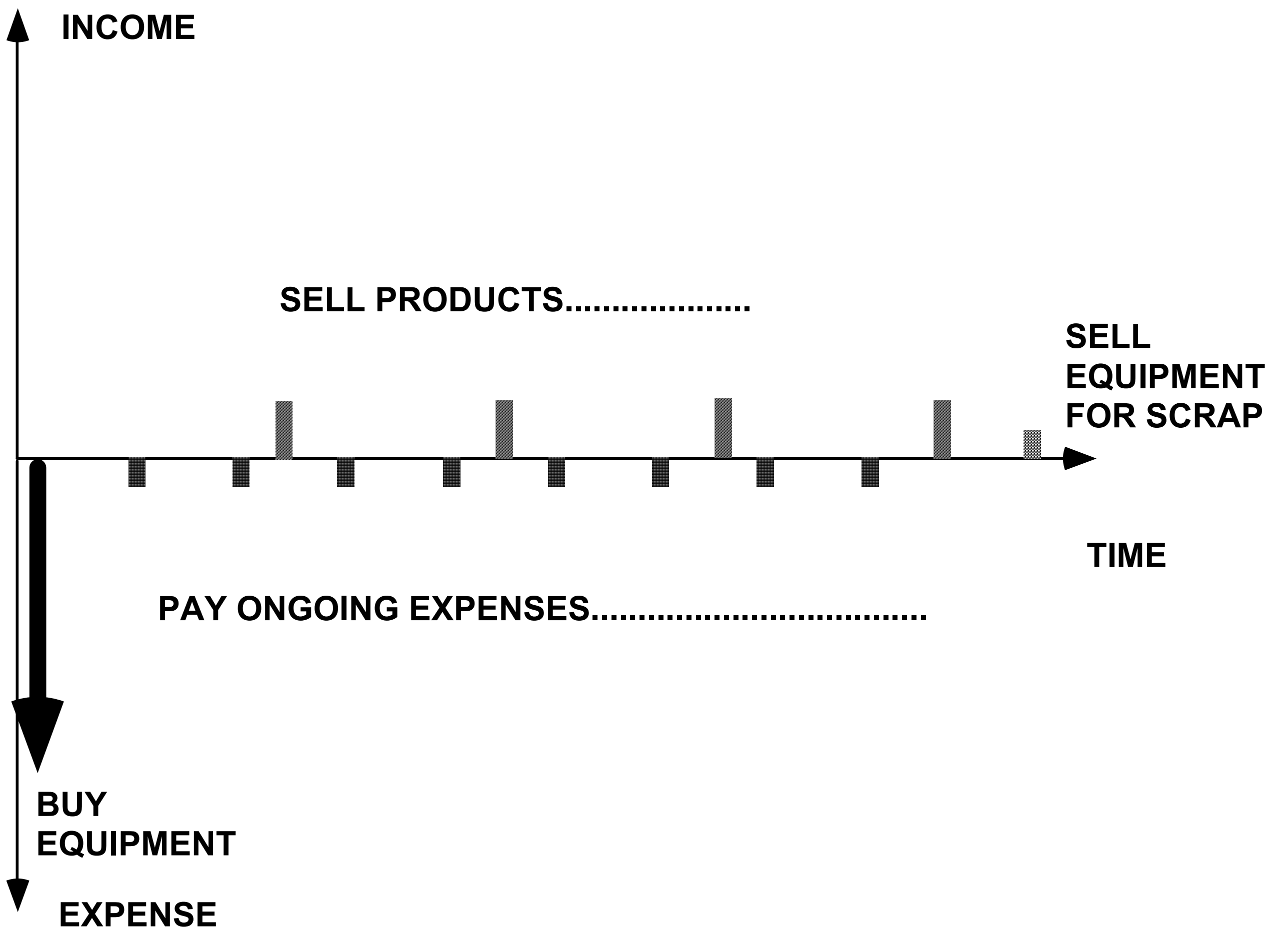
Source: Daimler Chrysler via Munro and Associates

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



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 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_o are (for zero salvage value)

