

Introduction to Technical Cost Modeling Concepts and Illustrations

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Why Is Cost Important?

- A measure of resource consumption
 - How much is required to do (e.g., produce) something?
 - Resources themselves are sometimes hard to define and measure
 - Cost is a useful shorthand
- Therefore, cost is usually a key **decision variable**
 - Reduces the issue of resources to a common metric
 - Actually measured in terms of a real thing - cash
 - Can also be a measure of a real amount (like a bank account balance!)
- Key uses of cost
 - Establishing cash requirements for an operation/project
 - Estimation of revenue requirements for project success
 - Determining strategies -- ways of acting
 - ▶ *Make-buy decisions*
 - ▶ *Choice of process, design, technology*
 - ▶ *Acquisition/Selling strategies*

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Diversity of Uses --> Diversity in Definitions of "Cost"

- What is Cost?
- Cost "definitions" a reflection of key assumptions
Assumptions which may defeat the uses of the cost metric if misunderstood
- Examples
 - Operating Cost
 - Overhead Cost
 - Depreciated Cost
- Let's start with some formal definitions.....

Cost To The Economist

- Cost is used to define resource constraints on production
- Recall how one finds the marginal conditions for production
$$\text{maximize } Q = f(X_1, X_2, X_3, \dots, X_i)$$
$$\text{subject to a budget constraint } B = \sum(p_i \times X_i)$$
- Efficiency in production is governed by
 - structure of cost
 - nature of the technology
(ratio of the marginal products to the marginal costs must be equal for all factors)

Cost In Practice

- Companies rarely juggle marginal products and marginal costs for optimality
- Instead, the day-to-day operational mantra becomes:
 - Maximize output
 - Minimize cost
- In practice, maximizing output means "keep the machines/process running"
- In practice, minimizing costs means "keep track of everything that is bought and try to find ways to buy less"
- Accounting is the tool for tracking expenses

Cost In Practice - Accounting

- Basic principle: Total all expenditures
- In practice, however, the total is not as useful as specific elements of cost
- Subdivisions of cost developed
 - Recurring (or variable) costs
 - One time (or fixed) costs
- Simplifications introduced to
 - Get the right total cost (thus making it possible to set revenue targets correctly)
 - Indicate which elements of the production process require the most control (because they most clearly influence total costs)
 - Without swamping the decisionmaker with too much information
- Example: Classical accounting practice focused upon Labor as the key cost driver
 - Demonstrations of errors have pointed to need for new estimation methods
 - Use of Activity-based accounting to rectify

Cost Modeling

- Problem:
 - Economist's cost is an abstraction, driven by considerations of optimality
 - Accounting cost depends upon measurement of an existing operation

 - How, then, to use cost as a decision tool when neither the economist's abstraction nor existing accounting information is appropriate?
- Examples:
 - Prediction of the cost of a new process, facility, technology
 - Comparison of alternative designs
 - Evaluation of strategic choices
- A "third way" is required

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Needed: A Tool Encompassing the Formality of Economics & the Empiricism of Accounting

- Why?
- Engineering Needs a Cost Tool to Evaluate:
 - State of Technology
 - Current Processing Conditions
 - Value of Research Directions
- Businessman Needs a Cost Tool to Evaluate:
 - Competitiveness of His Operation
 - Strategies for Development
 - Investment Needs and Opportunities
- Decisionmakers Need a Tool That:
 - Limits Assumptions
 - Is Explicit About The Assumptions Made
 - Imposes a Consistent Basis for Comparison & Evaluation

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Alternative Approach: Cost Modeling

