Introduction to
Technical Cost Modeling
Concepts and Illustrations

Materials Systems Laboratory
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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 <u>decision variable</u>
  - 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
    - Acqusition/Selling strategies

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 used to define resource constraints on production**

- **Recall how one finds the marginal conditions for production**

maximize $Q = f(X_1, X_2, X_3,...,X_i)$

subject to a budget constraint $B = \Sigma(p_i \times X_i)$

- **Efficiency in production is governed by**
  - –**structure of cost**
  - –**nature of the technology**

(ratio of marginal products to 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 production require the most control (because they most clearly influence total costs)
  - Without information overload on decisionmaker

Cost in Practice --Accounting -- Example

- 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 to use cost for decisions when both economist's abstraction and accounting information are not 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

Needed: A Tool with Formality of Economics & Empiricism of Accounting

- Engineering Needs a Cost Tool to Evaluate:
  - State of Technology ; Current Processing Conditions
  - Value of Research Directions

- Businesses Needs a Cost Tool to Evaluate:
  - Competitiveness of Operations
  - Strategies for Development
  - Investment Needs and Opportunities

- Decisionmakers Need a Tool That:
  - Limits Assumptions
  - Is Explicit About The Assumptions Made
  - Imposes a Consistent Basis fo Comparison & Evaluation

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

Inputs + Estimated Parameters → Cost Estimates

Inputs		Cost Estimates
Part Geometry	??	Material
Part Material		Energy
Production Parameters		Labor
Exogenous Parameters		Equipment
		Tooling
		Maintenance
		Overhead Labor
		Building
		Capital

Evolution of a Cost Model - Injection Molding

- **Conventional Wisdom** ***Part Cost*** **= 2 ×** ***Material Cost***
- **What Is Material Cost?**

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

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

Evolution of a Cost Model - Injection Molding

- **Classical Accounting Perspective:**
  Part Cost = Material Cost + Labor Cost × Burden Rate

- **What is Labor Cost?**
  Labor Cost = Effective Labor Rate × Time To Make A Part

Effective Labor Rate = Labor Wage / Labor Productivity
Time To Make A Part = Cycle Time
Cycle Time = f(Material, Geometry, Technology, ...)

- **Note introduction of elements of: Technology (Cycle Time), Production (Productivity) and Economics (Wage Rate)**
- **What is Burden Rate??? -- Accounting Construct**

Burden Rate

- **Concept Introduced By The Accounting Perspective on Cost Estimation**
- **Based on the Assumption that Physical Plant Must Be Bought To "Maintain" Labor**
- **ThUs: 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**

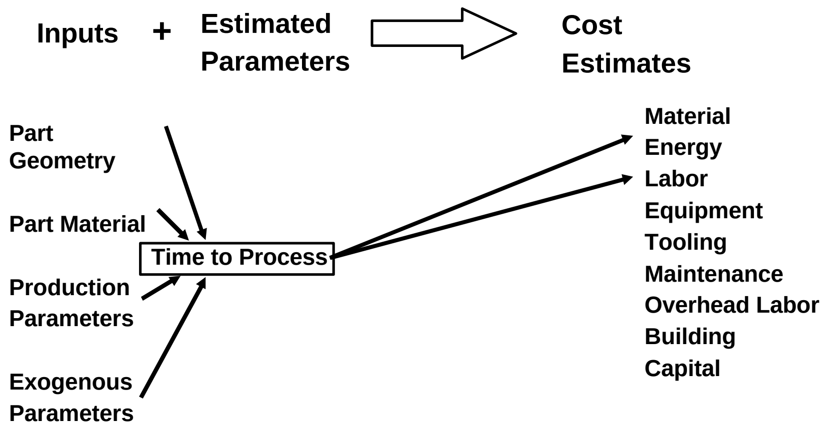
Injection Molding -- Elements of Burden

- 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

Processing Time/Rate Critical to Cost



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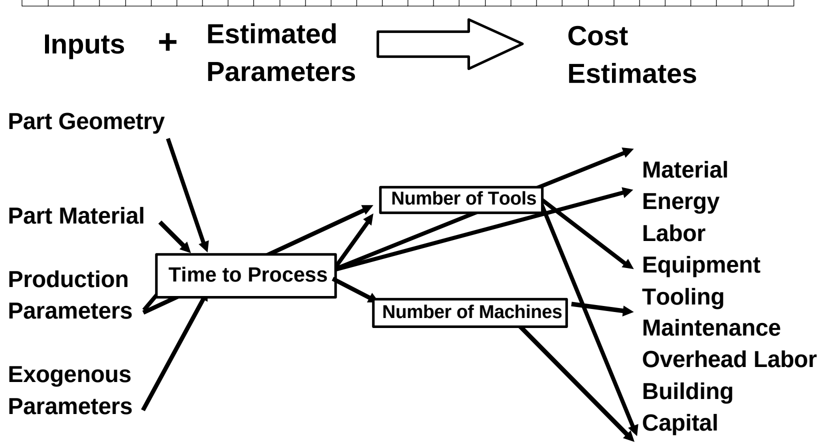
Processing Time/Rate Critical to Cost