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

Unit Cost Based on IRoR

- unit cost = variable cost

  + f_{AC} fixed cost /Q

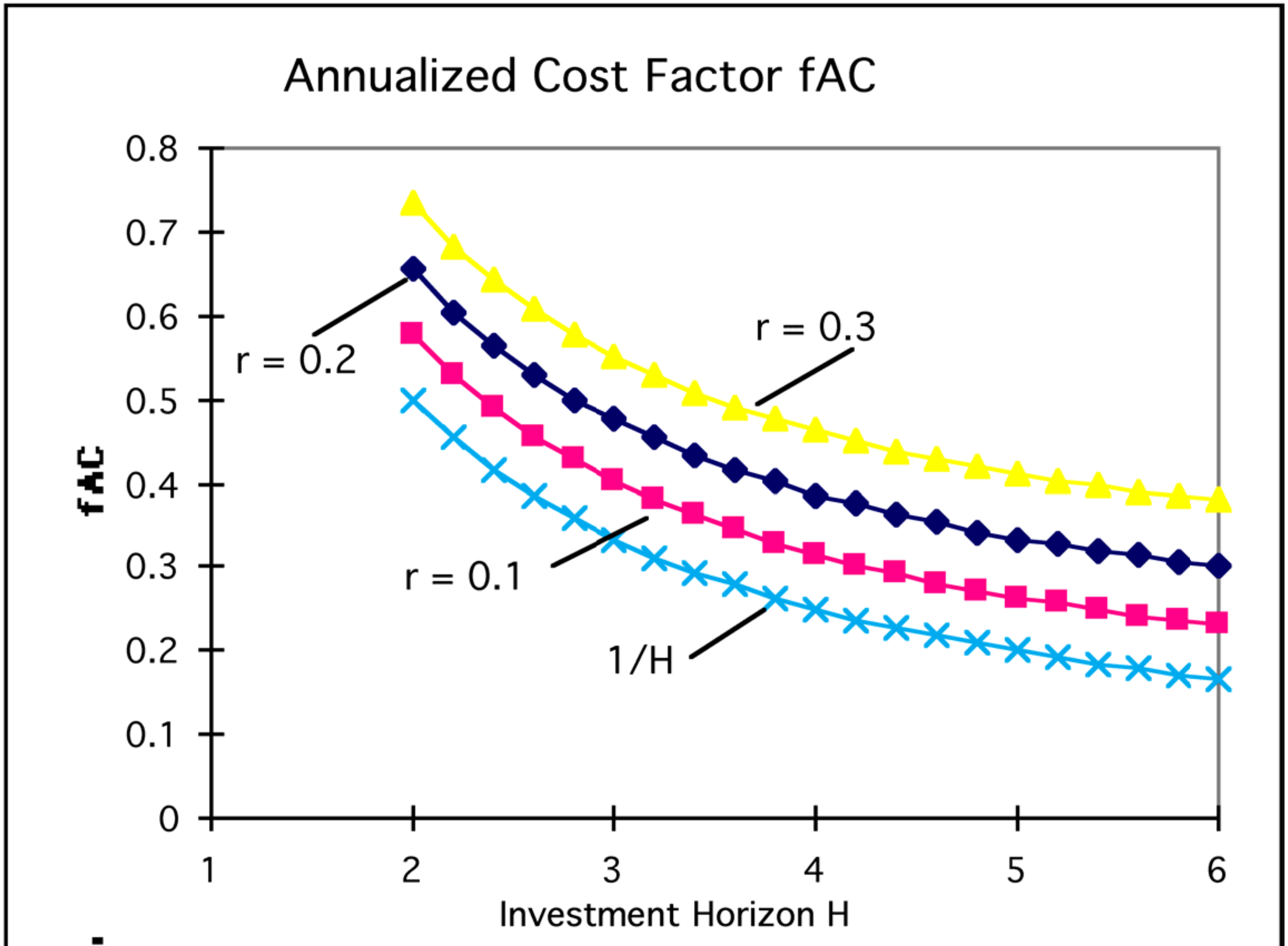
where Q = quantity made per year

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



Note: ignores depreciation

Simplified Unit Cost for Manual Assembly

$$COST_{UNIT\ MANUAL} = \frac{A\$ \quad \# People}{Q}$$

$$\# People = \left\lceil \frac{T\,N\,Q}{2000 * 3600} \right\rceil$$ [largest integer]

Q = annual production volume

T = assembly time per part, sec

N = number of parts per unit

A$ = annual cost of a person

$A\$ = \overline{L}_H * 2000$

L_H = labor cos t, $ / hr

2000 = hours per shift year

3600 = sec / hr

(assumes no investment required)

Simplified Unit Cost for Fixed Automation

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

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)

Simplified Unit Cost for Flexible Automation

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

where I = total investment in machines and tools

L$ = annual cost of workers associated with the system

I = # MACHINES * $ / MACHINE + # TOOLS * $ / TOOL

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

TOOLS = N

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

where w = number of workers / station

Combining the above yields:

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

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

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 Boothroyd chapter)

*P. M. Lynch, "Economic-Technological Modeling and Design Criteria for Programmable Assembly Machines," MIT ME Dept PhD Thesis, June 1976

Basic Nominal Capacity Equations

operations/unit * # units/year = # ops/yr

ops/sec = # ops/yr * (1 shift/28800 sec)*(1 day/n shifts)*(1 yr/280 days)

cycle time = 1/(ops/sec) = required sec/op

equipment capability = actual sec/op (including all stops)

actual sec/op < required sec/op -> happiness

required sec/op < actual sec/op -> 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

