# 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*
    - *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 is 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 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

# 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 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
  - Garbase In, Garbage Out
  - Time Consuming to Develop
  - Expensive -- $$$

# Conceptual Basis of Cost Model

| Inputs | + | Estimated Parameters | → | Cost Estimates |
|---|---|---|---|---|
| Part Geometry<br>Part Material<br>Production Parameters<br>Exogenous Parameters | | ?? | | Material<br>Energy<br>Labor<br>Equipment<br>Tooling<br>Maintenance<br>Overhead Labor<br>Building<br>Capital |

# Evolution of a Cost Model - Injection Molding

- Conventional Wisdom

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

- What Is Material Cost?

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

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

# 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 $\times$ Time To Make A Part**

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

**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

# 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

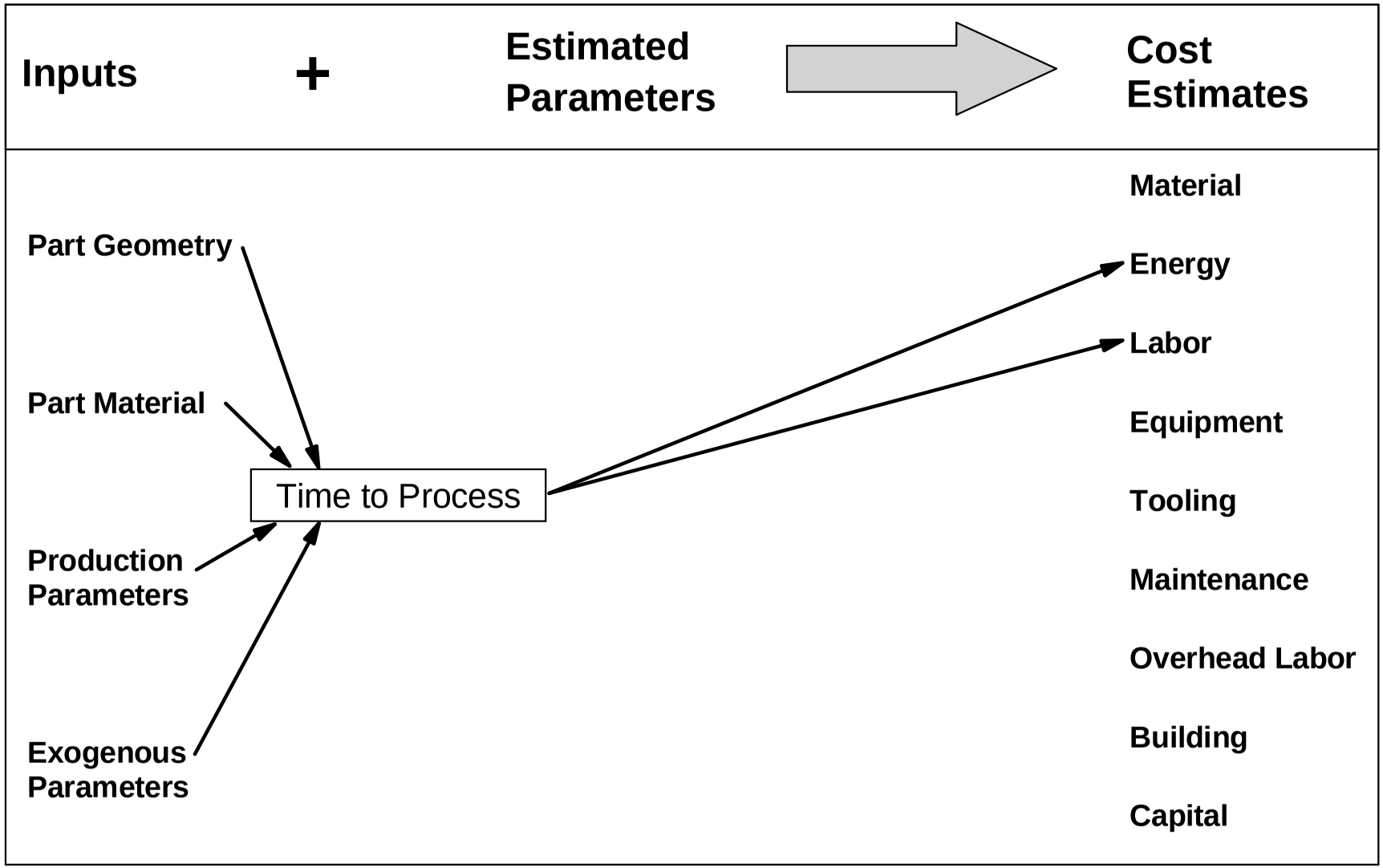
- Time To Process a Part - Underlies Almost All Cost Factors
- Directly Effects Key Production Parameters
  - Variable Costs:
    - *Labor*
    - *Energy*
  - Fixed Costs
    - *Number of Machines*
    - *Number of Tools*
- Total Production Time Available -- Critical To Capital Cost Allocations
  - Number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

