Dynamic Strategic Planning

Introduction to Technical Cost Modeling
Concepts and Illustrations

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Cost Modeling - Introduction

- **Cost as Concept - Neat and Cogent**
  Business
  Economics
- **Cost as Reality - Messy and Unclear**
- **Why?**

Consider Formal Approaches to Cost

- **Business**
  Accounting and Balance Sheets
  Global View of Costs
- **Economics**
  Production Functions and Cost Constraints
  Formal, Mathematical View
- **Both Views Have Strengths, BUT Analytically Limiting**

Consider: What Does It Cost to Manufacture a Product?

- **Buinessman/Accountant's Approach to Part Cost Estimation:**
  Establish Plant as Cost Center
  Track All Expenditures
  Divide All Expenditures by Total Production
  Yielding ⟶ Part Cost
- **Yes, But:**
  Not particularly useful for planning
  Assumes single product manufacture
  Does not provide competitive assessment
  Inadequately handles cost of reusable equipment/tooling

Consider: What Does It Cost to Manufacture a Product?

- Economist's Approach to Part Cost Estimation:
  Devise a production function
  Establish a cost function
  Set up marginal conditions
  Find efficient allocation of resources
  Operate at that level
  Yielding ⟶ Part Cost
- Yes, But:
  What about technological change?
  What about operational limits?
  What about production practice/non-optimal conditions?
  What about competition?

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

- Why?
- Engineer 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

Alternative Approach: Cost Modeling

- **Why "Modeling" Instead of Analysis or Studies or ... ?**
  - Imposition of Structure
  - Incorporation of Knowledge
  - Implementation of Assumptions
  - Inclusion of Technology
- **Cost Modeling Has Its Weaknesses Too**
  - Garbage In - Garbage Out
  - Time Consuming to Develop
  - Expensive - $$$

Conceptual Basis of Cost Model

Inputs + Estimated Parameters → Costs

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

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Evolution of a Cost Model - Injection Molding

- **Conventional Wisdom:**
  Part Cost = 2 x Material Cost
- **What is Material Cost?**

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

- **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 (cont'd)

- **Accounting Perspective:**
  Part Cost = Material Cost + Labor Cost x Burden Rate
- **What is Labor Cost?**
  Labor Cost = Effective Labor Rate x Time to Make a Part

$$\text{Effective Labor Rate} = \frac{\text{Labor Wage}}{\text{Labor Productivity}}$$

Time to Make a Part $\equiv$ Cycle Time
Cycle Time = f(Material, Geometry, Technology,...)

Evolution of a Cost Model - Injection Molding (cont'd)

- 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

Burden Rate

- Concept Introduced by Accounting Perspective on Cost Estimation
- Based upon the Assumption That Physical Plant Must be Bought to "Maintain" Labor
- Therefore, All Other Costs of a Plant Operation are Summed, and Then Divided By Total Labor Hours to Get a Burden Rate

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Burden Rate (cont'd)

- 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 Auxilliary Equip.
- 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!

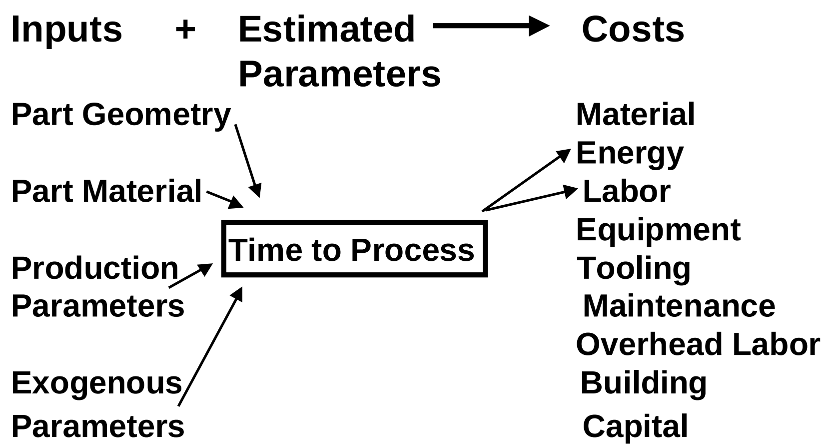
Time as Critical Parameter - Engineering and Practice Driven

- **Time to Process a Part - Underlies Almost All Cost Factors**
- **Directly Affects Key Production Parameters**
  Variable Costs: Labor, Energy
  Fixed Costs: Number of Machines
  Number of Tools

Time as Critical Parameter - Engineering and Practice Driven, (contd)

- **Total Production Time Available - Critical to Capital Costs**
  Number of Shifts
  Number of Days
  Productive Hours in a Shift
  U.S. - 240 Days, 2 Shifts, 6.4 hrs/shift = 3000 hours/year
  Korea - 320 Days, 2 Shifts, 6.4 hrs/shift = 4100 hours/year
  33% better capital utilization immediately!