Basic Cycle Time Equation

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

cycle time = net avg time per assembly

in – out time = time to move one pallet out and another in

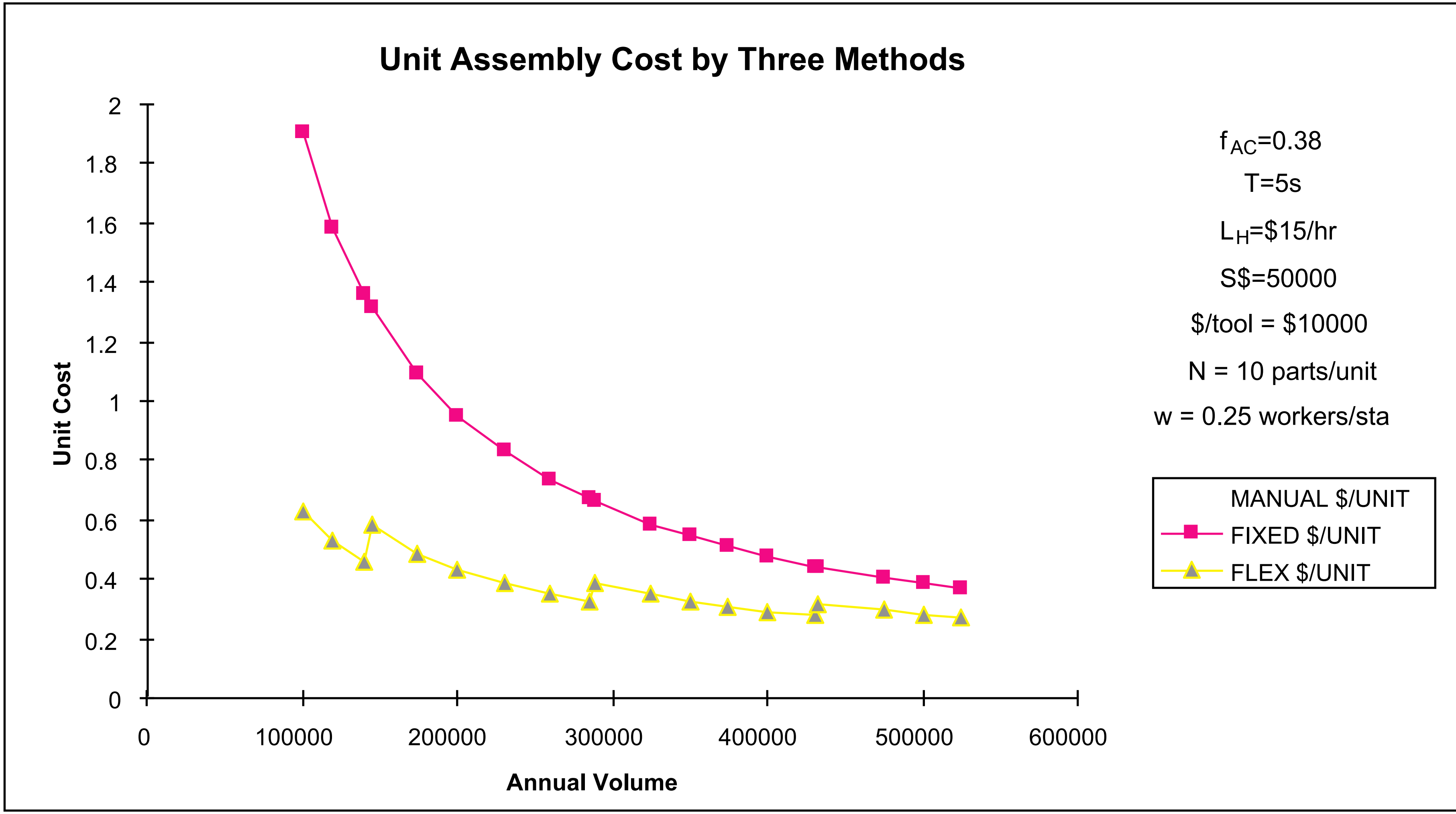
tool ch. time = time to put away one tool and pick up another

ch. / unit = number of tool changes needed to make one unit

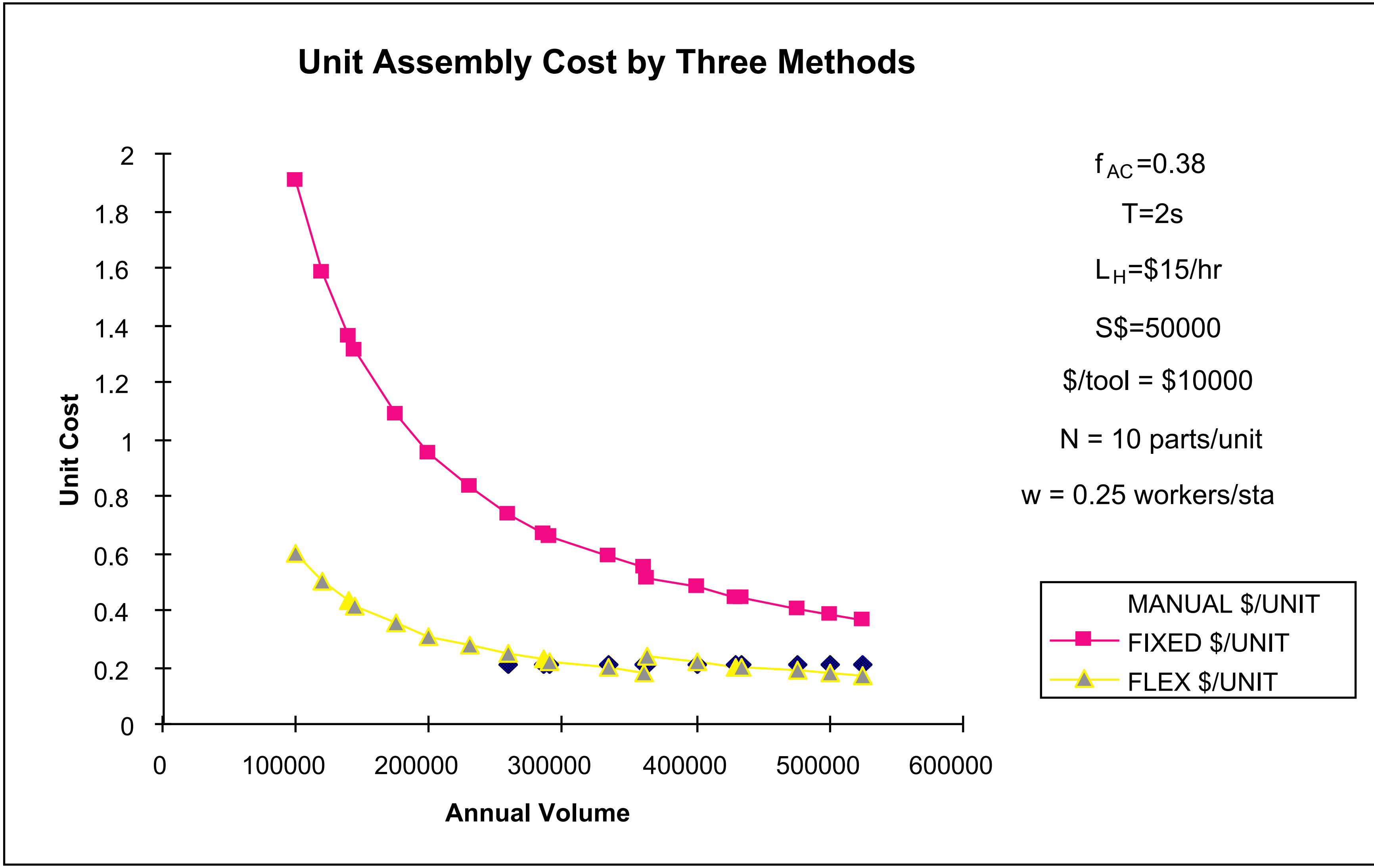
units / tool ch. = number of units worked on before tool is changed (cannot be larger than number units / pallet)

