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Presentation Overview

- Cost Estimation Background
- Project Objectives
- Phases of Project
  - Bottoms-up Cost Estimation
  - Feature Attributes
  - Part Geometry
- Results
Application of Cost Estimation

• Use Cost Estimating Relationships (CERs) to predict the cost of producing a part

• Done during preliminary design phase
  ➢ Many design decisions to be made
  ➢ Multiple options for achieving desired functionality
  ➢ One of primary decision criteria is often cost
  ➢ Need tools to evaluate cost of design decisions
Approaches to Cost Estimation

• Bottoms-up
  - For accuracy

• Parametric
  - For simplicity

• Other methods (Duverlie & Castelain, 1999)
  - Analogic
  - Intuitive
Bottoms-up Cost Estimation

- **Procedure**
  - CERs are determined for each feature
  - Feature costs for a part are summed to get total cost

- **Advantages**
  - Accurate
  - Transparent
  - CERs are reusable for new part types
  - New processes and new materials can be easily integrated
Parametric Cost Estimation

- **Procedure**
  - Relationships are identified between total cost and significant part parameters

- **Advantages**
  - Less information required from users
  - CERs for entire part can be quickly developed
Project Objective: Original

- Objective: Develop methodology to improve accuracy of cost estimates for jet engine components
- Bottoms-up approach was used, to achieve accuracy
  - Detailed CERs were developed to estimate the cost to produce each of the features and found on a part
  - Detailed geometric model to estimate material cost
  - Prototype developed for limited number of part families
- Full implementation of this approach was declined by project sponsor
  - Too time-consuming for users to generate a cost estimate
Project Objective: Revised

• Objective #1a: Develop methodology to improve accuracy of cost estimates for jet engine components

• Objective #1b: Minimize number of attributes required to produce a cost estimate
  ➢ Needed to maintain accuracy of bottoms-up approach, while producing a system that appeared more parametric to the user
Modified Project Approach

- Retain bottoms-up CERs for calculating cost of part features
- Develop Attribute Estimating Relationships (AERs)
  - Estimate values for some attributes needed as inputs for the CERs
  - Estimate values for geometric attributes related to overall part shape
Project Phases

- Development of Bottoms-up CERs
  - By feature
- Development of Attribute Estimating Relationships (AERs) for features
  - AER outputs were inputs to Bottoms-up CERs
- Development of AERs for part geometry
Development of Bottoms-up CERs

1. Identify the significant features on a part
2. Identify the process(es) used to create each feature
3. Develop feature CERs from standard machining formulas

Example:

\[ \text{time}_{\text{thread}} = k \cdot \text{dia} \cdot \text{length} \cdot \text{pitch} \]

- \( k \) is a constant that combines the process parameters (speed, feed, etc.)
Using Bottoms-up CERs

- Total Cost =
  \[
  \text{Material Cost} + (\text{Labor Hours} \times \text{Labor Rate})
  \]
  - Material Cost is determined using geometric attributes to determine the part volume
    - Material Cost = Initial Volume \times \text{Density} \times Utf/\text{pound}
  - Labor hours include
    - Time to produce the features
    - Time for all-over processes (e.g., inspection, cleaning)
Attribute Estimating Relationships

• **Purpose:**
  - Reduce the number of attributes that are needed as inputs to the CERs

• **Process:**
  - Identify relationships between high-level attributes and attributes needed for CERs

• **Examples of AER format:**
  - Thread length = 0.053 • Part Length
  - Flange OD = Flange ID + 2.42
Calculation of AERs

• General Form
  \[ y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n \]
  • \( y \) = attribute being estimated
  • \( x_i \) = value for given attribute
  • \( \beta_i \) = scaling coefficient

• Coefficients can be determined to minimize
  - Sum of Squared Error
  - Standard Deviation of Error
Attributes Used in AERs

• Dimensions
  ➢ Relationships between sizes

• Boolean attributes (Yes/No)
  ➢ Existence of a feature on a part

• List attributes
  ➢ Type(s) of features on a part

• Quantity attributes
  ➢ Number of features on a part
Feature AERS

- Features were primary focus of study
  - Needed to reduce number of values from user
  - AERs determine quantity and dimensions of most features
  - User only needs to define which features a part has
- AER-calculated values are used to calculate most inputs to bottoms-up CERs
- Different AERs can be used for different part types
Geometric AERs

• Most parts studied are axisymmetric
  ➢ Determine cross-sectional shape of part
  ➢ Revolve 360° around centerline to calculate volume

• Need to estimate amount of material required to create original part

• Some dimensions scale together
  ➢ e.g., as Flange ID increases, so does Flange OD
Testing AER Methodology

- Feature and Geometric AERs generated for jet engine disks
- Figure shows cross-section of a generic disk
  - 8 primary dimensions to describe shape
  - May also have appendages extending from both sides
Results with Feature AERs

- AERs developed for 16 features
  - All features do not appear on all disks
  - 56 AERs developed for feature input attributes

- Accuracy compared against actual cost for estimates with and without AERs
  - Average percent error was unchanged from detailed estimates
  - Standard deviation of error increased by 3%
Results with Geometric AERs

- Good accuracy achieved with models that use only extreme dimensions of the part
  - Accuracy measured against original volume estimate
- Disks without appendages
  - Min ID, Max OD, Hub Width, Web Geometry
  - Average Error = -3.5%
- Disks with appendages
  - Min ID, Max OD, Total Length
  - Average Error = 1.7%
Conclusions

• Attribute Estimating Relationships can be used to simplify cost estimation process
  ➢ Produces system with benefits of bottoms-up and parametric cost estimation

• Development process requires more effort than a bottoms-up system alone
  ➢ Savings is in reduced time required to generate the cost estimate of a part
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