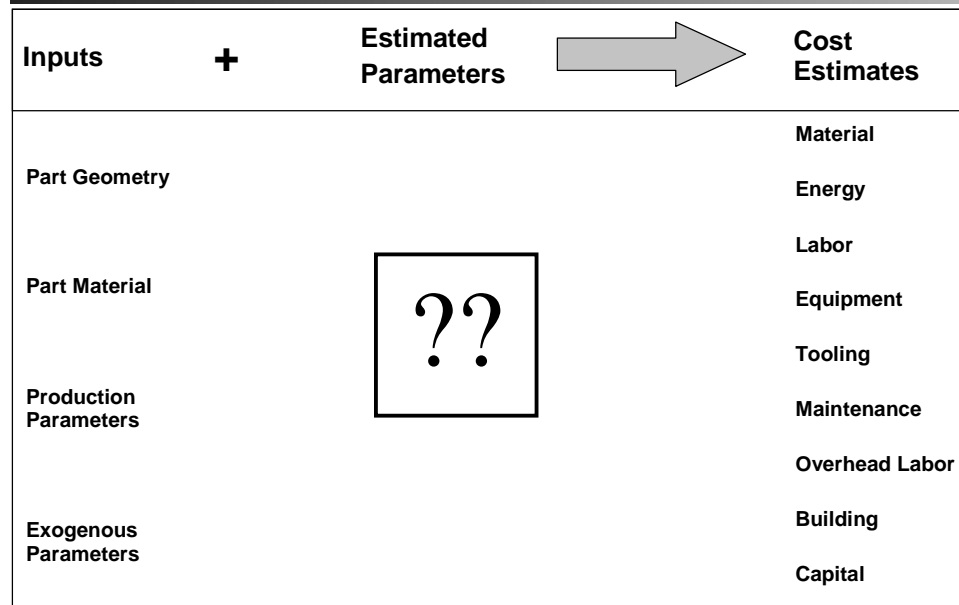
- Why Modeling Instead of Analysis or Structure or ...?
 - Imposition of Structure
 - Incorporation of Knowledge
 - Inclusion of Technology

- Cost Modeling Has Its Weaknesses, Too
 - Garbage In, Garbage Out
 - Time Consuming to Develop
 - Expensive -- \$\$\$

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Conceptual Basis of Cost Model



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Evolution of a Cost Model - Injection Molding

- Conventional Wisdom

$$Part\ Cost = 2 \times Material\ Cost$$

- What Is Material Cost?

$$Materials\ Cost = \frac{(Part\ Weight \times Raw\ Material\ Price)}{(1 - Material\ Scrap\ Rate)}$$

- Limited Perspective
 - No Consideration of Technology Improvement
 - Cannot Incorporate Process Improvement
 - Too Much Weight Placed On Material Cost

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Evolution of a Cost Model - Injection Molding

- Classical Accounting Perspective

$$Part\ Cost = Material\ Cost + Labor\ Cost \times Burden\ Rate$$

- What is Labor Cost?

Labor Cost = Effective Labor Rate × Time To Make A Part
Effective Labor Rate = $\frac{Labor\ Wage}{Labor\ Productivity}$
Time To Make A Part = Cycle Time
Cycle Time = f(Material, Geometry, Technology, ...)

- Note that a Technological Element (Cycle Time), A Production Element (Productivity) and a Factor Price (Wage Rate) Have Been Introduced
- What is Burden Rate??? -- Accounting Construct

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Burden Rate

- Concept Introduced By The Accounting Perspective on Cost Estimation
- Based on the Assumption that Physical Plant Must Be Bought To "Maintain" Labor
- Therefore, All Other Costs Of A Plant Operation Are Summed, Then Divided By Total Labor Hours To Get A "Burden" Rate
- Includes: Machines, Tooling, Utilities, Buildings, Support Staff, Maintenance
- Can Also Include: Research , Sales, Management, etc.
- However, Can Estimate Most Of These Elements From Process Considerations

Injection Molding -- Elements of Burden

- Tooling Cost
- Machine Cost -- Press and Auxiliary Equipment
- Machine Maintenance
- Building
- Support Labor
- Energy Consumption
- Opportunity Cost of Capital/Cost of Money
- Each of These Can Be Estimated Directly, Based Upon Engineering, Economic and Processing Considerations!

Time As A Critical Parameter - Engineering & Practice Driven

- Time To Process a Part - Underlies Almost All Cost Factors
- Directly Effects Key Production Parameters
 - Variable Costs:
 - Labor
 - Energy
 - Fixed Costs
 - Number of Machines
 - Number of Tools
- Total Production Time Available -- Critical To Capital Cost Allocations
 - Number of Shifts
 - Number of Days
 - Productive Hours in a Shift