ε = station uptime fraction: $0 < \varepsilon < 1$

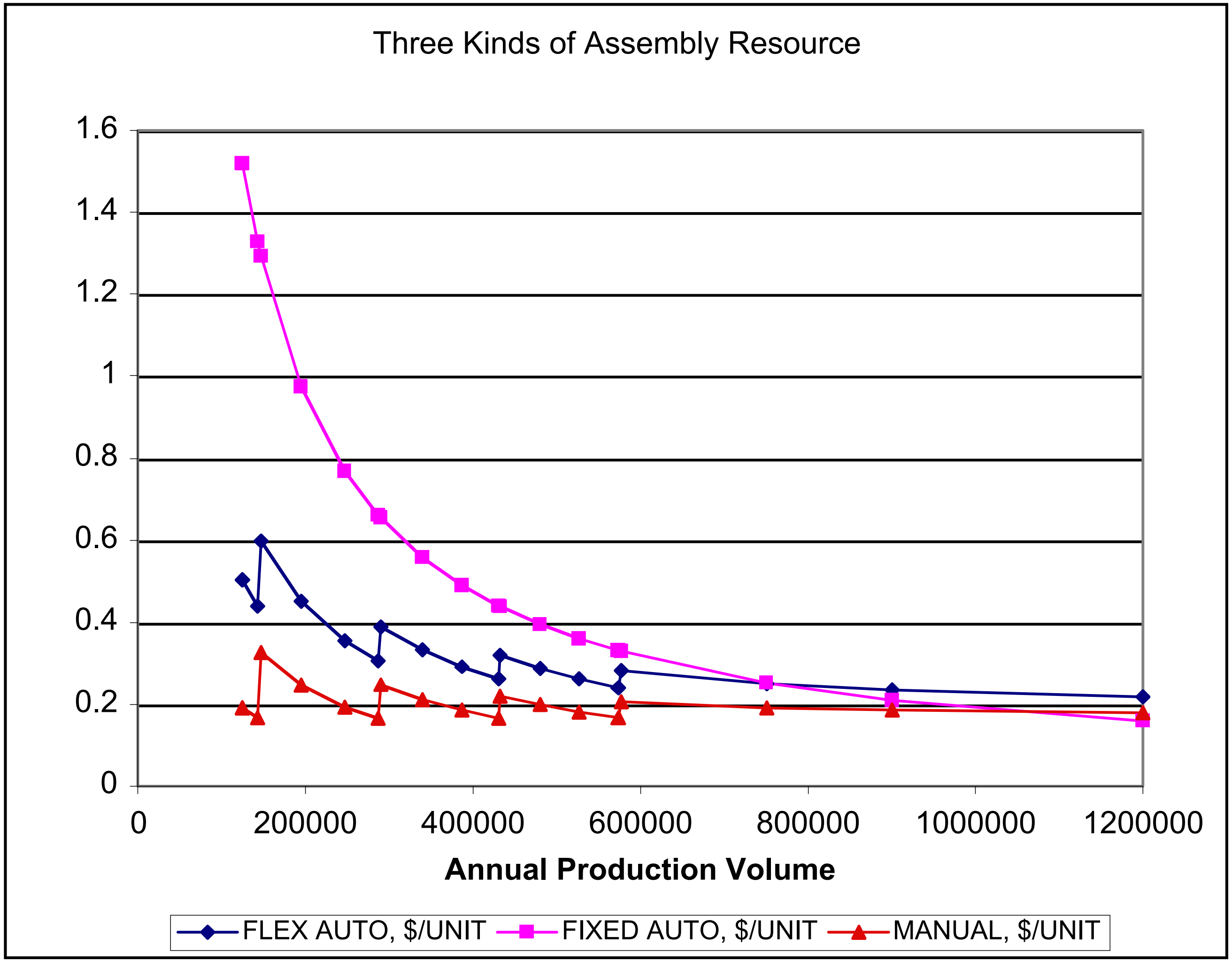
Unit Cost Example



Unit Cost Example - 2



More Detailed Cost Model



Caveats About Examples

- If T = 2 s, then Q = 3.6 million, or else the line runs only part of one shift
- If # people > # 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