**Example of Differences In Time of Equipment Use**

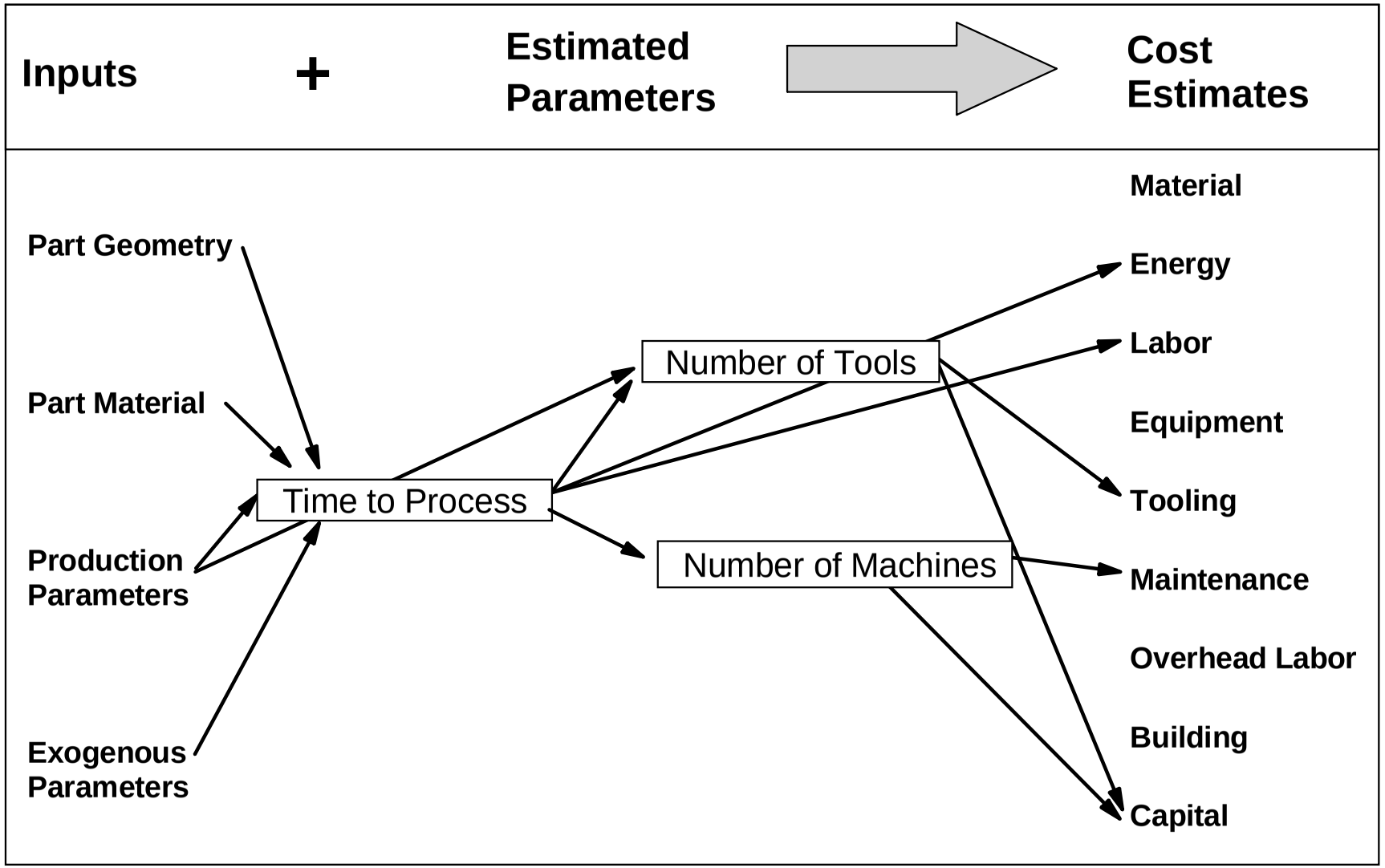
| | US | Korea |
|---|---|---|
| **days/shift** | 240.0 | 320.0 |
| **shifts/day** | 2.0 | 2.0 |
| **hrs/shift** | 6.4 | 6.4 |
| **total hrs/yr** | 3,000.0 | 4,100.0 |

**33% Better Capital Utilization In Korea**

# Processing Time/Rate Critical to Cost



# Processing Time/Rate Critical to Cost



# 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

# Dedicated/Non-Dedicated Equipment Assumption

- If a piece of capital equipemnt is used to manufacture more that one product in a year, the cost of the part should reflect this
- Typically, cost is scaped according tot he 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 thie number of lines term when equipment is assumed not dedicated
- But - Tooling is ALWAYS dedicated