Example of Differences In Time of Equipment Use

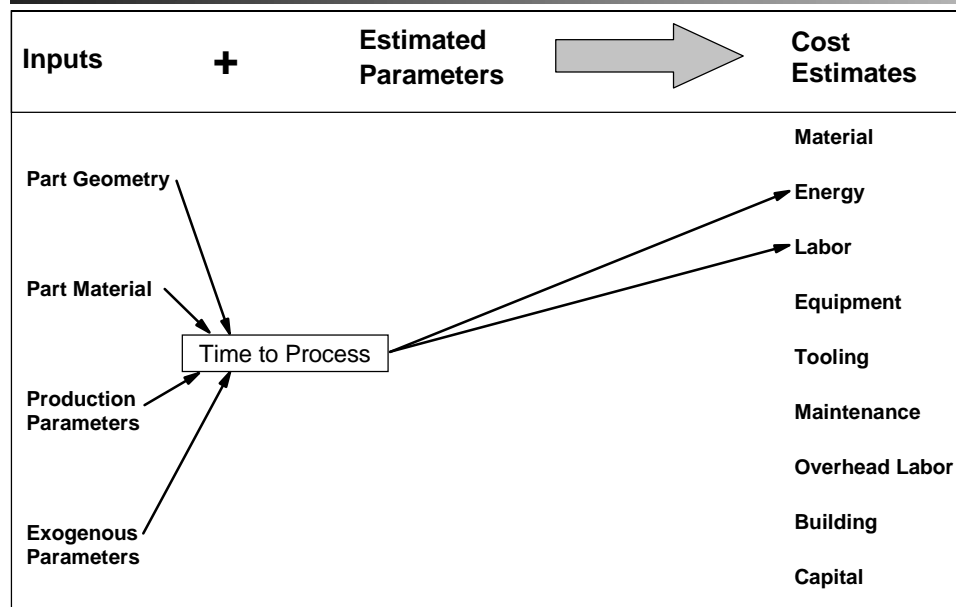
	US	Korea
days/shift	240	320
shifts/day	2	2
hrs/shift	6.4	6.4
total hrs/yr	3000	4100

33% Better Capital Utilization In Korea

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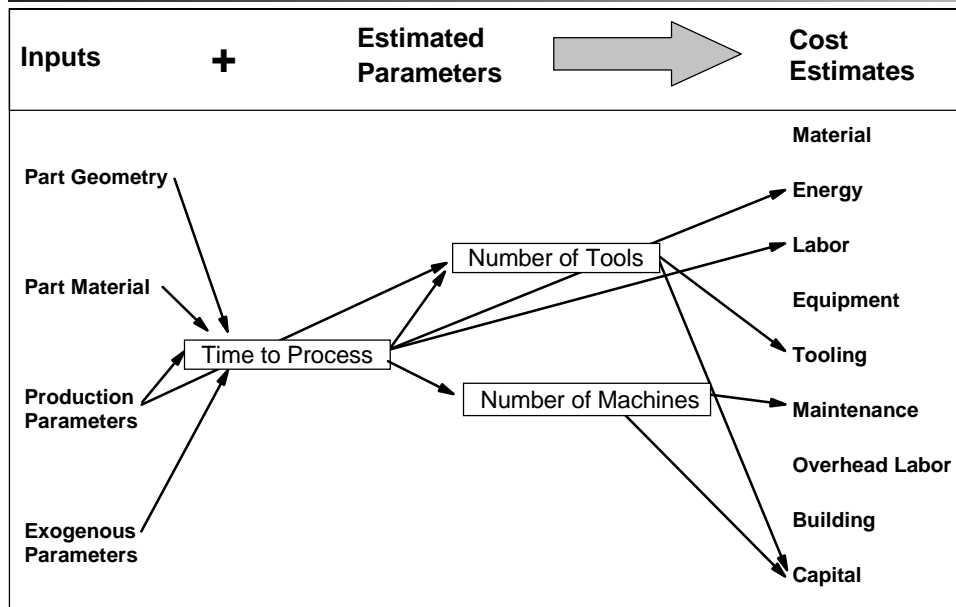
Processing Time/Rate Critical to Cost



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Processing Time/Rate Critical to Cost



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Processing Time and Its Relationship with Capital Costs

- Number of Machines/Production Lines

$$\# \text{ of lines} = \frac{\text{Cycle Time} \times \text{Annual Production Volume}}{\text{Available Production Time} \times \# \text{ of Cavities}}$$

(rounded up to the next integer value)

- Number of Tools

$$\# \text{ of Tools} = \# \text{ of Lines}$$

- Lifetime of Tools

$$\text{Tool Life (yrs)} = \frac{\text{Tool Life (cycles)} \times \# \text{ of cavities}}{\text{Annual Production}}$$

- Critical Accounting Assumption -- Dedication

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Dedicated/Non-Dedicated Equipment Assumption