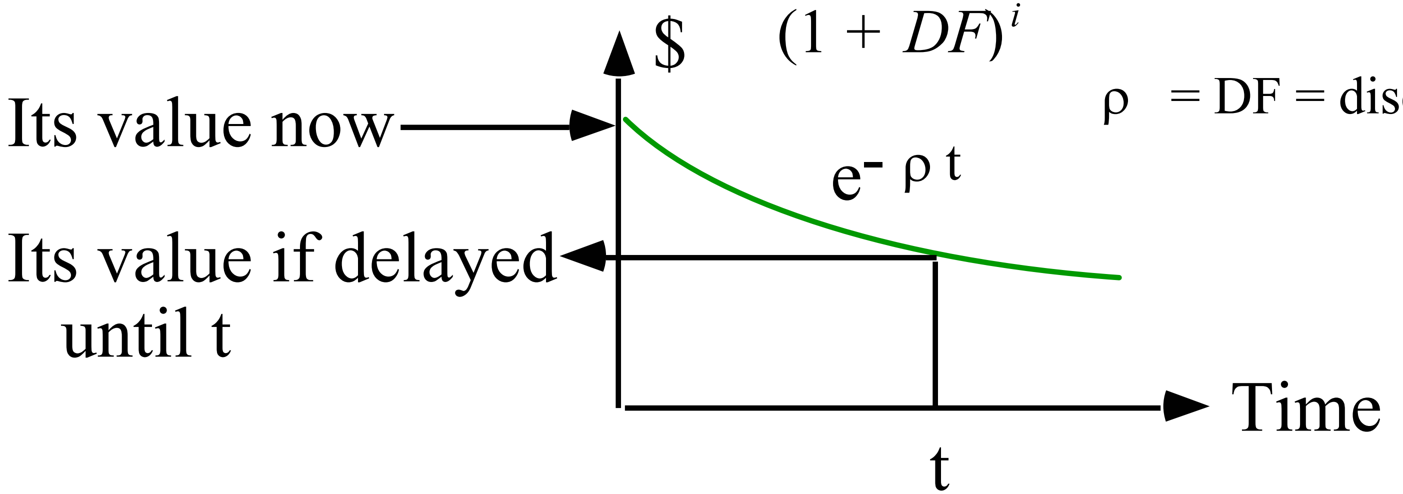
- AKA net present value calculation
- More detailed and sophisticated than unit cost comparisons
- Seeks to determine if an investment is “good”
- Based on comparing return on investment
  - a base case is compared to an alternate
  - the alternate requires upfront investment
  - it creates a saving 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)