# Amortization of Capital Costs

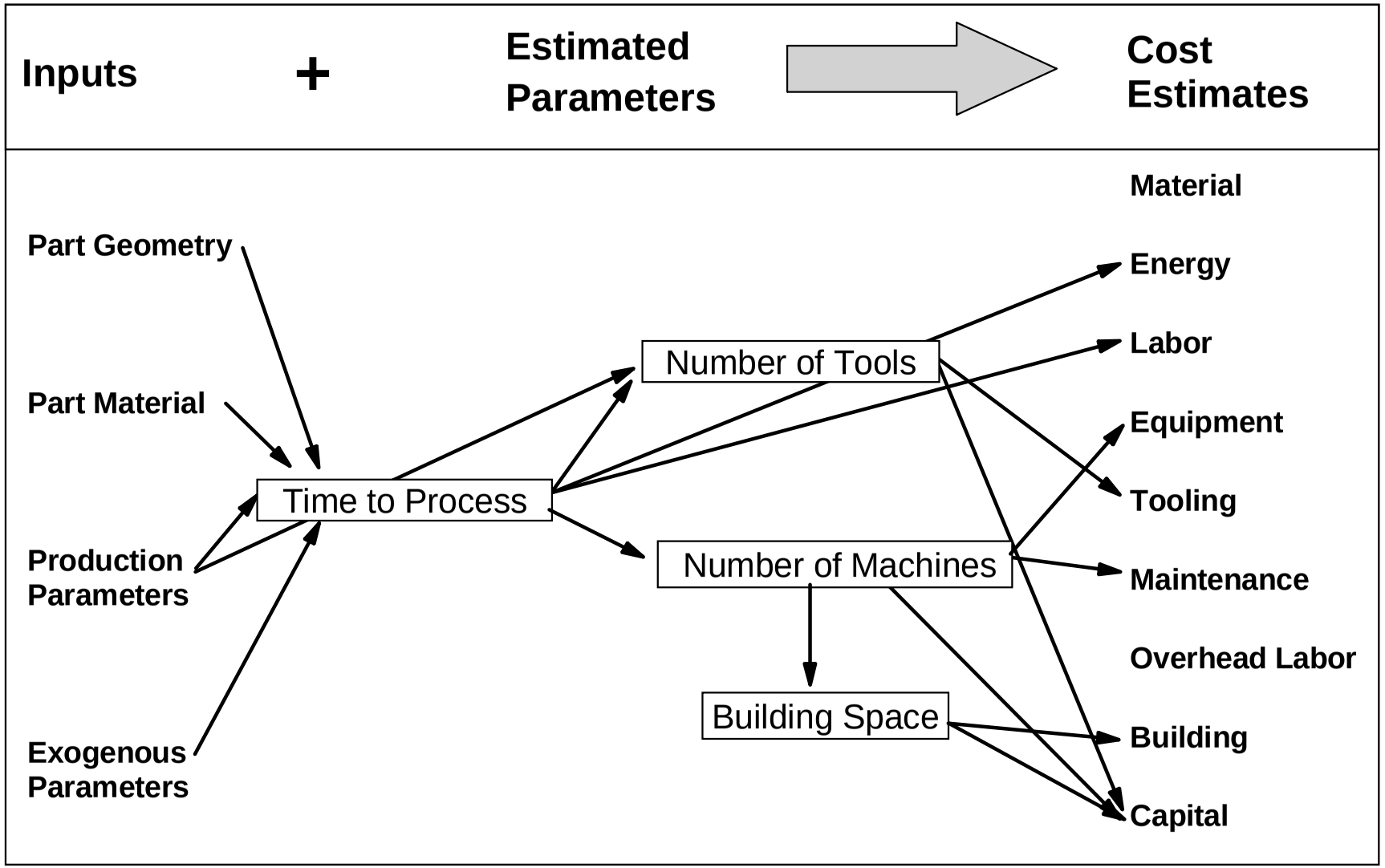
- Capital Costs Must Be Annualized/Amorized to Account for Financing Costs or Opportunity Costs

- 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 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