- If a piece of capital equipment is used to manufacture more than one product in a year, the cost of the part should reflect this
- Typically, cost is shared according to the fraction of total operating time required to produce the targeted production

$$\text{Run Time} = \frac{\text{Cycle Time} \times \text{Annual Production Volume}}{\text{Available Production Time} \times \# \text{ of Cavities}}$$

- Note: This term is substituted for the number of lines term when equipment is assumed not dedicated
- But - Tooling is ALWAYS dedicated

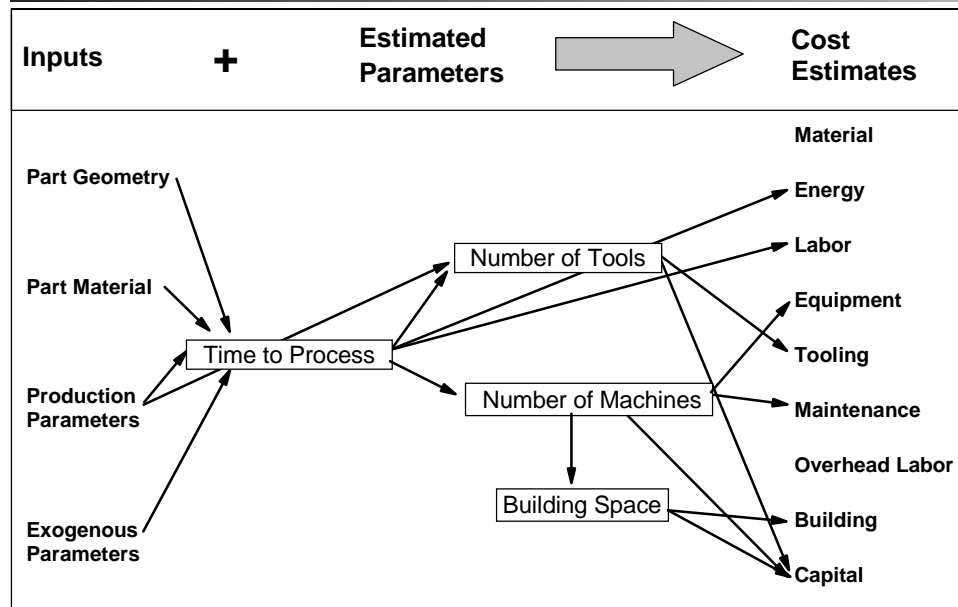
Amortization of Capital Costs

- Capital Costs Must Be Annualized/Amortized to Account for Financing Costs or Opportunity Costs
- Simple Annuity Calculation:

$$\text{Annual Cost} = \text{Total Capital Cost} \times \frac{r \times (1+r)^n}{(1+r)^n - 1}$$

- Note: The period of the annuity/payback is determined by either
 - the accounting lifetime of the capital good (machines, buildings, etc.),
 - the lifetime of the product being produced (tooling) or
 - the physical lifetime of the capital good, whichever is shorter.

Processing Time/Rate - Critical To Cost



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Time To Process A Part - Engineering Parameter

- Use Combination of Engineering and Theoretical Approaches
- Cooling Time - Theoretical Determination

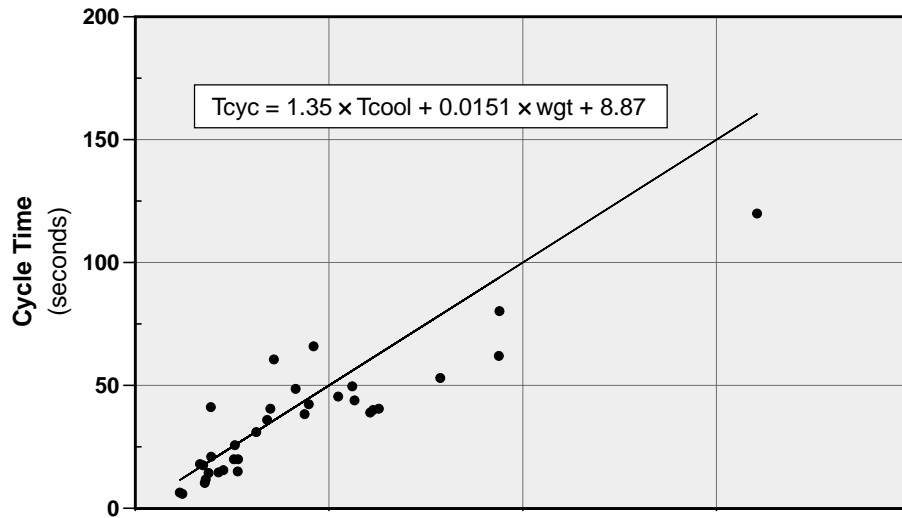
$$\text{Cooling Time} = \frac{\rho d^2 c_p}{\pi^2 \kappa} \ln \left[\frac{8 \times (T_{\text{Melt}} - T_{\text{Mold}})}{\pi^2 \times (T_{\text{Eject}} - T_{\text{Mold}})} \right]$$

