Conceptual Cost Estimation and the Futility of Bottom-Up Cost Methods

ADRIAN MITCHELL

16 May 2019
About Us – QinetiQ Group Plc

Air

C4ISR

Cyber

Weapons

Space

Training

Advisory Services

Robotics

Maritime

Land & Critical Infrastructure
Advisory - QinetiQ Australia has costed over 158 projects since 2014

Costing Tasks by Type of Project

- Explosive Ordnance: 11%
- Infrastructure: 3%
- Platform: 8%
- Software: 8%
- System: 20%
- Equipment: 50%

Costing Tasks by Method

- Parametric: 61%
- Bottom-Up: 24%
- Parametric & Bottom-Up: 3%
- Analogous & Bottom-Up: 12%
Background

Bottom or build-up cost methods used in large complex projects provide a high level of detail and therefore are perceived by stakeholders to be more accurate than other cost methods.

This general view is not supported by objective empirical data.

There are time and resource trade-offs in developing detailed unit rate, bottom-up estimates at the expense of using additional methods to triangulate your estimates and cost other options.
Background

The accuracy of an estimate is not primarily a function of the cost method used.

<table>
<thead>
<tr>
<th>ESTIMATE CLASS</th>
<th>PRIMARY CHARACTERISTIC</th>
<th>SECONDARY CHARACTERISTIC</th>
<th>EXPECTED ACCURACY RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 5</td>
<td>0% to 2%</td>
<td>End usage</td>
<td>-20% to -50%</td>
</tr>
<tr>
<td>Class 4</td>
<td>1% to 15%</td>
<td>Methodology</td>
<td>-15% to -30%</td>
</tr>
<tr>
<td>Class 3</td>
<td>10% to 25% (excluding)</td>
<td>Control or bid/tender</td>
<td>-10% to -20%</td>
</tr>
<tr>
<td>Class 2</td>
<td>30% to 60%</td>
<td>Control or bid/tender</td>
<td>-5% to -15%</td>
</tr>
<tr>
<td>Class 1</td>
<td>65% to 100%</td>
<td>Check estimate or bid/tender</td>
<td>-3% to -10%</td>
</tr>
</tbody>
</table>

Accuracy of an estimate is driven by the quality of data inputs used in the model; the degree to which project scope and requirements are represented; and behavioural factors that influence cost practitioners, stakeholders and decision makers.
Background

• The Evidence
  – On average civil infrastructure projects are subject to a cost overrun of 39 per cent. The international trend since the 1950s has remained similar (n = 1603, p<0.0001). Bent Flyvbjerg, “The Fallacy of Beneficial Ignorance: A Test of Hirschman’s Hiding Hand” World Development Vol. 84, pp. 176–189, 2016.
  – For ‘mega’ projects: “Costs are underestimated in almost 9 out of 10 projects. For a randomly selected project, the likelihood of actual costs being larger than estimated costs is 86%.” (n = 258, p<0.001). Bent Flyvbjerg, Mette Skamris Holm, and Søren Buhl, "Underestimating Costs in Public Works Projects: Error or Lie?" Journal of the American Planning Association, vol. 68, no. 3, Summer 2002, pp. 279-295.
Background

If cost overruns were only due to estimating errors, then according to Central Limit Theorem the actual/estimate result should tend towards a normal distribution. Instead, the results tend towards a distribution that is heavily skewed, suggesting that behavioural biases produce overly optimistic project cost estimates.
Background

• Early estimates set the budget for the project.
• However, project’s often have little idea of future requirements.
• Therefore, it is more appropriate to cost a range of options using performance and design characteristics.
• This can only be achieved using multiple types of statistical cost methods and datasets.

During conceptual stage of the project life there is the opportunity to influence the Whole Life Cost of the project at minimum expense.
Background

Measure of Effectiveness (MOE)

Current MOE

Option A

Option B

Option C

Option D

Budget

Net Present Value (NPV)
Knowledge Based Estimating
Knowledge Based Estimating

• Data
  – The provision of cost and technical data from past projects to estimate the cost of future projects.
  – Data is the ‘lifeblood of estimating’.

• Tools
  – The use cost estimation tools to help cost analysts interpret historical data, create cost estimating relationships and
  undertake resource and material calculations.
  – Commercial cost tools and models FACET, TruePlanning, Excel models, etc.

• People
  – Appropriately qualified and experienced people to translate technical and business requirements into cost estimates;
    source, collate and interpret cost and technical data; and use the right tools or models for generating estimates for various
    types of projects.

• Processes
  – The use cost estimation processes and training packages to ensure people conduct an estimate in a logical, traceable and
    repeatable way across the organisation.
Data

- Conceptual parametric cost estimates require the following types of data sets.

<table>
<thead>
<tr>
<th>Type of Data</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>The magnitude of the problem</td>
<td>m³, kilograms, production quantities, software lines of code, RICEFW, m², kilowatts, metres.</td>
</tr>
<tr>
<td>Complexity</td>
<td>The level of difficulty</td>
<td>Technology, materials, manufacturing processes and tolerances, design difficulty, mission type, type of software language.</td>
</tr>
<tr>
<td>Productivity</td>
<td>The achievement of the activity</td>
<td>Organisational maturity, country of origin, staff skills, communication, team cohesion, learning curve percentages.</td>
</tr>
</tbody>
</table>

Collect data on the size of the project, the complexity of the project deliverable and the productivity of the organisation delivering the project.

