Fundamentals of Process-Based Cost Modeling

3.56 Special Session One

Session Goal & Outline

- Goal:
  Understand the basic steps necessary to create a process-based cost model used to educate strategic technology choices

- Topics Covered
  - Define Question to be Answered
  - Identify Relevant Cost Elements
  - Relate What is Known to Cost
    - *Identify What is Known*
    - *Establish Contributing Factors*
    - *Determine Required Factor Quantity*
    - *Determine Price of Allocation*
  - Understand Uncertain Characteristics

Review of Process-Based Cost Model (PBCM)

- Objective
  - Map from Process Description to Operation Cost
- Purpose
  - Inform decisions amongst technology alternatives BEFORE operations are in place
  - et al. ....

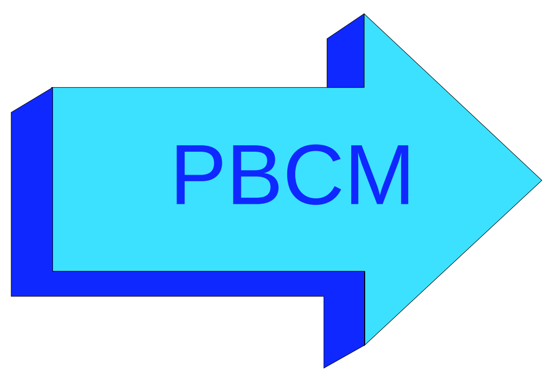
Process Description

Part Description

Material Properties

Economic Characteristics

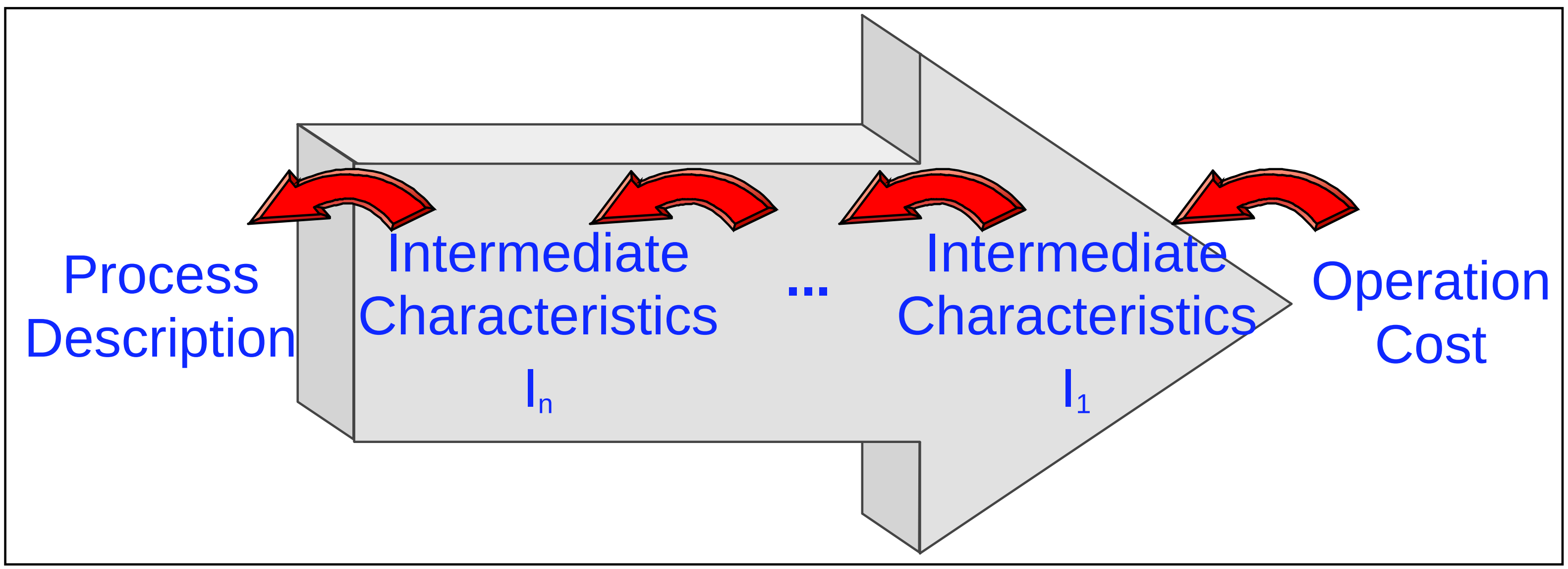
Operation Variables



Operation Costs

Creating a PBCM: Overview

- Models are created by decomposing problem from cost backwards
  - Determine what characteristics, I_1, effect cost
  - Determine what characteristics, I_2, effect I_1 ... and so on until...
  - Determine how process description effect I_n



★ Model works from inputs to costs <> Modeler works from costs to inputs

Cost Modeling: Nomenclature, Notation, & Necessities

- Operation Cost
  - Cost is generally measured as one of two rates

    C^u — per unit

    C^t — per time period
  - The denominator of the cost rate will be referred to as its **basis**
- Cost Element
  - Cost elements are the distinct categories of cost which together sum to the Total Operation Cost
    - *e.g. Materials Cost, Direct Labor Cost, Energy Cost*
- Factor
  - Any product of service, required to produce, for which money must be spent

Creating a PBCM: Critical Steps

1. Define Question to be Answered
2. Identify Relevant Cost Elements
3. Relate What is Known to Cost
   - Identify What is Known
   - Establish Contributing Factors
   - Determine Required Factor Quantity