- Filling Time - Function of Shot Size - Function of Part Weight
- Mold Cycle - Function of Press Size, But Likely A Small Variation
- Cannot Expect Perfect Match To Theory, So Try To Correlate

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Cooling Time, Part Weight and Cycle Time Correlation



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Evolution of a Cost Model - Injection Molding

- Equipment and Tooling Cost - Primary Capital Expenditures
- Equipment Size Function of Clamping Force
- Clamping Force Function of Part Geometry and Processing Parameters
- Empirical Relation:

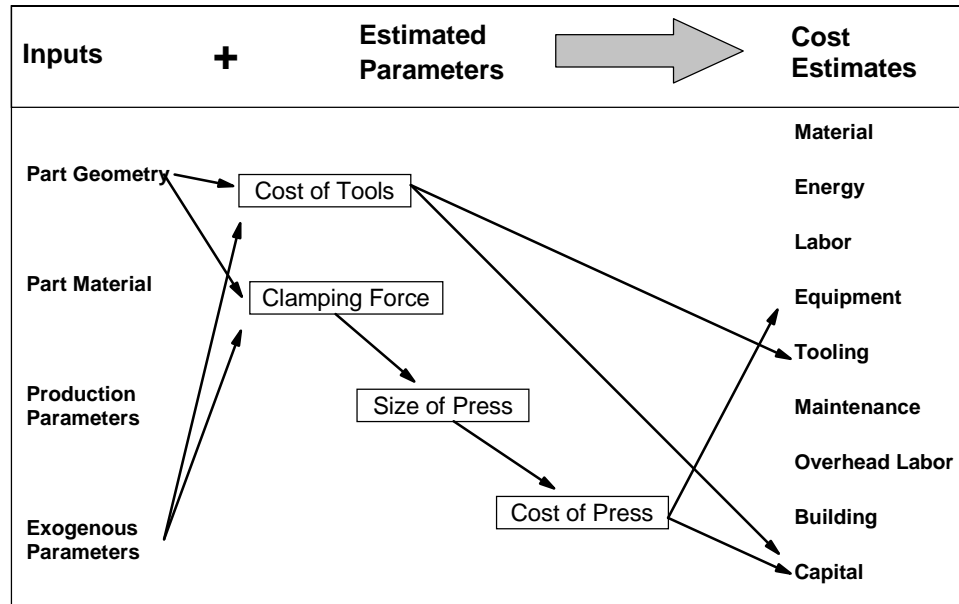
$$\text{Clamp Force} = \text{Projected Area} \times N_{\text{cavities}} \times \frac{224}{\sqrt{\text{nominal wall}}} + 172$$

- Clamp Force Can Then Be Related To Press Cost

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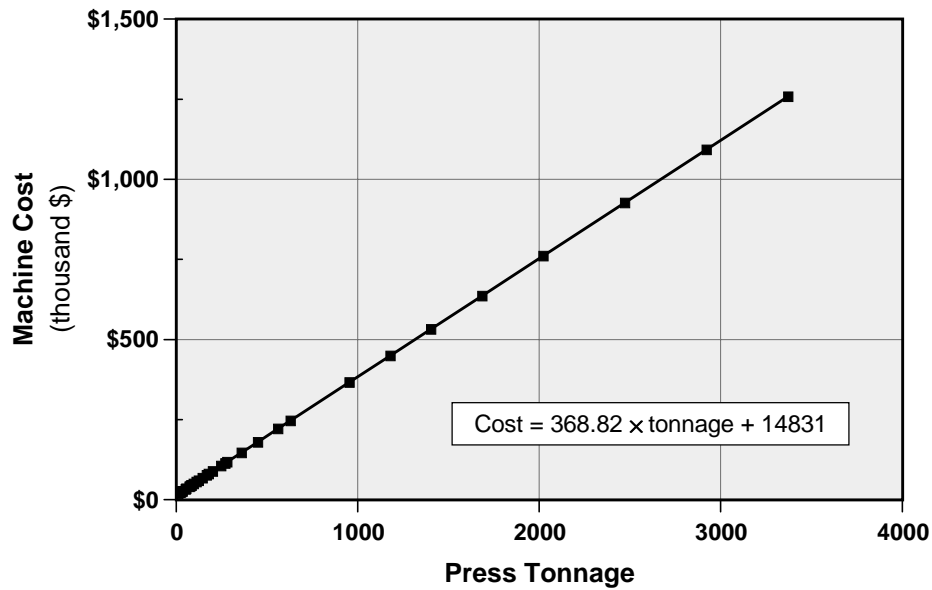
Capital Cost Relationships



