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Modelling Costs for Through Life Availability

Linda Newnes, Head of Costing Research
University of Bath
Through Life Costing

• Our focus is on concept design through to disposal.
• Emphasis on knowledge information and management for cost modelling.
• Importance of ‘servitisation’ cost modelling (PSS).

The overall aim is to provide methods and tools for managing TLC from concept design to in-service/disposal.
Why is cost modelling important

• NAO (2008) highlights key areas
  – MOD projects late delivery and over budget
  – 20 largest projects on average 96 months late and £205M over budget

• Deloittes (2008)
  – Cost overruns in defence and aerospace in next 10 years 26% increase
  – Equates to 46%.

• MOD DES
  – 2007/8 the in-service costs were £10b
  – Availability contracting

• MOD & supplier joint risk
Through Life Costing

- Improving Quality of Information for Use in Costing
- Estimating Non-Recurring Costs for Tooling
  - CAD/CAM Models of costing data for re-use
- Plug and Play costing
- In-Service to Design (with School of Management)
- Through Life Costing for Low Volume Long Life Electronic Defence products (IeMRC + IdMRC)
- In-Service Uncertainty Cost Models
- Product Service Systems Cost Models
- Modelling uncertainty in cost data and cost models
Through Life Costs

70-80% COSTS INBUILT

IN-SERVICE
Upgrades/Obsolescence

Majority of expenditure is in-service costs and upgrades

Up to 75%
Costing for Availability – current modelling

• Cost modellers have focused on costing products.
• Commercial systems are in general still product based.
• Little evidence of in-service/utilisation modelling.
• However product and services debated since 1776 by Smith*
• Availability contracts already in place, however benefitted with transition between products and service.

Challenge

**How do you cost for through life availability or capability?**

- How can industry estimate the TLC for their products? In particular,
  - How can you predict the in-service (utilization/operations support) costs for the products at the concept design stage to enable informed decision making?
  - Model the cost of decisions e.g. last time buy – how many parts are stored in warehouses from last time buys
- Uncertainty modelling to aid decision making
Through Life Cost

- Decision making for the acquisition, development and ongoing support of complex engineering systems with extended life
  - Most meaningful at early stage but highly uncertain
  - Quantitative and objective estimating of TLC taking into account of uncertainty in estimate
  - Use uncertainty modelling for decision making through the supply chain
The Framework

- Scenarios
  - Cost Data
    - Estimated Costs
      - Cost Models
        - Actual Costs
          - Uncertainty Theories
            - Context (technology, economy, socio-politics etc.)
              - Uncertainty Modeling
Uncertainty and Decision Making

• **Aleatory uncertainty**
  – Irreducible randomness associated with the physical system or the environment
  – e.g. repair time, failure rates
  – Decision making under risk

• **Epistemic uncertainty**
  – Reducible uncertainty due to a lack of knowledge of quantities or processes of the system or the environment
  – e.g. future decisions
  – Decision making under uncertainty

• Important to make a distinction
  – Different theories and methods to model these uncertainties
  – Can be updated as knowledge is accumulated
Current Approach

- Probabilistic cost risk analysis
  - Three-point estimate is common, most likely, min and max to describe triangular distributions
  - Subjective probability is often used to represent uncertainty
- Commercial software incorporate probabilistic modelling technique
  - Monte Carlo with various types of distributions (e.g. uniform, triangular, normal)
## Cost Models Uncertainty

### More important to characterise **epistemic** uncertainty

<table>
<thead>
<tr>
<th>Estimation Methods</th>
<th>Sources of Uncertainty</th>
<th>Uncertainty to Characterise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intuitive/expert opinion</td>
<td>• Judgement</td>
<td>• Epistemic</td>
</tr>
<tr>
<td>Analogical</td>
<td>• Selection of benchmark model (qualitative characteristics)</td>
<td>• Epistemic</td>
</tr>
<tr>
<td>Parametric</td>
<td>• Cost drivers/parameters • CER choice • Goodness-of-fit • Data uncertainty • Extrapolation</td>
<td>• Epistemic and aleatory</td>
</tr>
<tr>
<td>Analytical/engineering</td>
<td>• Scope • Level of details • Available data</td>
<td>• Epistemic and aleatory</td>
</tr>
<tr>
<td>Extrapolation from actual costs</td>
<td>• Changes in conditions • Limited data</td>
<td>• Epistemic and aleatory</td>
</tr>
</tbody>
</table>

### More important to characterise **aleatory** uncertainty
## Cost Data Uncertainty

<table>
<thead>
<tr>
<th>Data Uncertainty</th>
<th>Source</th>
<th>Type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variability</td>
<td>Inherent randomness</td>
<td>Aleatory</td>
<td>Repair time, Mean Time Between Failure, labour cost.</td>
</tr>
<tr>
<td>Statistical errors</td>
<td>Lack of data</td>
<td>Epistemic</td>
<td>Reliability.</td>
</tr>
<tr>
<td>Vagueness</td>
<td>Linguistic uncertainty</td>
<td>Epistemic</td>
<td>The component may need to be replaced every 2 to 3 months.</td>
</tr>
<tr>
<td>Ambiguity</td>
<td>Multiple sources of data</td>
<td>Epistemic</td>
<td>Expert 1 and expert 2 provides different values to end-of-life costs.</td>
</tr>
<tr>
<td>Subjective judgement</td>
<td>Optimism bias</td>
<td>Epistemic</td>
<td>Over confidence in schedule allocation.</td>
</tr>
<tr>
<td>Imprecision</td>
<td>Future decision or choice</td>
<td>Epistemic</td>
<td>Supplier A or B.</td>
</tr>
</tbody>
</table>
Scenario Uncertainty

- A scenario is a conceptual model that is developed (with assumptions) to approximate the actual TLC of the artifact
  - new technologies or legislation, supply chain disruptions, design changes
- Typical scenarios are the most likely, worst and best cases, and the outcomes of these are then used as 3-point estimates
- No distinction between risk and uncertainty
Imprecise probability

- When both variability and imprecision is present, e.g. uncertain about the distribution parameters e.g. reliability

<table>
<thead>
<tr>
<th>Normal</th>
<th>Mean</th>
<th>St Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper bound</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Lower bound</td>
<td>20</td>
<td>2</td>
</tr>
</tbody>
</table>

PDF

CDF

Probability Bounds
There is 90% probability that in service cost is within £23M.

There is 90% probability that cost is within £22M-£24M.

→ Use this information to set contingency budget, best case £22M worst case £24M.
How does this link to availability modelling

Chris Paredis
Georgia Tech

Ricardo Valerdi
MIT

Peter Sandborn
CALCE

Knowledge and data required for
Through life management
Long life products

Future Products
In-Service Availability Contracts Operating
Legacy

Feedback from in-service to concept design
Conclusions

• Uncertainty important in the context of decision making in TLC
• Separating epistemic and aleatory uncertainty in costing
  – Can update the model when imprecision is reduced/eliminated, e.g. deciding on alternative
  – Allows reuse of objective data e.g. repair time independent of the probability of repair events
• More transparent decision making under uncertainty and risk
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Any Questions