   - Determine Price of Allocation
4. Understand Uncertain Characteristics

Creating a PBCM: Step One

1. Define Question to be Answered
   - Cost of What?
   - Cost to Whom?
   - Cost When?
   - Cost Varying How?
   - Cost Compared to What?
     - *Relative to Other Options*
     - *Absolute Measure of Operation*

★ More than any physical measure cost is fully dependent on context
- Cost estimation requires exhaustive definition of context

Creating a PBCM: Step Two

2. Identify Relevant Costs
   - Pertinent to Decision
   - Necessary for Completeness / Credibility

Common Elements of Manufacturing Cost

Material	Tooling
Energy	Overhead
Labor	Building
Equipment	Transportation
Marketing	Packaging
Advertising	Insurance

Exclude Unimportant Elements

Common Relevant Cost Elements

Material	Tooling
Energy	Overhead
Labor	Building
Equipment	~~Transportation~~
~~Marketing~~	~~Packaging~~
~~Advertising~~	~~Insurance~~

Creating a PBCM: Step Three - *The Real Deal*

3. Relate Costs to What is Known
   - What will You Know?
     - *Engineering principles underlying process*
     - *Factor prices*
     - *Design Concept*
     - *Design Specifications* ***
   - General Form of Relationship

$$C^x = \sum_{\text{all } i} c_i^x$$

$$c_i^x = \sum_{\text{all } f} (Q_f^x \times P_f^x)$$

   - *i = Cost Element, f = Factor*

Step Three - *Identify Factors*

3. Relate Costs to What is Known

$$c_i^x = \sum_{\text{all } f} (Q_f^x \times P_f^x)$$

A. Describe Factors which Contribute to Each Cost Element

- *Fixed:*
  - ► *Electricity*
  - ► *Laborers*
- *Variable:*
  - ► *Resin used*
- *Design Dependent:*
  - ► *Inj. Molding Press Clamping Force = f(Part Size, Number of Cavities)*

★ Whenever feasible, forecast type of factor used based on design specs

Step Three - *Understand Quantity & Price*

3. Relate Costs to What is Known

$$c_i^x = \sum_{\text{all } f} \left(Q_f^x \times P_f^x \right)$$

B. Relate Quantity to Process & Design
   - *Quantity of Factor f required to produce the number of parts for the basis u*