Processing Time/Rate Critical to Cost



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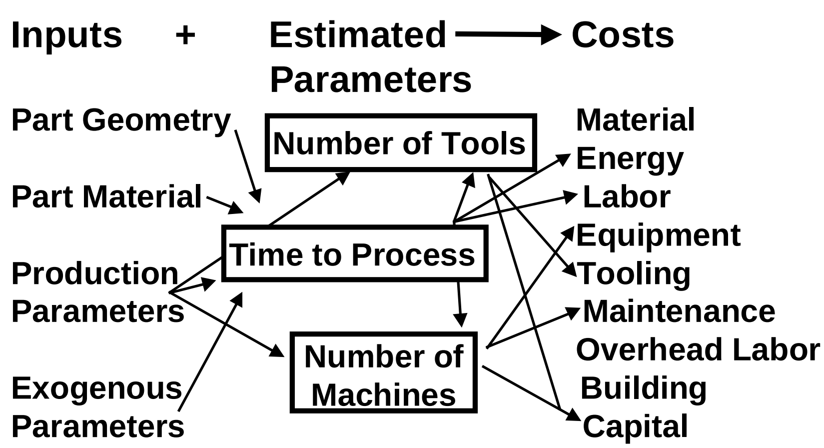
Processing Time/Rate Critical to Cost



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Processing Time and Its Relationship with Capital Costs

- **Number of Machines/Production Lines**

  # of Lines = Cycle Time x Production Volume / Available Processing Time x # of Cavities
  (rounded up to the next integer value)

- **Number of Tools**
  #of Tools = # of Lines

- **Lifetime of Tool**

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

- **Critical Accounting Assumption - Dedication**

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, the Cost is Scaled According to the Fraction of Total Operating Time Required to Produce the Target Production**

Dedicated/Non-Dedicated Equipment Assumption (cont'd)

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

NOTE: This term is substituted for the NUMBER OF LINES term when equipment is assumed not dedicated

- **BUT - Tooling is ALWAYS Dedicated!**

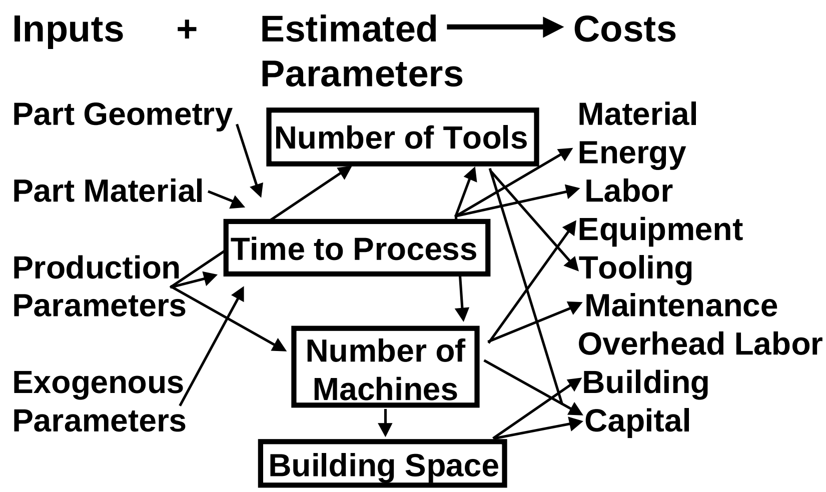
Amortization of Capital Costs

- **Capital Costs Must be Annualized/Amortized to Account for Finance Costs or Opportunity Costs**
- **Simple Annuity Calculation**

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

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

Processing Time/Rate Critical to Cost



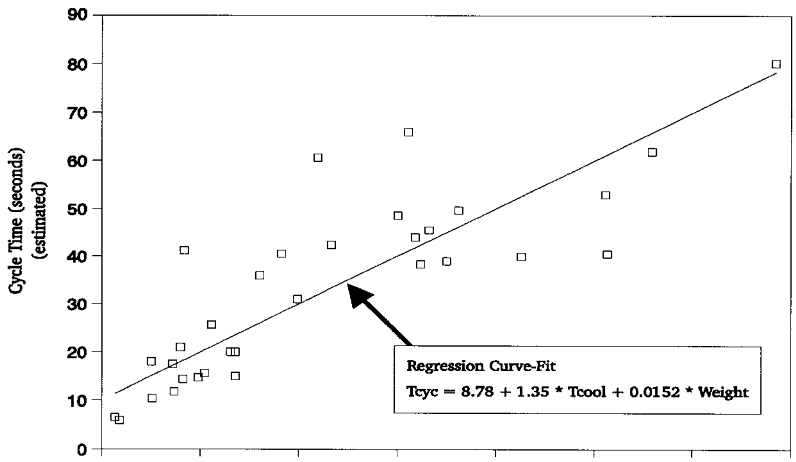
Time to Process a Part - Engineering Parameter