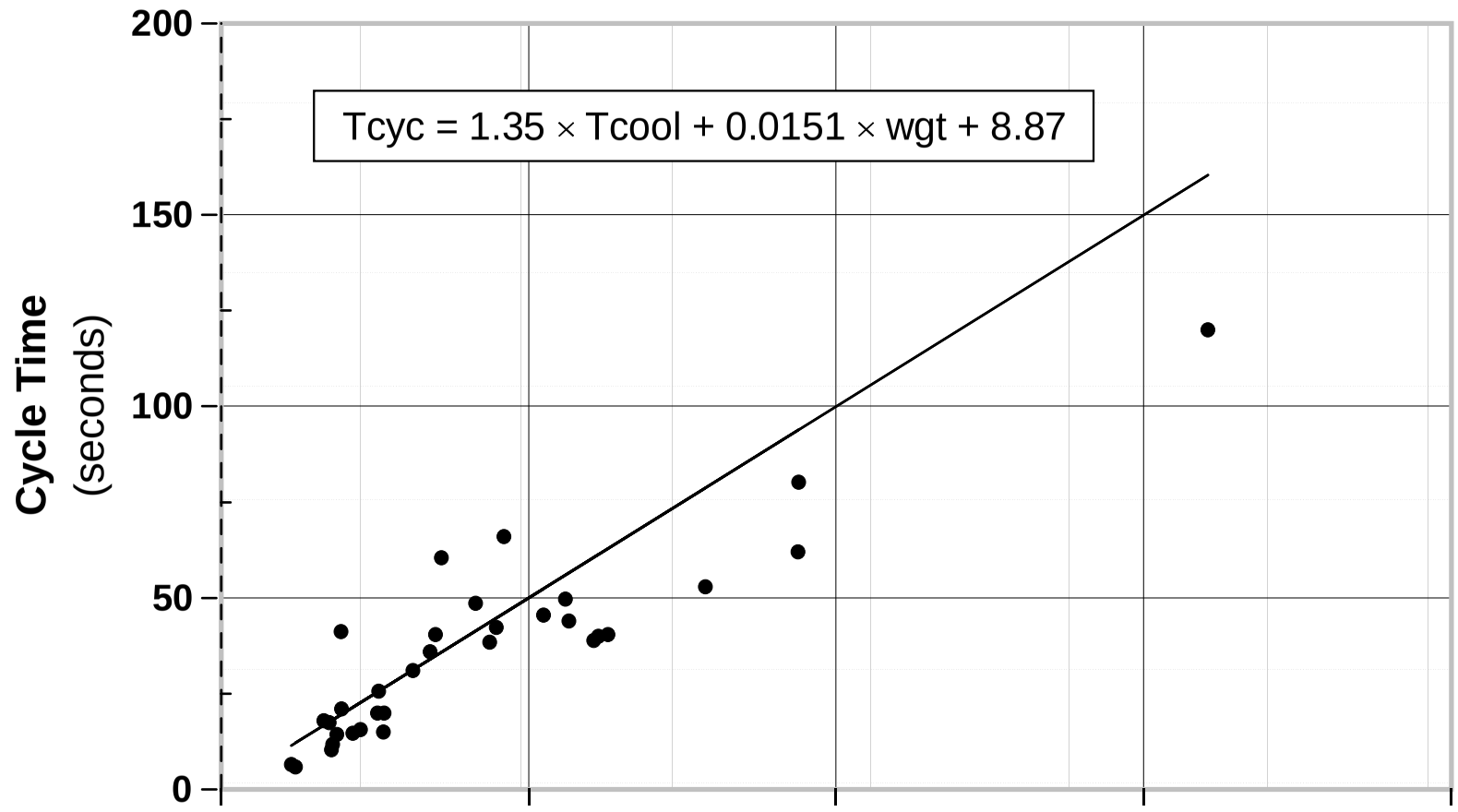
# Time To Process A Part - Engineering Parameter

- Use Combination of 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 of Shot Size - Function of Part Weight
- Mold Cycle - Function of Press Size, Bu tLikely A Small Variation
- Cannot Expect Perfect Match To Theory, So Try To Correlate

# Cooling Time, Part Weight and Cycle Time Correlation



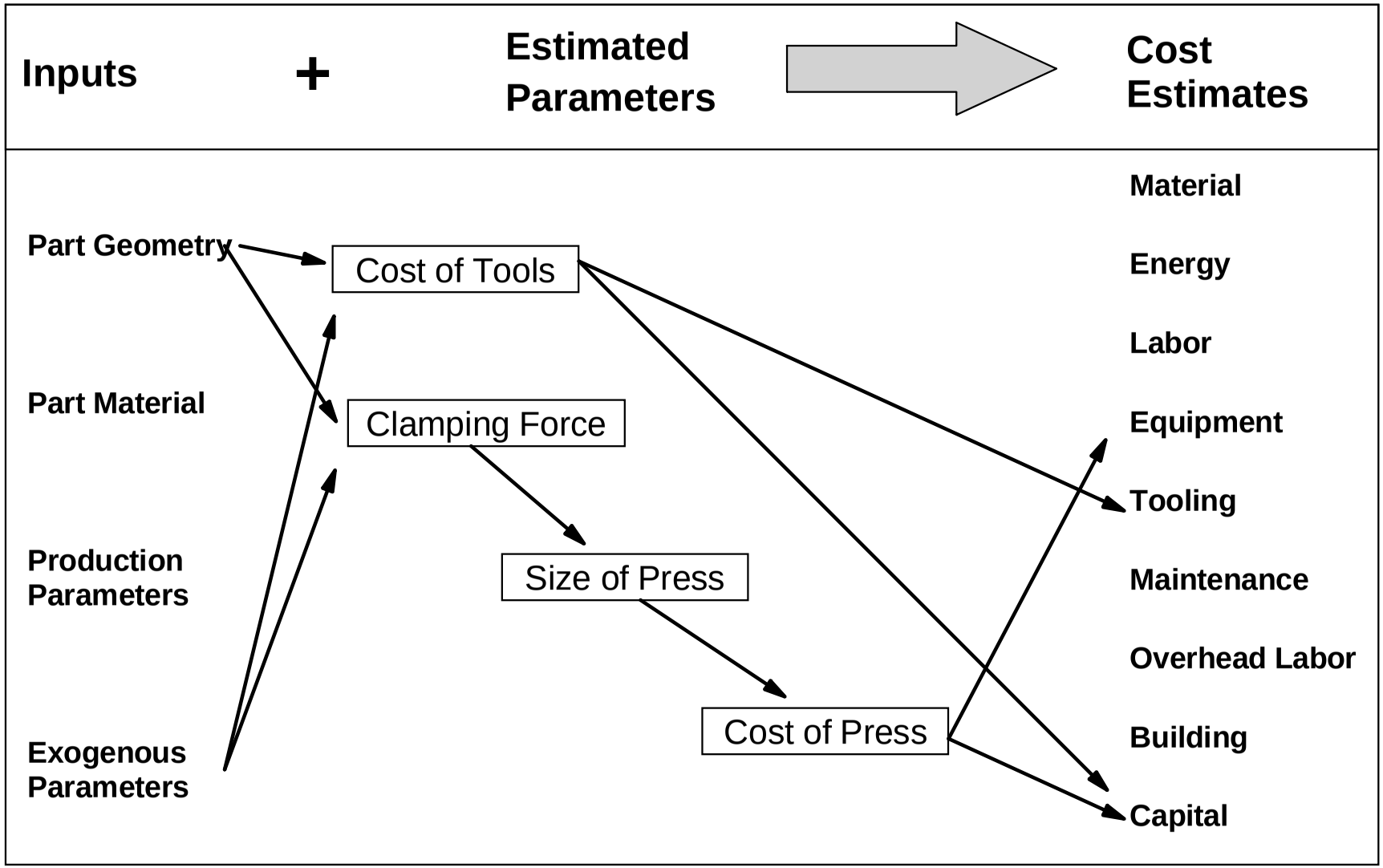
# Evolution of a Cost Model - Injection Molding