C. Relate Factor Price to Process & Design
   - *Price allocated to use a unit of Factor f for the basis u*

★ Basis u should be chosen to facilitate calculating Q and P

Variable vs. Fixed Costs

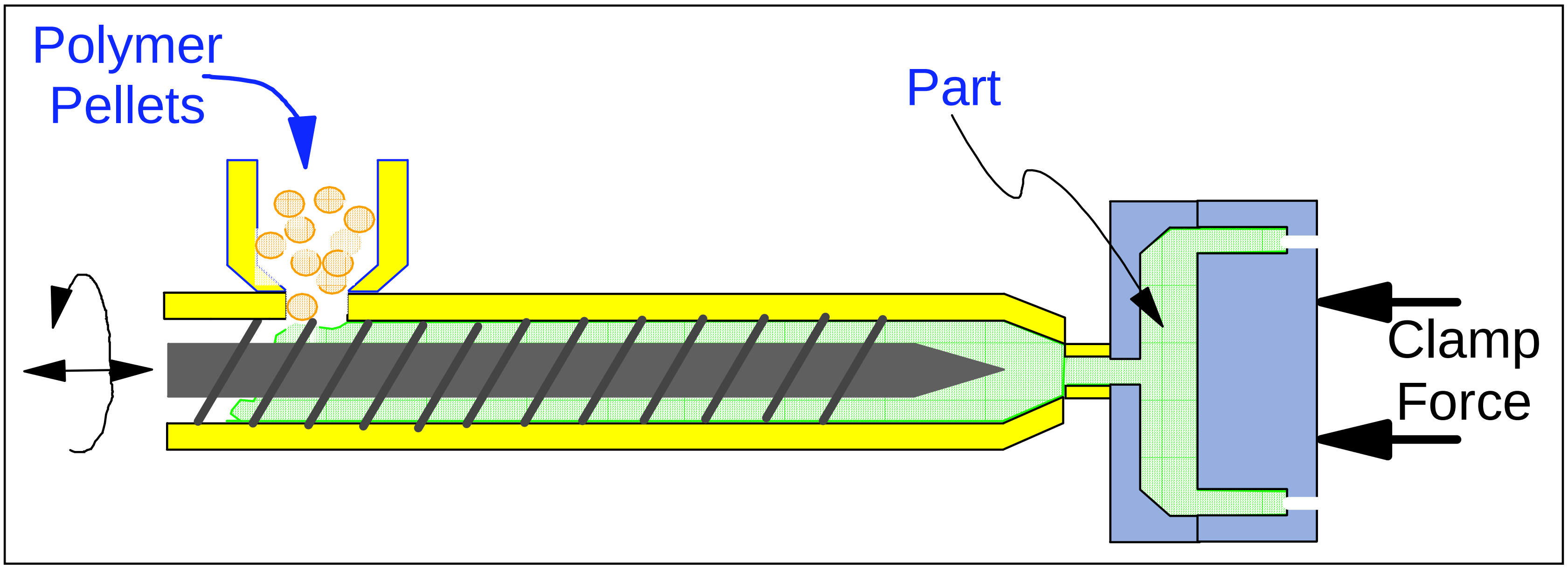
3. Relate Costs to What is Known

$$c_i^t = \sum_{\text{all } f} (Q_f^t \times P_f^t)$$

- **Per period** element cost form two categories
  - *Variable Cost*
    - ► *Those directly proportional to production volume in that period*
  - *Fixed Cost*
    - ► *(Obviously) Those little influenced by production volume*
- This behavior influences convenient basis for cost
  - *Variable*
    - ► *Calculate Per Unit*
  - *Fixed*
    - ► *Calculate Per Period*

Modeling Specific Cost Elements

- Case Study: Polymer Injection Molding (PIM)
  - Conceptually simple process
    1. *Melt polymer feedstock*
    2. *Inject into mold*
    3. *Cool*
    4. *Remove Part*