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

$$\text{Cooling Time} = \frac{\rho\, d^2\, Cp}{\pi^2\, k}\ \ln\left[\frac{8 \times (T_{melt} - T_{tool})}{\pi^2 \times (T_{eject} - T_{tool})}\right]$$

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

Cooling Time, Part Weight, and 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

Evolution of a Cost Model - Injection Molding (cont'd)

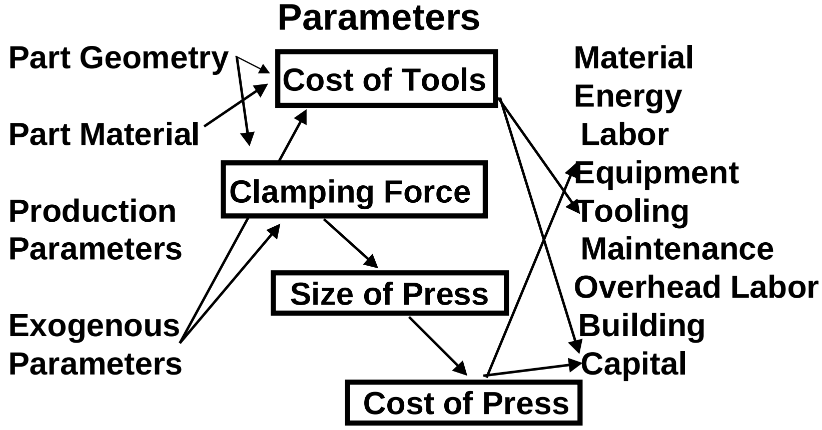
- **Empirical Relation:**

  Clamp Force =
  Proj. Area x $N_{cavities}$ x $\left(\text{¦}\ \frac{224}{\text{nominal wall}} + 172 \right)$

- **Clamp Force Can then be Related to Press Cost**

Capital Cost Relationships

Inputs + Estimated Parameters → Costs



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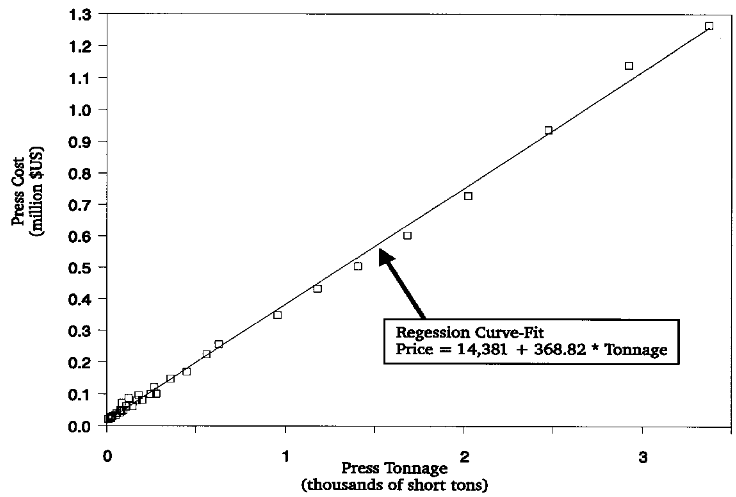
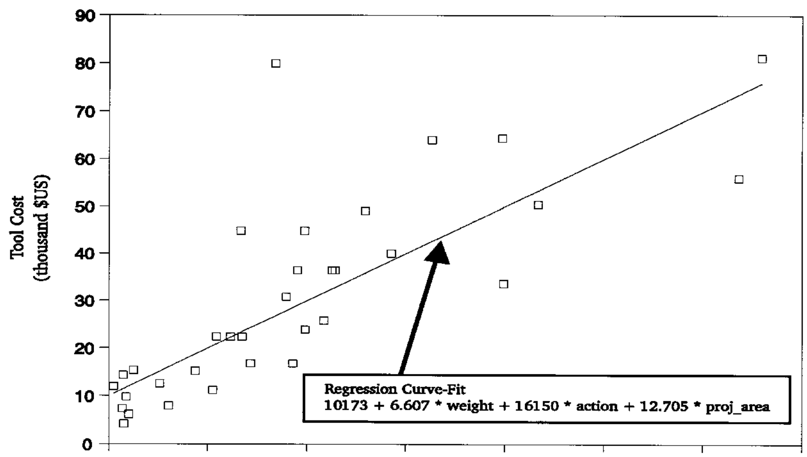
Correlation Between Press Cost and Tonnage