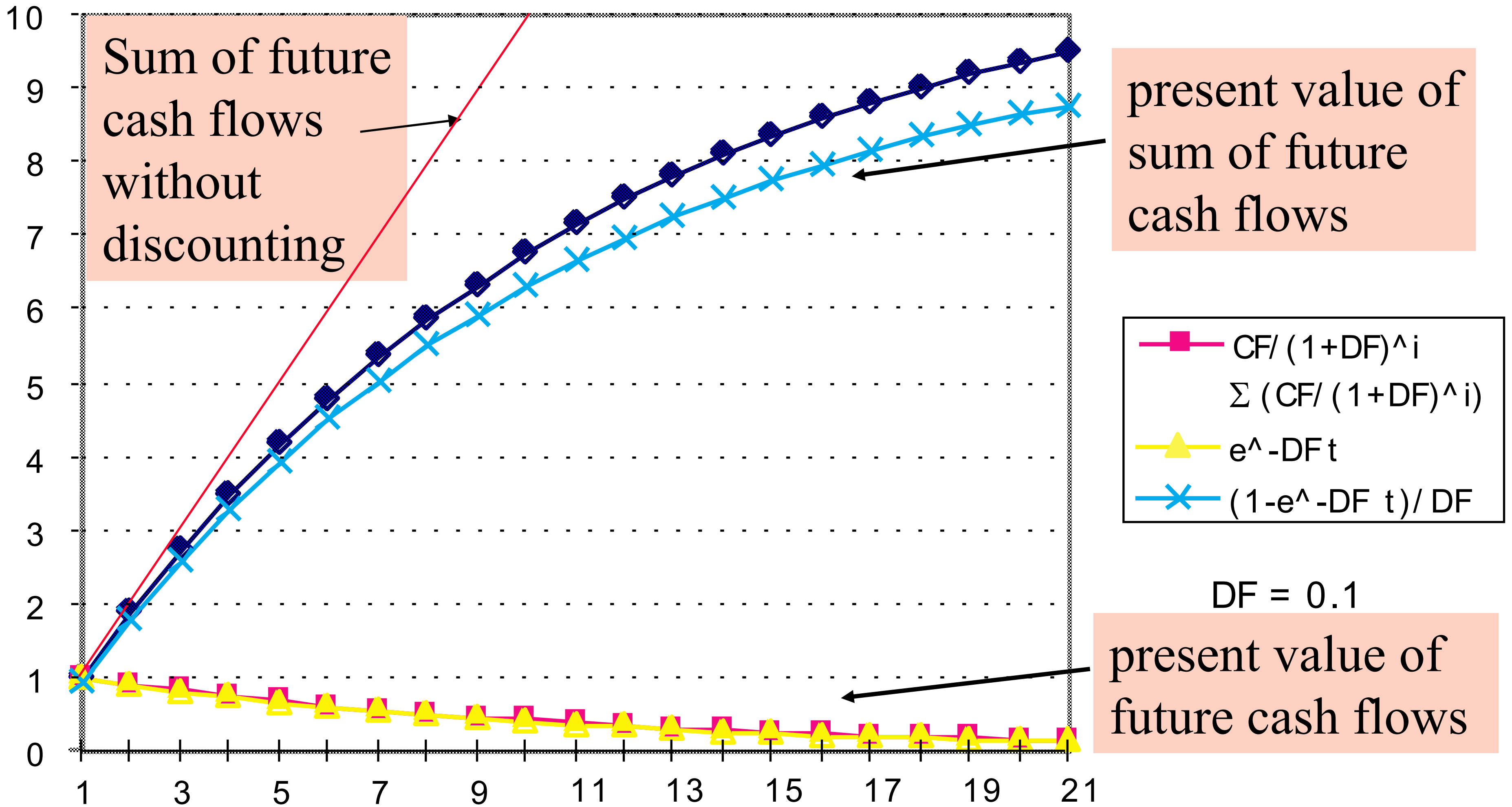
$$\frac{1}{(1 + DF)^{i}}$$

ρ = DF = discount factor



Two Cash Flow Formulas

Takaway: The early cash flows contribute the most.



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?

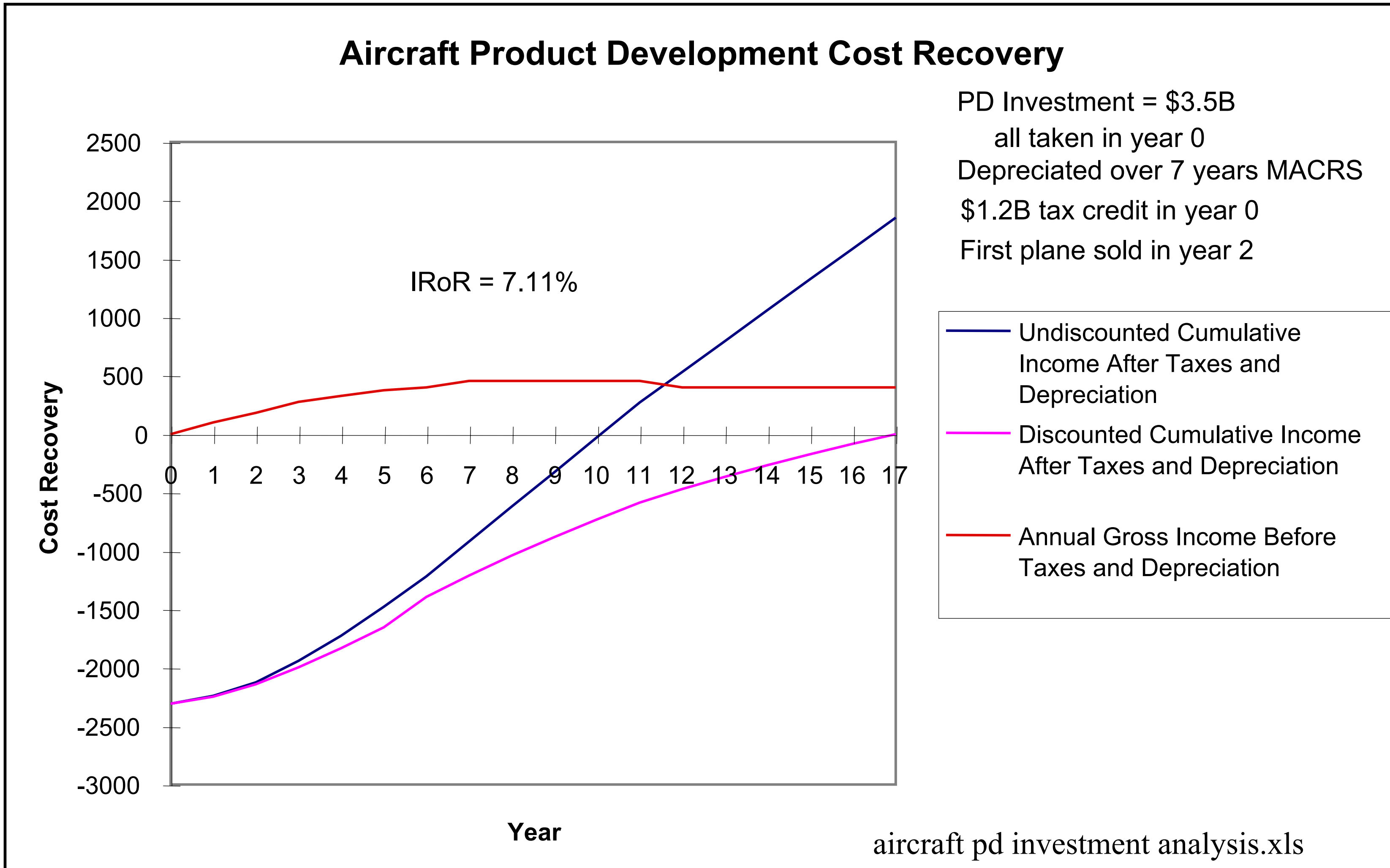
$$\text{Investment}_{\text{alt}} - \text{Investment}_{\text{base}} = \sum_{i=1}^{H} \text{Net savings}_i \,/\, \left(1 + DF\right)^i \; .$$