PIM Example - Material Cost

Rem: $c^u_{matl} = Q^u_f \times P^u_f$

- Variable Cost:
- Factor Required: Polymer Pellets
  - Factor Type: Design Dependent
- Q_f = (Material in Part) + (Other material used)

(Material in Part) = (Part Volume) x (Density) or (Mass of Part)

(Other material used) = Scrapped Parts + Delivery Material + Finishing Scrap - Reusable Material

$$= \frac{\text{(Mass of Part)}}{\text{(1 - Scrap Rate)}}$$

- P_f = Price of Polymer Pellets

PIM Example - Labor Cost

- Variable Cost
- Factor Required: Polymer Industry Labor
  - Factor Type: Fixed
- $Q_f = \frac{\text{Laborers per Line}}{\text{Parts per Line}} \times (\text{Time To Make A Part} + \text{Other Time})$

  Parts per Line → # Cavities in Mold

  Time To Make A Part → Cycle Time

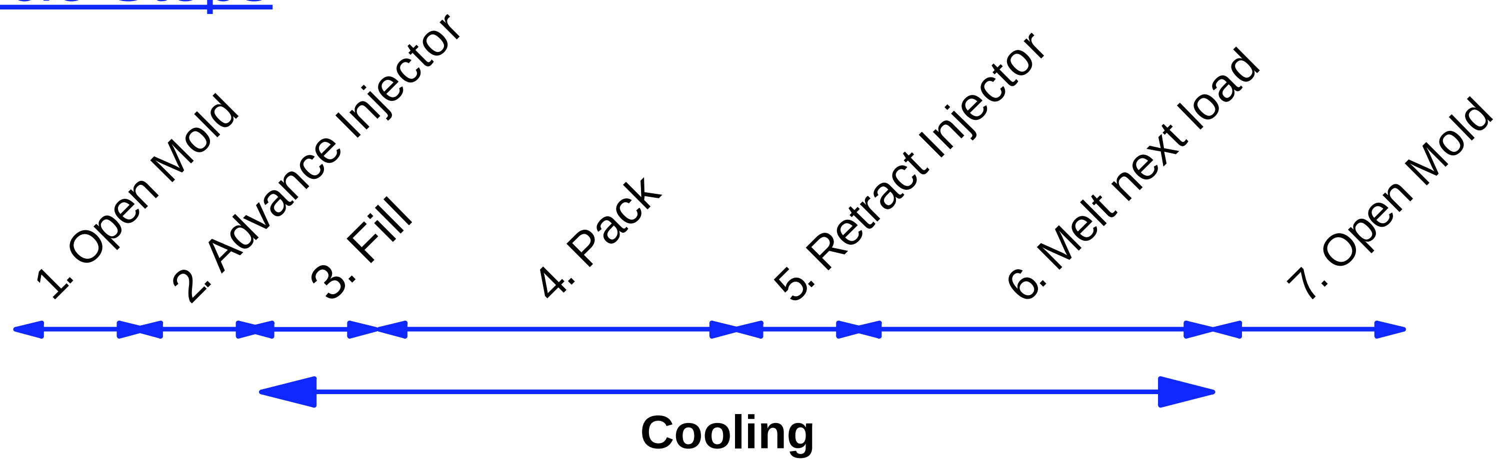
  Other Time → Maintenance + Breaks + General Inefficiency