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

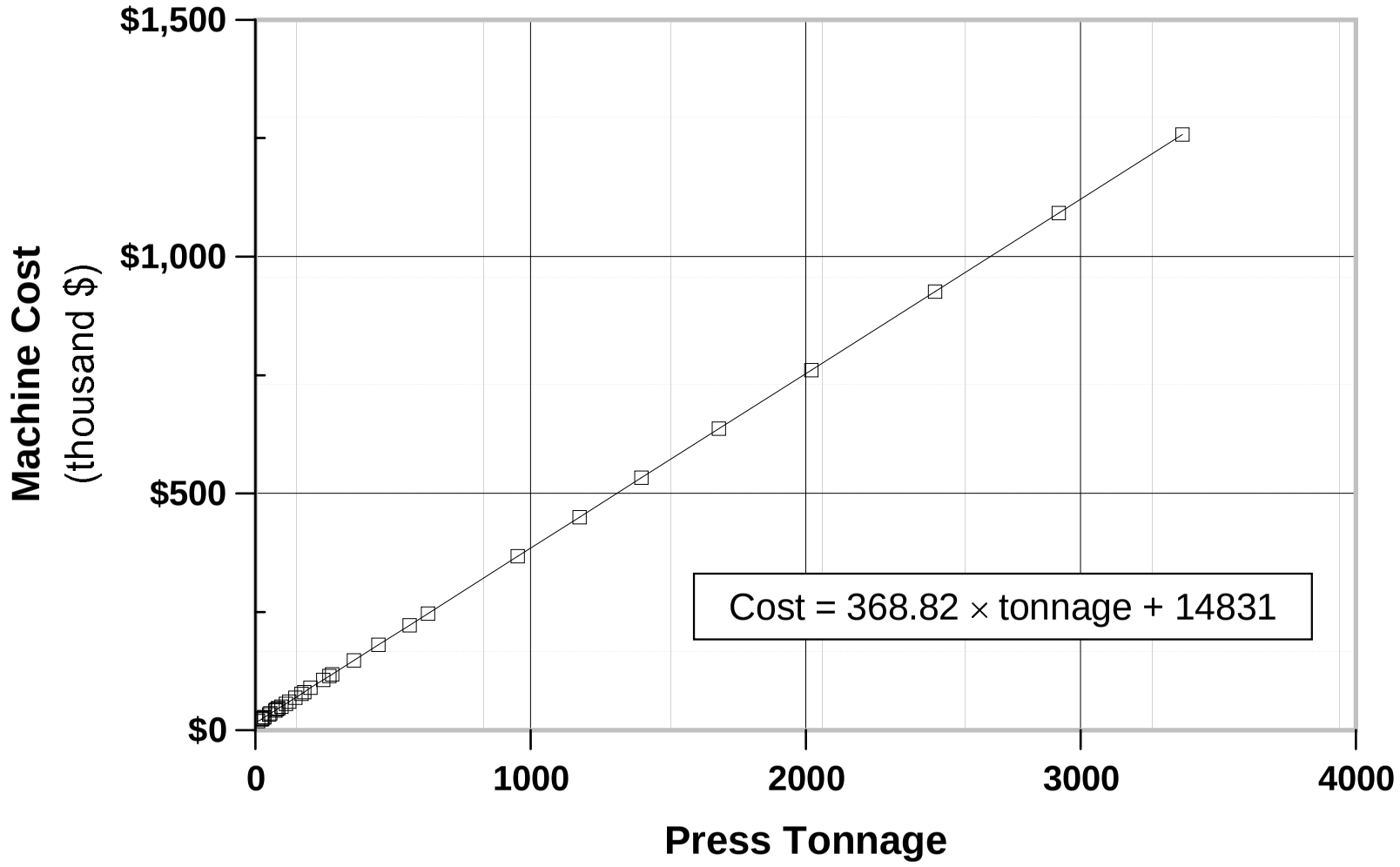
$$\text{Clamp Force} = \text{Projected Area} \times N_{cavities} \times \frac{224}{\sqrt{nominal\ wall}} + 172$$