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Processing Time 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 = # of Lines

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

Critical Accounting Assumption -- Dedication

Dedicated/Non-Dedicated Equipment Assumption

- If capital equipment is used to manufacture more that one product, the cost of the part should reflect this
- Typically, cost is prorated to the fraction of total operating time required to product 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

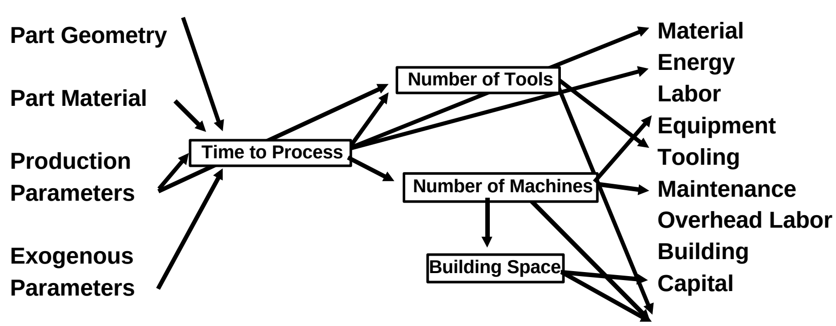
- Capital Costs Must Be Annualized/Amorized to Account for Financing Costs or Opportunity Costs
- Simple Annuity Calculation:

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

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

Processing Time/Rate - Critical To Cost

Inputs + Estimated Parameters ⇨ Cost Estimates



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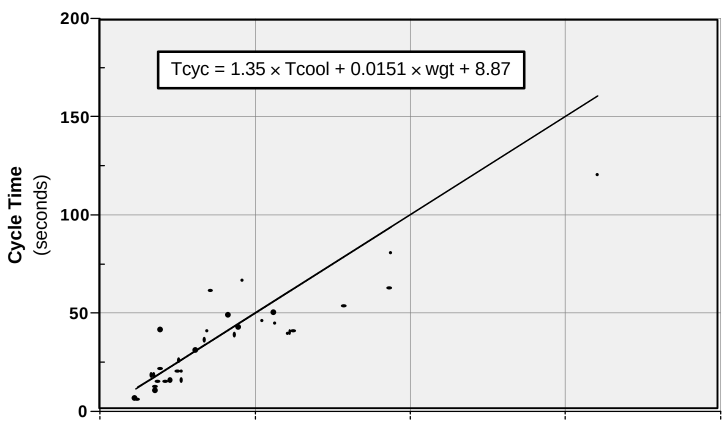
Time To Process A Part - Engineering Parameter

- Combine Engineering and Theoretical Approaches
- Cooling Time - Theoretical Determination

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

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

Cooling Time, Part Weight, Cycle Time Correlation



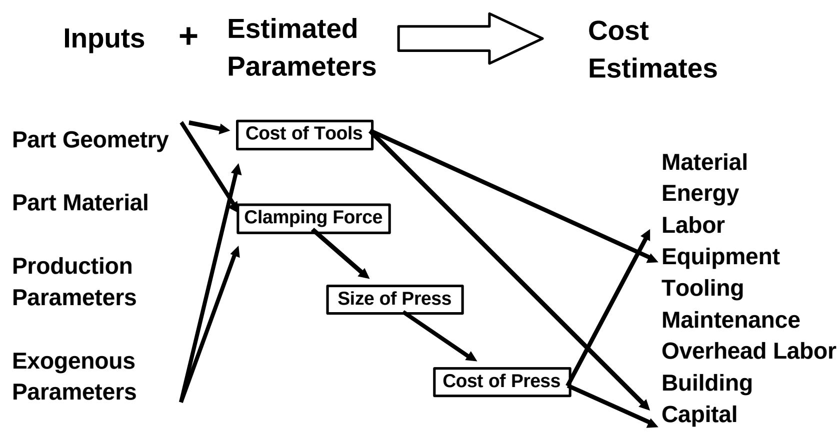
Evolution of a Cost Model - Injection Molding

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

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

- Clamp Force Can Them Be Related To Press Cost

Capital Cost Relationships



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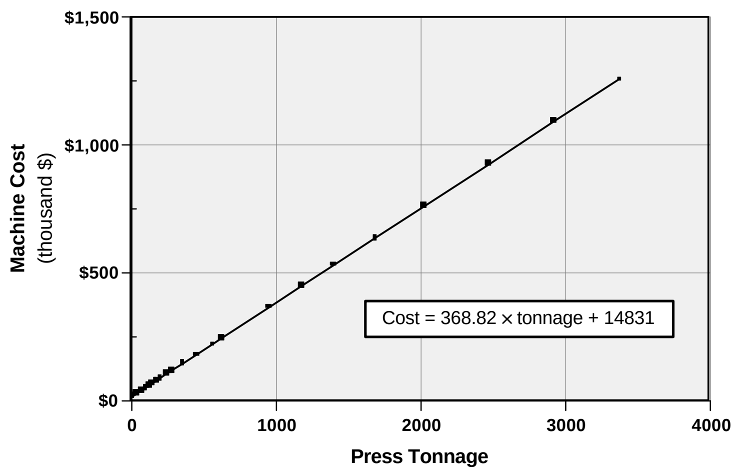
Correlation Between Press Cost and Tonnage