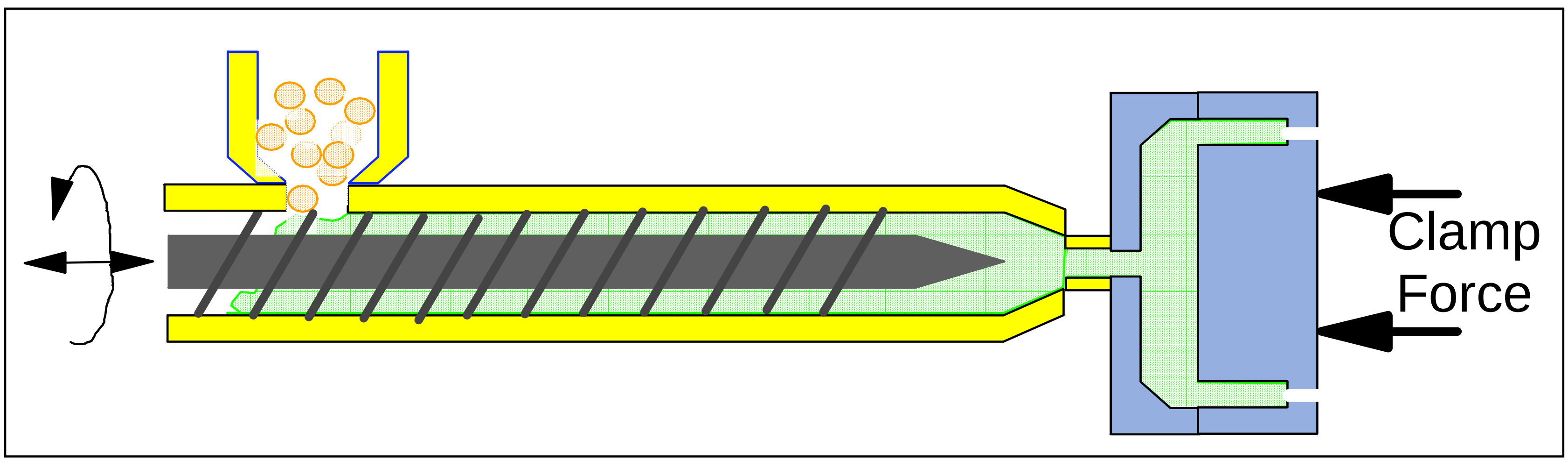
  Cycle Time = f(Material, Geometry, Technology, ...)

- P_f = Total Labor Wage

Injection Molding Cycle Time

Cycle Steps





Cycle Time - Engineering Parameter

- Use Combination of Engineering and Theoretical Approaches
  - Cycle Time = (Filling Time) + (Cooling Time) + (Cycle Reset)