- Clamp Force Can Them Be Related To Press Cost

# Capital Cost Relationships



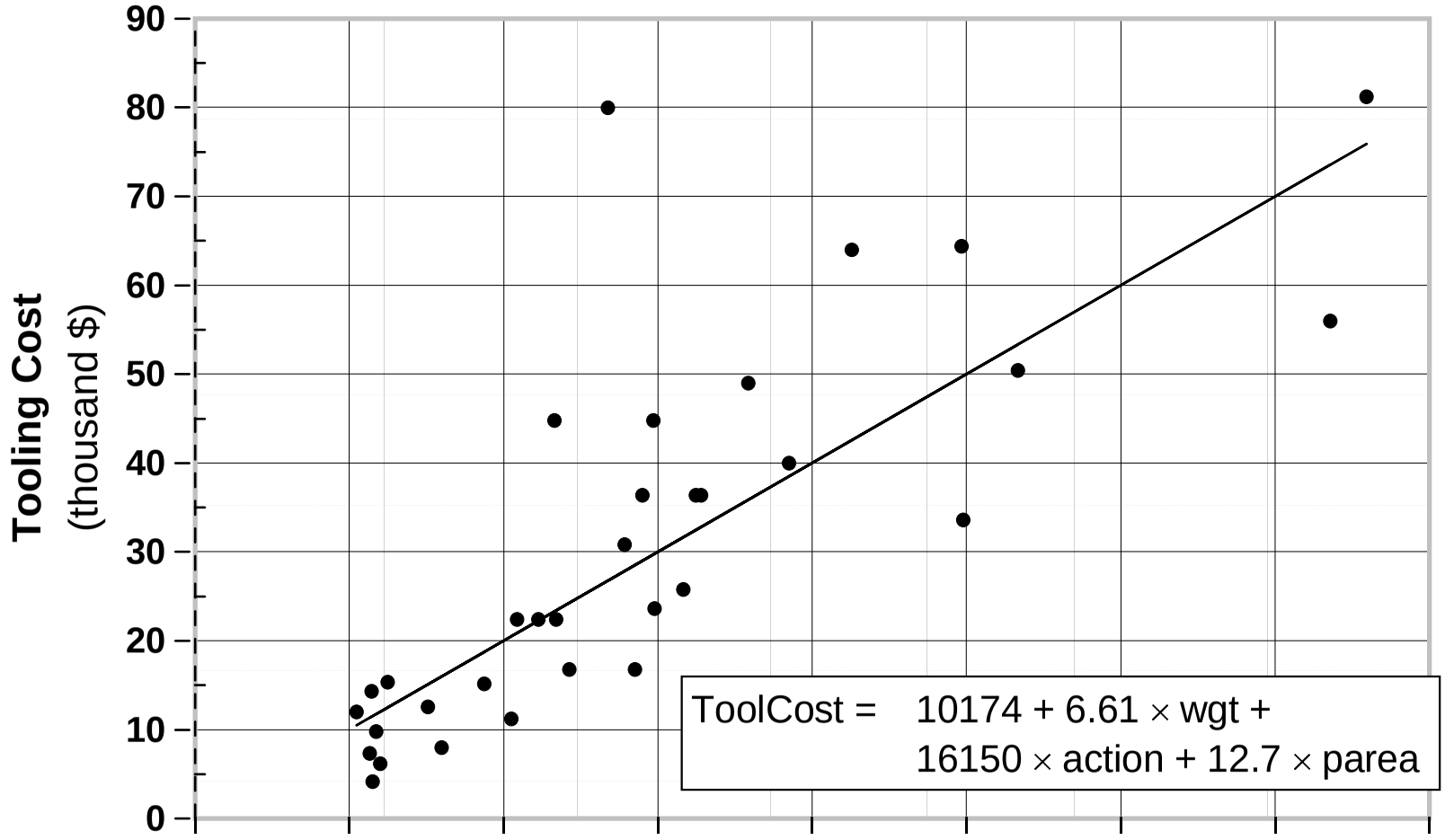
# Correlation Between Press Cost and Tonnage