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Correlation Between Press Cost and Tonnage



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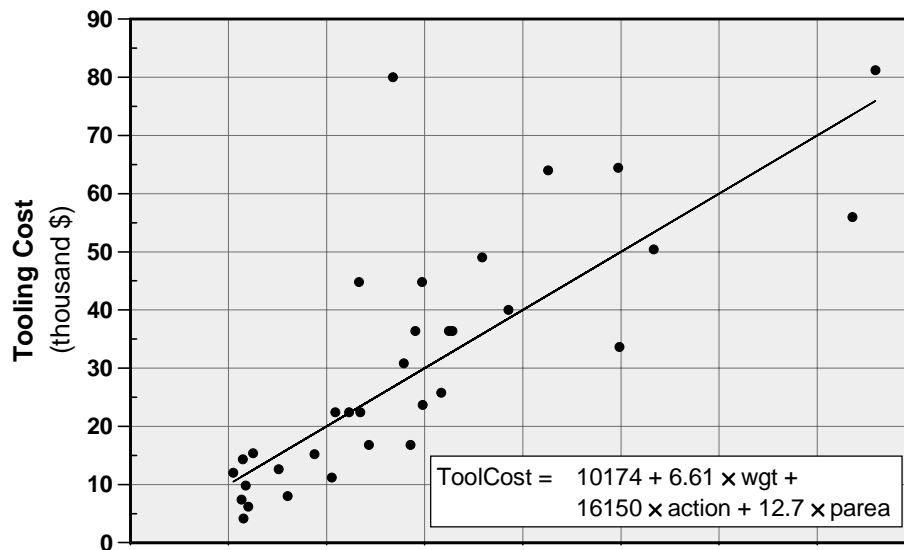
Evolution of a Cost Model - Injection Molding

- Tooling Cost Estimation Extremely Difficult To Do Reliably
- Process Tooling Is Usually
 - Customized
 - Made By Hand
 - Without Consistent Specification
 - Without Consistent Lifetime
 - Subject to Multiple Revisions
- Nevertheless, Some Guidelines Can Be Established
 - Physical Size of the Tool
 - Complexity of the Machining Required
 - Special Treatments of Surfaces
 - Actions, Other Features

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Tooling Cost Regression Estimates



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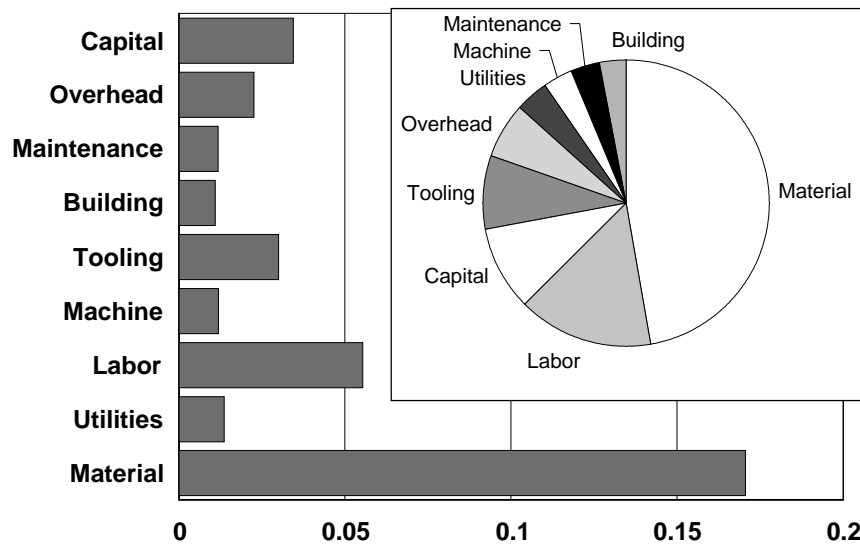
Industry Practice Parameters