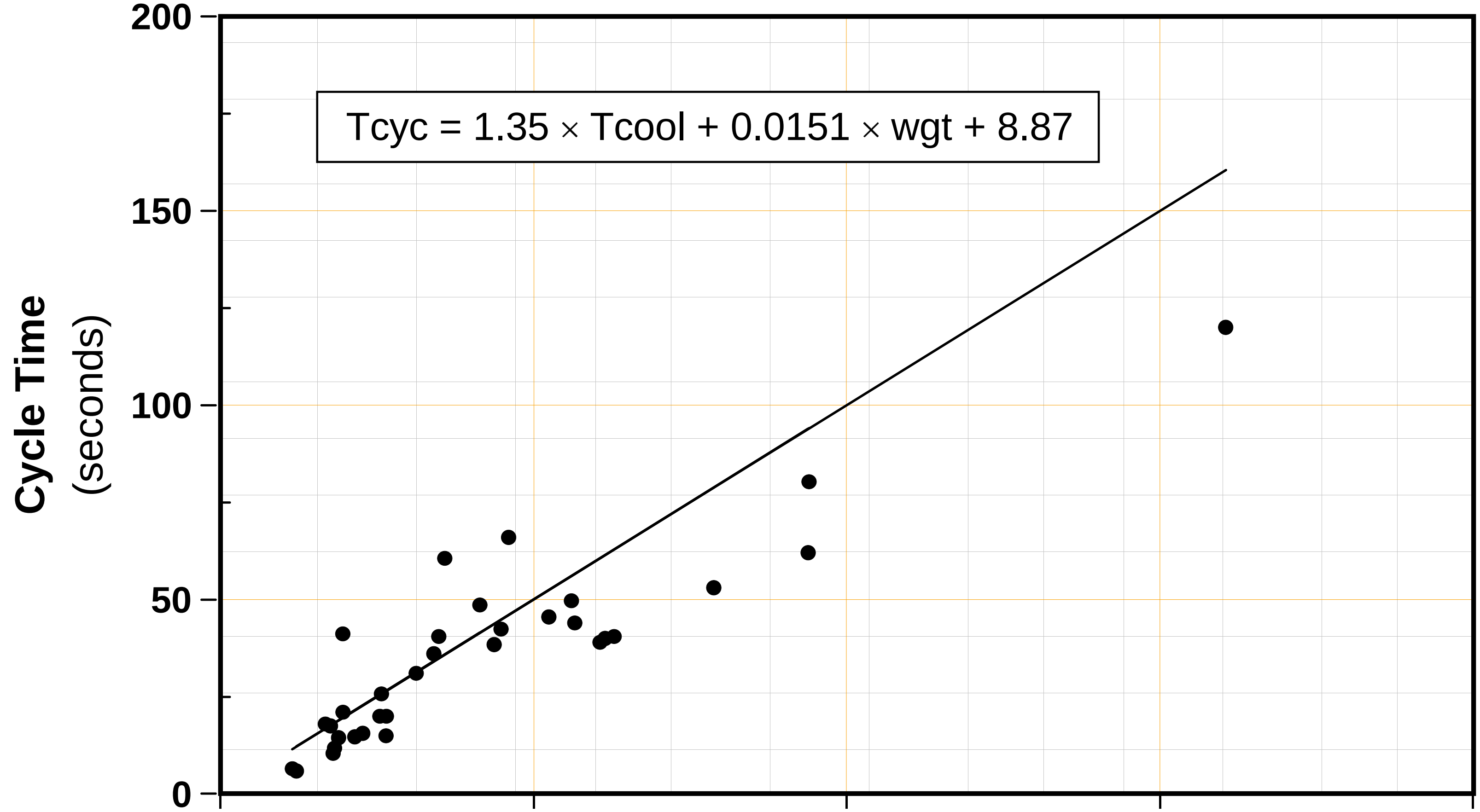
- Cooling Time - Theoretical Determination

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

- Filling Time - Function of Shot Size - Function of Part Weight
- Mold Cycle - Function of Press Size, But Likely Only Weakly

★ Cannot Expect Perfect Match To Theory, So Try To Correlate

Cooling Time, Part Weight and Cycle Time Correlation



PIM Example - Equipment Cost

- Fixed Cost (calculate on per time period basis)
- Factor Required: Injection Molding Machine
  - Factor Type: Design Dependent
  - Machine Type = f(Part Geometry)

- Q_f = Number of Lines Required
- P_f = Price x Fraction Allocated to each Period

Capital Recovery Factor

★ ... However, this is not good enough !

