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 measure 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 technology; buy/sell 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 \( B = \sum (p_i \times X_i) \)

• 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 decision maker
Cost in Practice --Accounting -- Example

- Example: Classical accounting practice focused upon Labor as the key cost driver
  - Think of productivity – output/"man-hour"

- Consequently
  - 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; Development Strategies
  - Investment Needs and Opportunities

- Decisionmakers Need a Tool That:
  - Limits Assumptions
  - Is Explicit About The Assumptions Made
  - Imposes a Consistent Basis for 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 -- $$$
Conceptual Basis of Cost Model

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- Part Geometry
- Part Material
- Production Parameters
- Exogenous Parameters

Material
Energy
Labor
Equipment
Tooling
Maintenance
Overhead Labor
Building
Capital

Evolution of a Cost Model - Injection Molding

- Conventional Wisdom
  \[ Part Cost = 2 \times Material Cost \]

- What Is Material Cost?
  \[
  Materials \text{ Cost} = \frac{(Part \text{ Weight} \times \text{Raw Material Price})}{(1 - Material \text{ Scrap Rate})}
  \]

- 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:

  \[ \text{Part Cost} = \text{Material Cost} + \text{Labor Cost} \times \text{Burden Rate} \]

- What is Labor Cost?
  \[ \text{Labor Cost} = \text{Effective Labor Rate} \times \text{Time To Make A Part} \]

  | Effective Labor Rate | = \text{Labor Wage} \div \text{Labor Productivity} |
  | Time To Make A Part | = \text{Cycle Time} |
  | Cycle Time | = f(\text{Material, Geometry, Technology, ...}) |

- Note introduction of elements of: Technology (Cycle Time), Production (Productivity) and Economics (Wage Rate)

- What is Burden Rate?? - Accounting Construct

  - 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

Inputs + Estimated Parameters → Cost Estimates

Part Geometry

Part Material

Production Parameters

Exogenous Parameters

Time to Process

Inputs Estimated

Parameters + Cost Estimates

Material

Energy

Labor

Equipment

Tooling

Maintenance

Overhead Labor

Building

Capital

Number of Tools

Number of Machines

Inputs Estimated

Parameters + Cost Estimates

Material

Energy

Labor

Equipment

Tooling

Maintenance

Overhead Labor

Building

Capital
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 than one product, the cost of the part should reflect this.

- Typically, cost is prorated 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/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.

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Processing Time/Rate - Critical To Cost

Inputs + Estimated Parameters → Cost Estimates

- Part Geometry
- Part Material
- Production Parameters
- Exogenous Parameters

Time to Process

- Number of Tools
- Number of Machines
- Building Space

Inputs:
- Material
- Energy
- Labor
- Equipment
- Tooling
- Maintenance
- Overhead Labor
- Building
- Capital

Cost Estimates:
- Time to Process
- Exogenous Parameters
Time To Process A Part - Engineering Parameter

- Combine Engineering and Theoretical Approaches

- Cooling Time - Theoretical Determination

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

- 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

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Cooling Time, Part Weight, Cycle Time Correlation

\[ T_{cyc} = 1.35 \times T_{cool} + 0.0151 \times wgt + 8.87 \]
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

Capital Cost Relationships

Inputs + Estimated Parameters → Cost Estimates

- Part Geometry
- Part Material
- Production Parameters
- Exogenous Parameters
- Cost of Tools
- Clamping Force
- Size of Press
- Material Energy
- Labor
- Equipment Tooling
- Maintenance
- Overhead Labor
- Building Capital
- Cost of Press
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**

![Graph showing tooling cost regression estimates]

ToolCost = 10174 + 6.61 × wgt + 16150 × action + 12.7 × parea

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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 (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

Model Results - Cost Estimate
Model Results - Sensitivity to Production Volume

Part Cost

$0.35 $0.40 $0.45 $0.50 $0.55 $0.60

Annual Production Volume (thousands)

Model Results - Sensitivity to Cycle Time

Part Cost

$0.60 $0.80 $1.00 $1.20 $1.40

Time (seconds)

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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