- Operating Hours & Labor Productivity
- Building Space Requirements and Land Cost
- Amount of Auxiliary Equipment
- Amount of Overhead Labor
- Cost of Capital

Elimination of Burden - Example

- Injection Molding Machine Size - Function of Molding Pressure
- Molding Pressure - Function of Resin Being Molded and Part Geometry
- Strong Linear Correlation Between Press Tonnage and Press Cost
- Amortize Machine Cost and Divide By Annual Production Rate
- If Not Dedicated to Single Part Production, Scale Cost By Operating Fraction

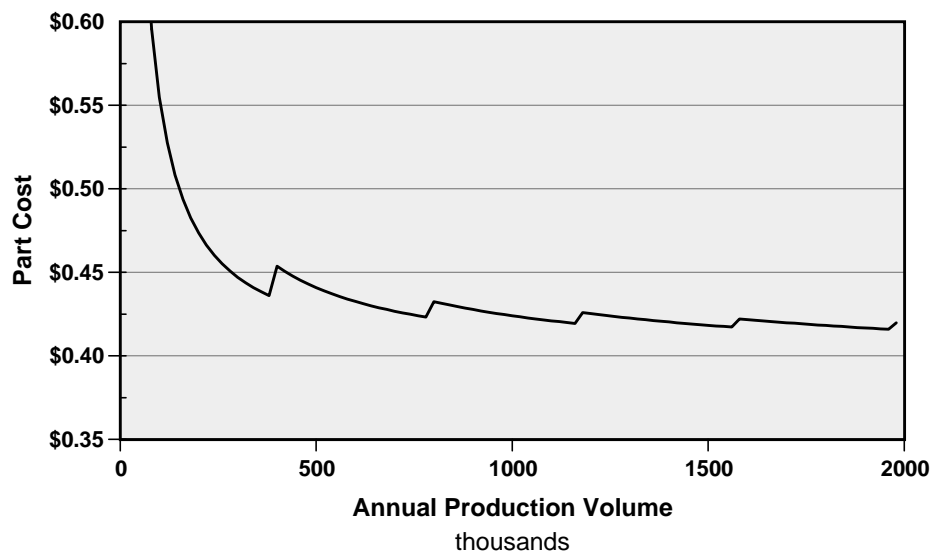
Model Results - Cost Estimate



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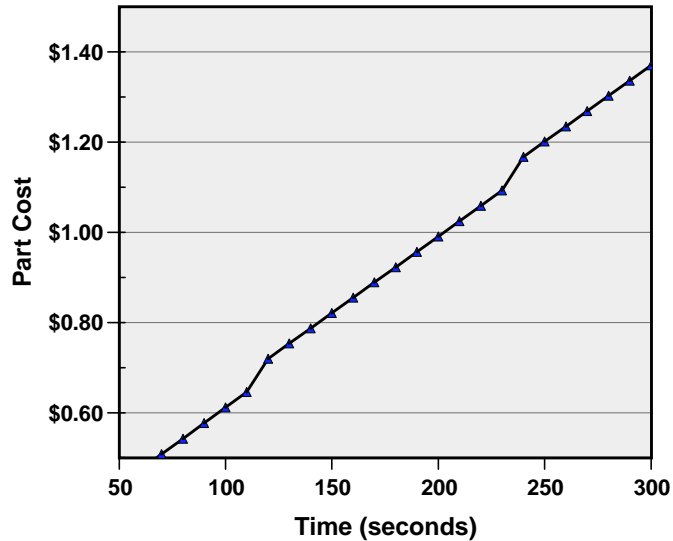
Model Results - Sensitivity to Production Volume



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Model Results - Sensitivity to Cycle Time



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Technical Cost Modeling - Summary

- Systematic Erosion of Complex Problem of Cost Estimation
- Reduction To Set of Simpler Analyses or Explicit Assumptions
- Can Incorporate Engineering Knowledge, Economic Assumptions and Processing Practice, Within A Consistent Framework For Analysis
- Yields Detailed Results -- With All Assumptions Presented and Explicit
- Can Be Readily Customized To Specific Situations

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