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

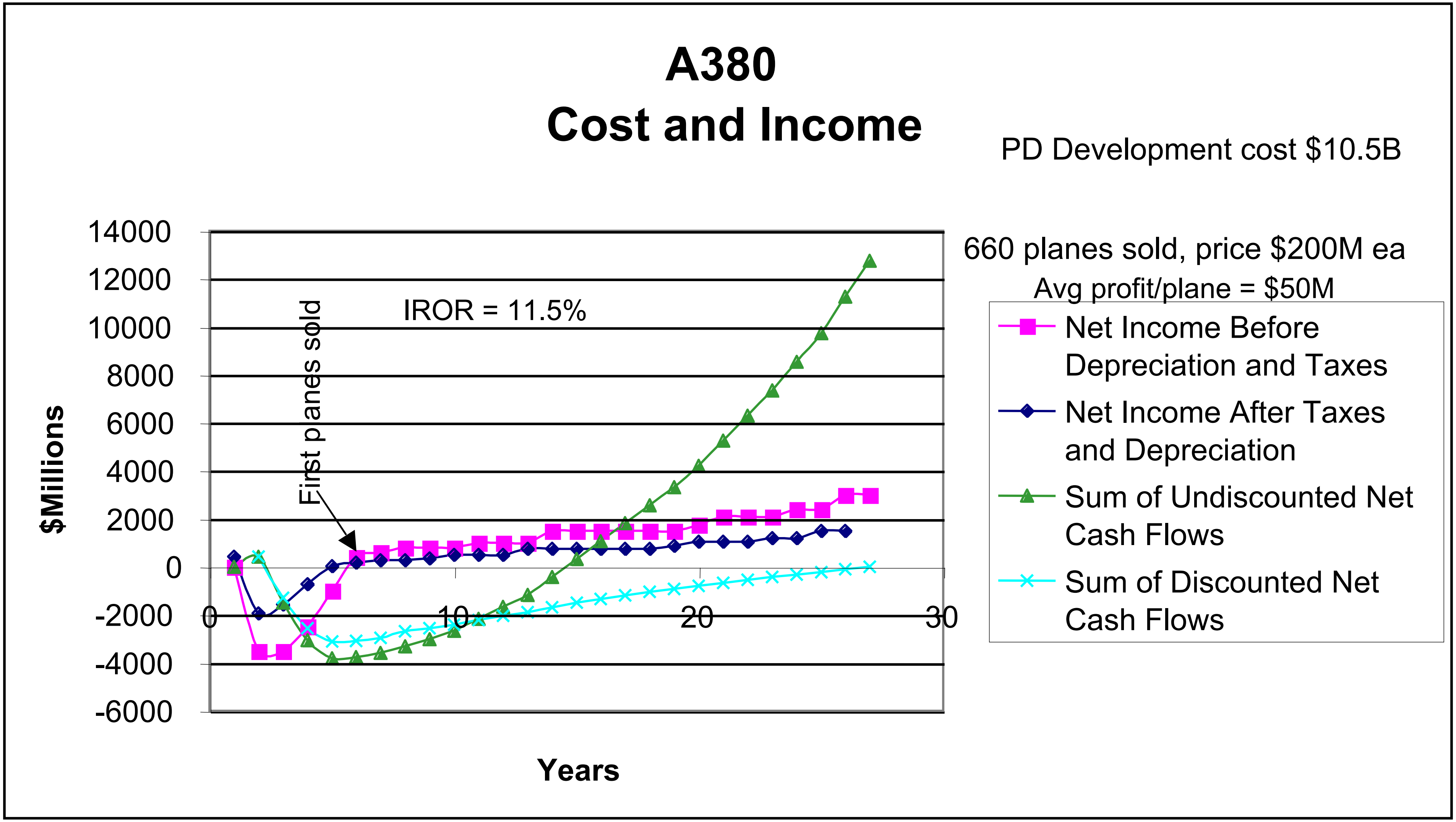
Discounted Cash Flow (DCF) and Economic Value Added (EVA)

- 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/~roztocki/abc/abc.htm
- See Econ DEMO-Stanley Hammer.xls on SloanSpace