Evolution of a Cost Model - Injection Molding

- Equipment Size ===>
  Function of Clamping Force

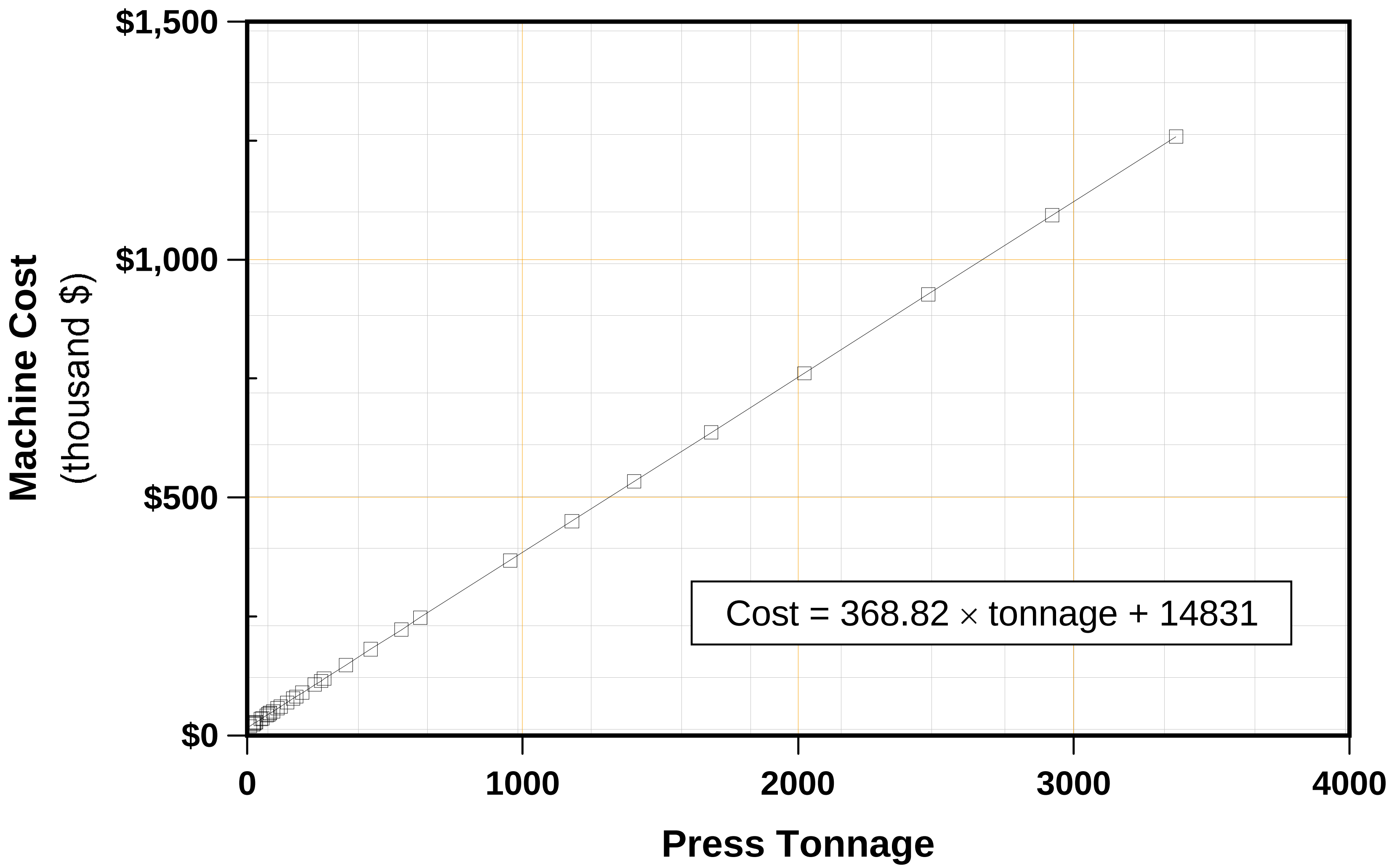
- Clamping Force ===>
  Function of Part Geometry and Processing Parameters

- Empirical Relation:

$$\text{Clamp Force} = \text{Projected Area} \times N_{cavities} \times \frac{224}{\sqrt{\textit{Wall Thick.}}} + 172$$

★ Clamp Force Can Then Be Related To Press Cost

Correlation Between Press Cost and Tonnage



Processing Time and Its Relationship with Capital Costs

- Number of Machines/Production Lines

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

(If dedicated, rounded up to the next integer value)

- Critical Accounting Issue -- Dedication
  - Will lines be fully dedicated to producing only this product?
  - Only impacts lines not fully utilized

Cost Modeling Important Concepts

- Break down problem as much as possible
- Relevant cost elements vary with question and context
- Clearly identify cost elements considered
- Calculate element cost with convenient basis
  - Variable <==> Per Unit
  - Fixed <==> Per Period
- Be careful of spurious precision