Evolution of a Cost Model - Injection Molding

- **Tooling Cost Estimation - Extremely Difficult to Do Reliably**
- **Process Tooling is Usually:**
  - **Customized**
  - **Made by Hand**
  - **No Consistent Specification**
  - **No Consistent Lifetime**
  - **Subject to Multiple Revisions**
- **Nevertheless, Some Guidelines Can be Established**

Tooling Cost Estimation



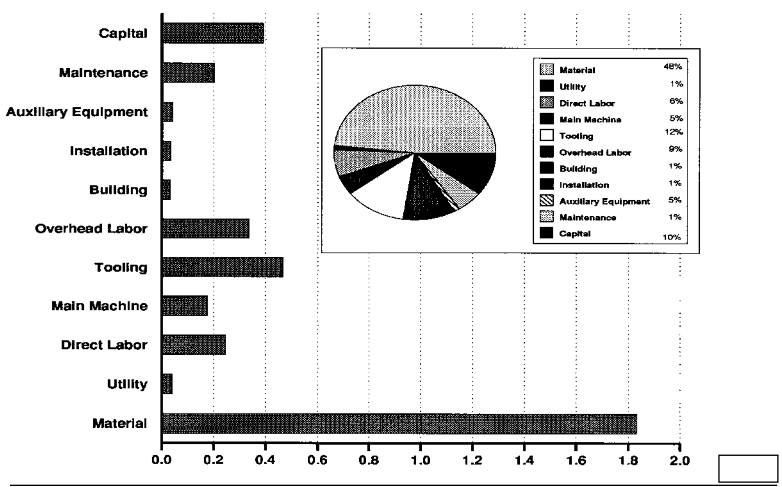
Industry Practice Parameters

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

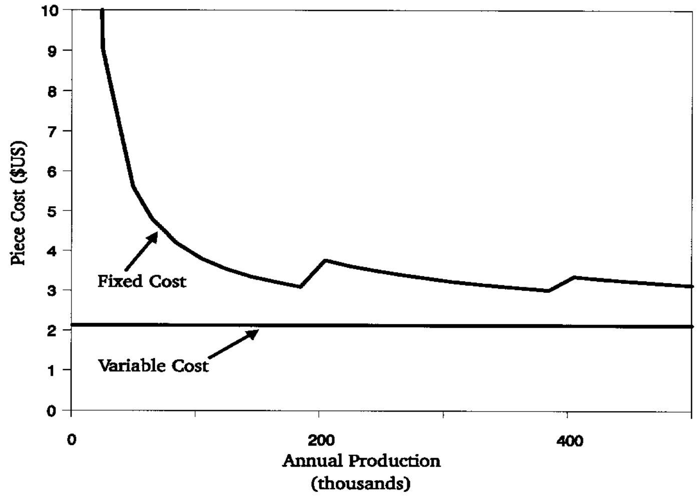
Elimination of Burden

- 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

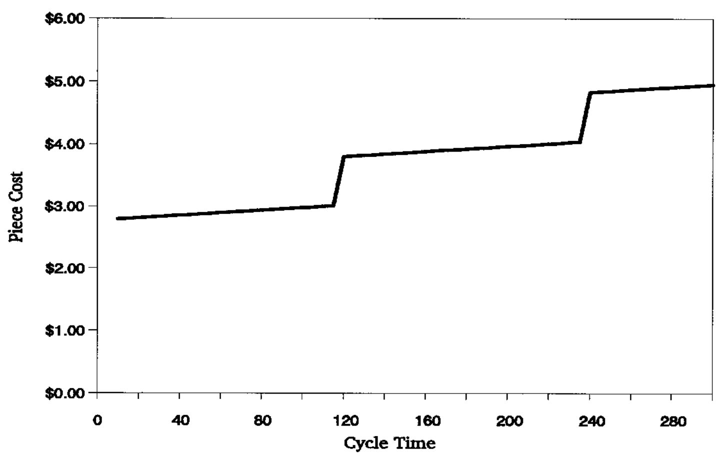
Model Results - Cost Estimate



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 Similar Analyses or Explicit Assumptions**
- **Can Incorporate Engineering Knowledge, Economic Assumptions, and Processing Practice Within a Consistent Framework for Analysis**

Technical Cost Modeling - Summary (cont'd)

- **Yields Detailed Results - With All Assumptions Presented**
- **Can be Readily Customized to Specific Situations**