# 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
  - 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

# Tooling Cost Regression Estimates



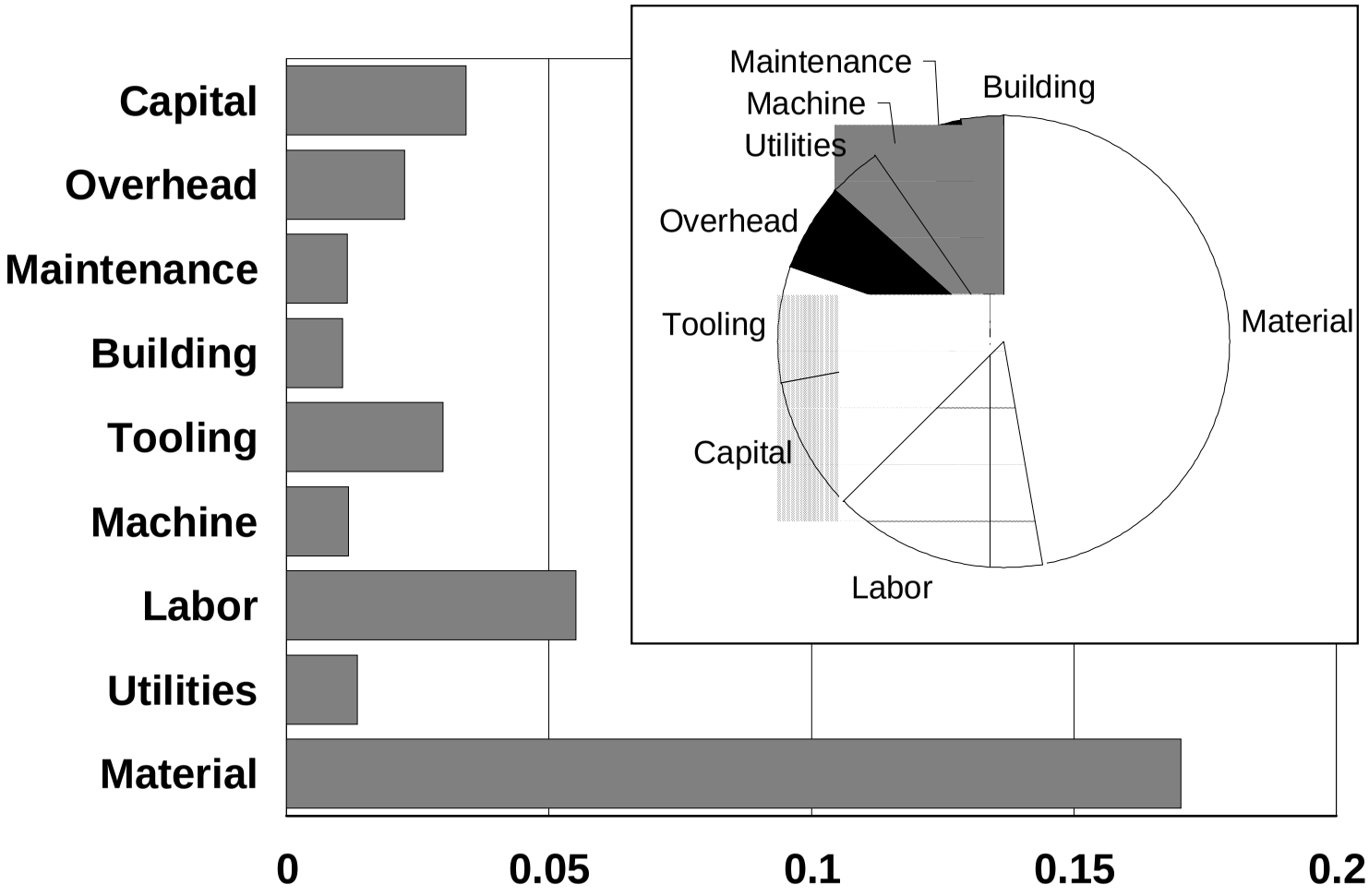
# Industry Practice Parameters

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

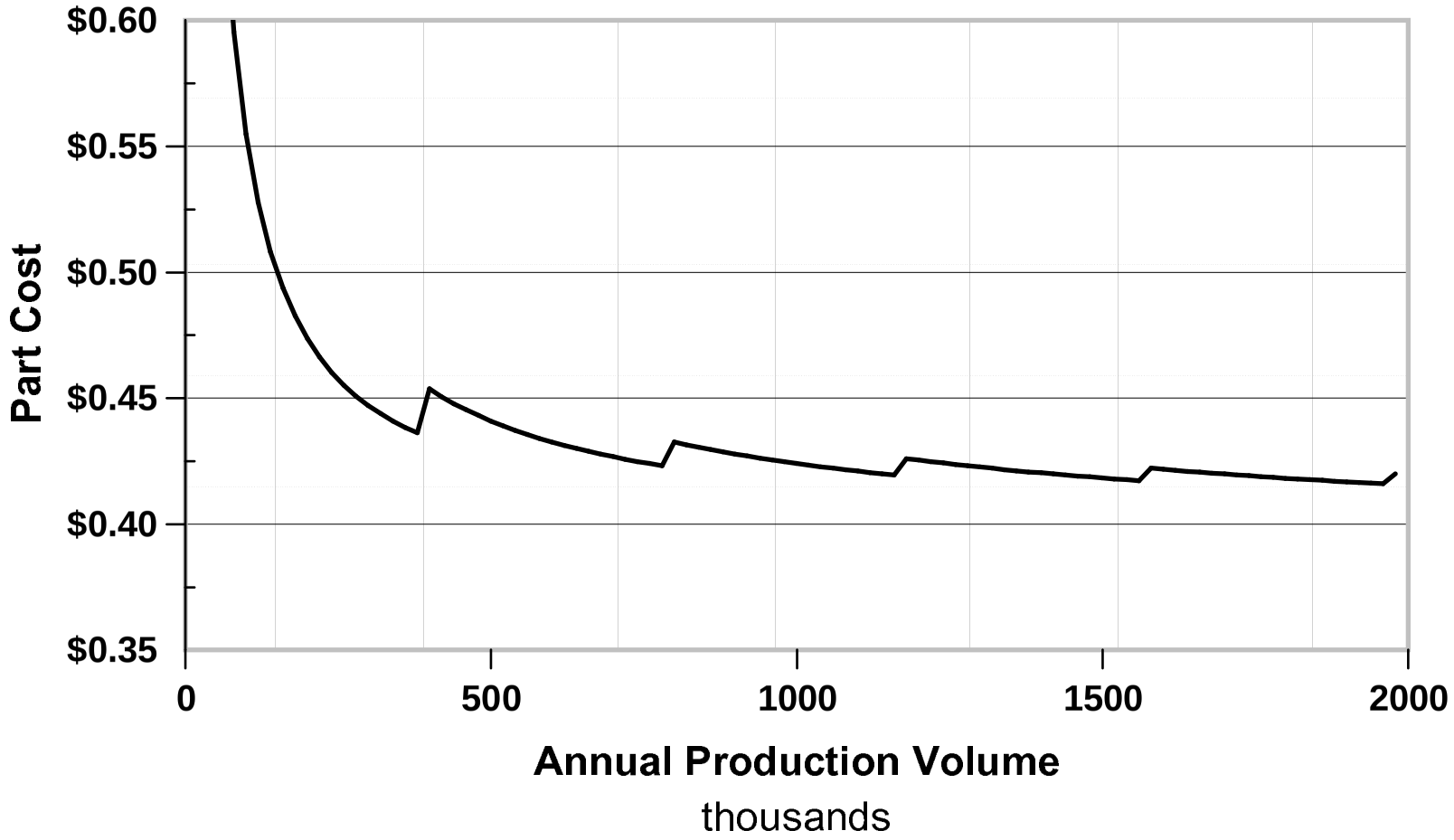