Amortization of Capital Costs

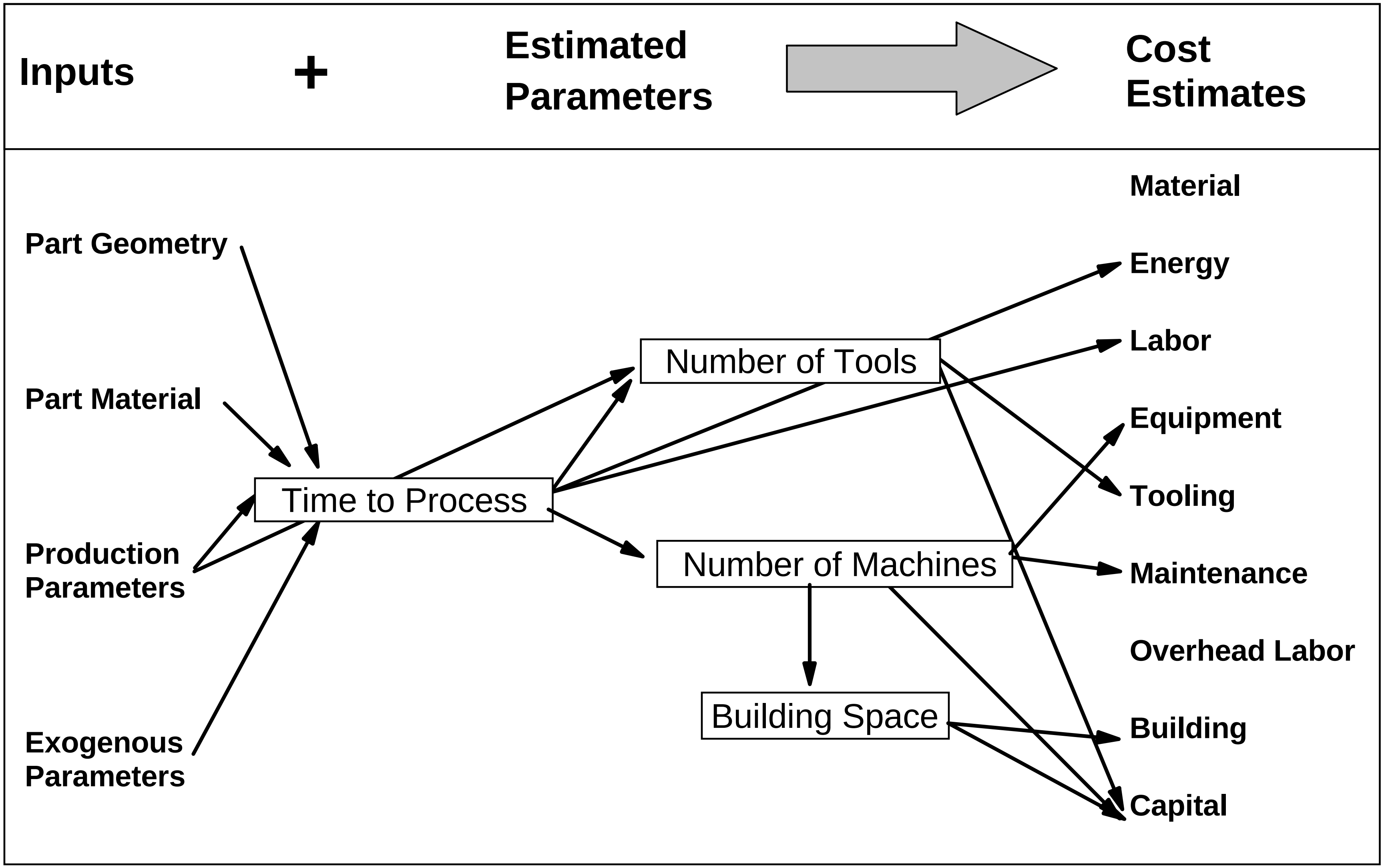
- Capital Costs Must Be Annualized / Amortized to Account for Financing Costs or Opportunity Costs

- Simple Annuity Calculation:

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

- 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



Capital Cost Relationships