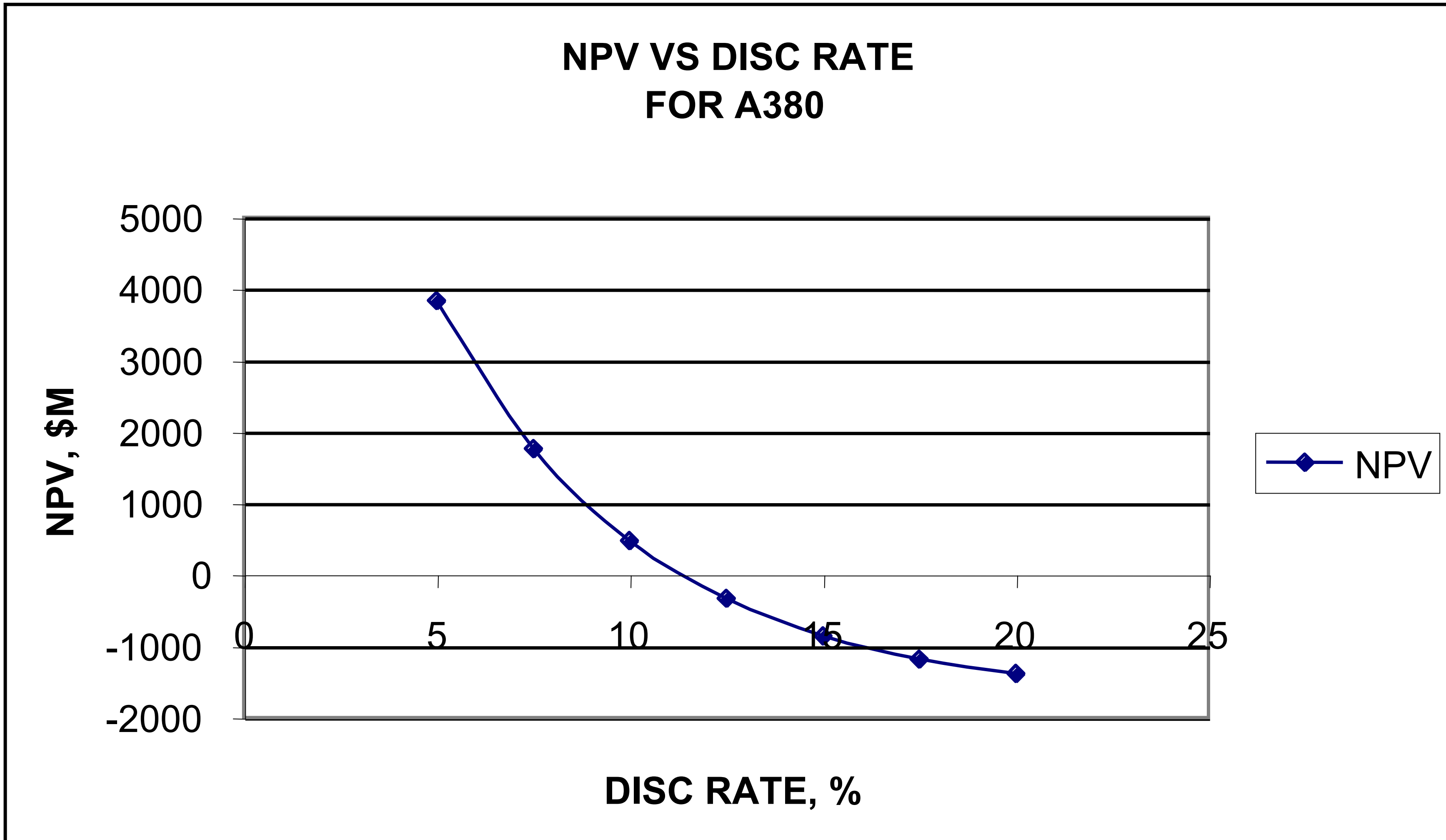
Aircraft Development Cost Quandry



A380 Business Case



NPV vs Discount Rate for A380



Zero or Net Present Value Calculations

- Comparing two investments, the savings Sv are considered income
- You pay taxes on the income at tax rate Tx, yielding your net income Ni
- You can claim depreciation Dp 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: $Ni = Sv - Tx(Sv - Dp)$
- "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 WORTH CASH FLOW ANALYSIS						
7	YEARS ECONOMIC LIFE		0%	SALVAGE VALUE % OF COST AT END OF ECONOMIC LIFE				
	EXPENSE FORECAST			**INCOME FORECAST**				
YEAR	**RATIO**	**TAX RATE**	**DEPRECIABLE**	**SAVINGS**	**DEPRECIATION**	**TAX RATE**	**CREDIT**	
0	100.00%	34.00%	66.67%					
1				$100	14.29%	34.00%		
2				$181	24.49%	34.00%		
3				$198	17.49%	34.00%		
4				$150	12.49%	34.00%		
5					8.92%	34.00%		
6					8.92%	SUM OF UNUSED YRS		
7					8.92%	DEPR=	31.22%	
8					4.46%	USED FOR SALVAGE VALUE		
						OF REMAINING DEPRECIABLE INVESTMENT		
			TOTAL INVESTMENT		$400		TAX CREDIT IN YR 0 0N	
			DEPRECIABLE INVESTMENT		$267		UNDEPRECIATED INVESTMENT	
			INTERNAL RATE OF RETURN		18.41%	RESULT OF		
					GOAL SEEK			
					ON CELL G38 = 0			
			PRO FORMA CASH FLOW					
YEAR	**INCOME**	**DEPRECIATION**	**TAXES**	**CREDITS**	**NET**	**DISC NET**	SUM OF UNDISC INC	
0	($400)		($45)	$0	($355)	($355)		
1	$100	$38	$21	$0	$79	$67	$79	
2	$181	$65	$39	$0	$142	$101	$221	
3	$198	$47	$51	$0	$147	$88	$368	UNDISC PAYBA
4	$150	$33	$40	$0	$110	$56	$478	FOR EX IN FIG
4	$83	$0	$0	$0	$83	$42	$561	
SALVAGE VALUE								
IN YEAR 4								
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

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