# Elimination of Burden - Example

- Injection Molding Machine Size - Function 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

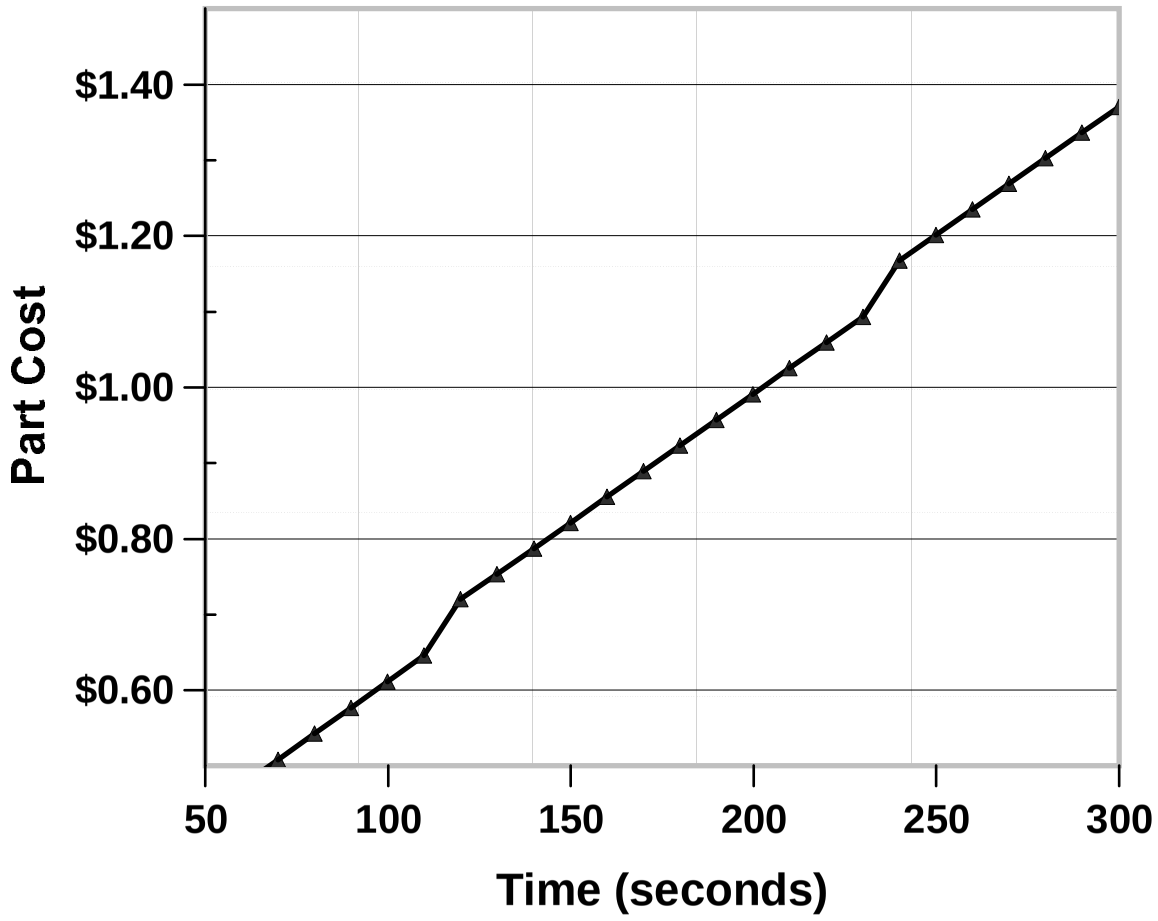
# Model Results - Cost Estimate



# 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 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