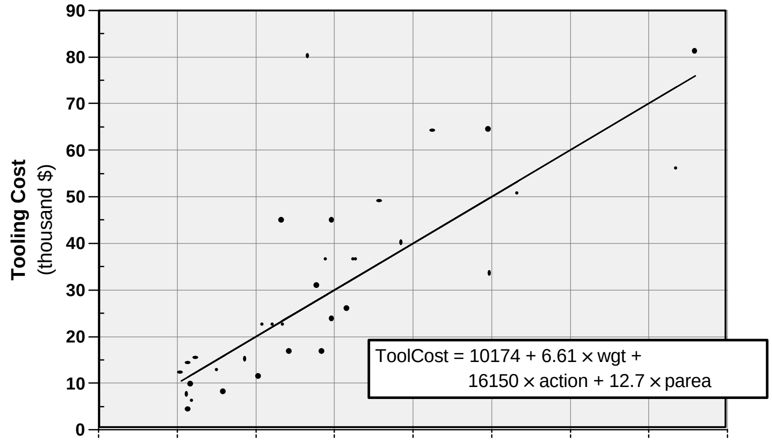
Evolution of a Cost Model - Injection Molding

- **Tooling Cost Estimation Extremely Difficult To Do Reliably**

- **Process Tooling Is Usually**
  - **Customized ; Made By Hand**
  - **Without Consistent Specification or 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**

Tooling Cost Regression Estimates



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 (Molding Pressure)
- Molding Pressure - Function (Resin Being Molded; 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

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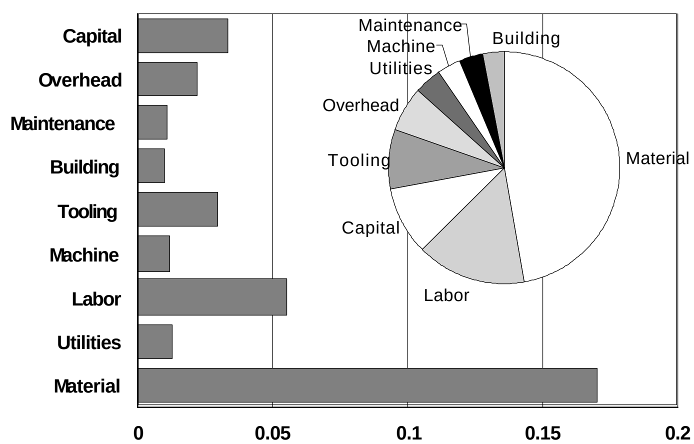
Model Results - Cost Estimate



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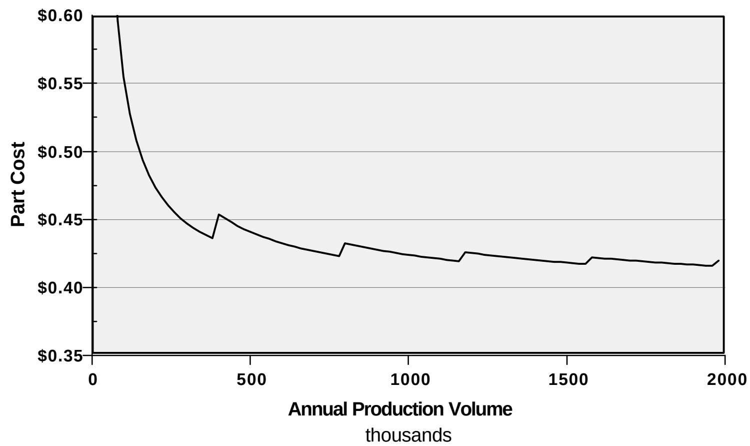
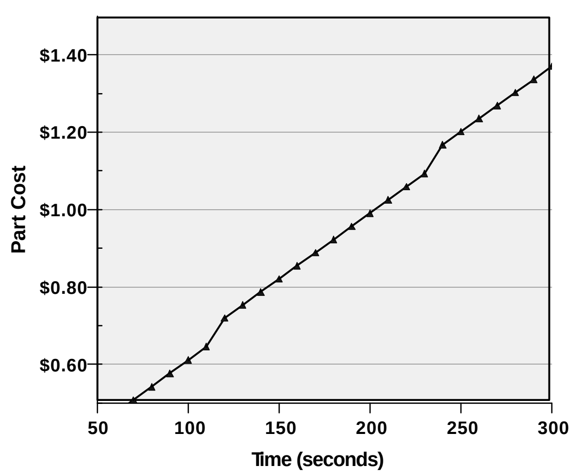
Model Results - Sensitivity to Production Volume



Model Results - Sensitivity to Cycle Time



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