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Units associated with activities or quantities</td>
<td>Hourly rates, unit prices, unit production costs, activity costs.</td>
</tr>
<tr>
<td>Technical</td>
<td>Requirements or specifications</td>
<td>Engineering (hardware or software) or system related data: speed, weight, lines of code.</td>
</tr>
<tr>
<td>Programmatic</td>
<td>Program level requirements that affect costs</td>
<td>Schedule milestones</td>
</tr>
<tr>
<td>Contextual</td>
<td>Any information that provides context for cost, technical and programmatic data.</td>
<td></td>
</tr>
</tbody>
</table>
Data

• A study of 120 Boeing software development projects found that estimates derived without historical data had variances against expenditure of up to 140 per cent.

• When project estimates were derived using historical data, the variance was less than 20 per cent. John D. Vu, Boeing presentation for the Process Group, 2001.
Tools

• A 2011 experiment at the Joint Propulsion Laboratory involving 507 persons found that bottom-up estimating was little better than a guess at a supposed P50 confidence level.
  – “Deep decompositions do not improve accuracy.”
  – “…more time consuming than helpful.”
  – “…compound psychological effects.”

• A 2018 validation study at the Joint Propulsion Laboratory of 10 projects found that quick turnaround parametric cost methods generated estimates within 21 per cent of project actuals (not accounting for uncertainty and risk).
  – Within JPL’s 30 per cent project reserve tolerance level for developmental items.

A cost model is a simplified representation of a real world undertaking and is therefore known to be incorrect. It is hoped that the model is sufficiently accurate to be useful.
Tools

- **FACET** is a Macro Parametric model
  - Platform / System level focus
  - Multiple platform / system models (70+)
  - Few independent project specific parameters

- **TruePlanning** is a Micro Parametric model
  - Technology sub-system level focus
  - Single universal model
  - Multiple independent project specific parameters

**Example:** estimate the cost of a two-stage conventional ballistic missile

Developing multiple cost estimates of the same project using different methods and data sources is usually preferable than developing a single bottom-up estimate.
In 2017, BAE Systems found that parametric costing tools reduced the time to generate an estimate by 40% - 55%, or 15 full time equivalents, compared to bottom-up methods.
Tools: FACET

- Design derived from the user performance
- FACET generated combined Design
- User Design

Performance based cost estimates

Performance / Design based cost estimates

Design based cost estimates
**Tools: FACET**

<table>
<thead>
<tr>
<th>Performance Specifications</th>
<th>Min</th>
<th>ML</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Mass, kg</td>
<td>28,000</td>
<td>30,000</td>
<td>32,000</td>
</tr>
<tr>
<td>Guidance Error, mil*</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>Range, km</td>
<td>5,000</td>
<td>6,000</td>
<td>7,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design Specifications</th>
<th>Min</th>
<th>ML</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of Propulsion System, kg</td>
<td>20,000</td>
<td>22,000</td>
<td>24,000</td>
</tr>
<tr>
<td>Number of Stages</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Mass of Warhead, kg</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Programmatic Specifications</th>
<th>Min</th>
<th>ML</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of Technology</td>
<td>2000</td>
<td>2005</td>
<td>2005</td>
</tr>
<tr>
<td>Production Quantities</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Development Status</td>
<td>-</td>
<td>New Development</td>
<td>-</td>
</tr>
</tbody>
</table>

*Guidance error = (Circular error probable, m)/(Range of missile, km). Where ‘Circular Error probable’ is measured at impact after flight over maximum range.
Tools: FACET

**Study Name:** Theatre missile

**Economic Conditions:** $ / 2005 / Million

<table>
<thead>
<tr>
<th>Costs</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acquisition Costs</strong></td>
<td></td>
</tr>
<tr>
<td>Development</td>
<td>12,692.37</td>
</tr>
<tr>
<td>Production</td>
<td>3,063.67</td>
</tr>
<tr>
<td>Total Acquisition</td>
<td>15,756.04</td>
</tr>
<tr>
<td><strong>In-Service Costs</strong></td>
<td></td>
</tr>
<tr>
<td>Non Crew</td>
<td>18,528.77</td>
</tr>
<tr>
<td>Total In-Service</td>
<td>18,528.77</td>
</tr>
<tr>
<td><strong>Total LCC</strong></td>
<td>34,284.81</td>
</tr>
<tr>
<td><strong>Unit Production Cost (Units)</strong></td>
<td>$61,273,398</td>
</tr>
</tbody>
</table>

75% confidence limits ($M) are: Lower = 51.96, Upper = 69.55
Tools: TruePlanning

TruePlanning is a combination of parametric and activity based costing.

- Detailed estimates can be provided irrespective of where the project is within the lifecycle.

**TruePlanning Estimates:**

- The labour hours required to complete the project;
- The hourly rates for each labour resource;
- The cost of material; and
- Inflation and foreign exchange (market & PPP) parameters, calculated against labour and material costs.

Source: PRICE Systems
Tools: TruePlanning

• Reuse the same design, performance and programmatic assumptions to refine the estimate using a micro-parametric approach.
Tools: TruePlanning

Will the missile traverse into space?

How will the weight of the missile change as the mission changes?
Tools: TruePlanning

How will complexity of the missile change as the mission changes?

Where will the missile be produced?
People

• Aware, Competent, Expert (ACE) Framework
  – Ensuring the appropriate people are working on the most appropriate task.

• Types of Cost Practitioners
  – Analysis
    – Collecting historical data and translating it into usable information for developing and defending a cost estimate.
    – Analysis looks at the past and provides a means for evaluating the cost estimate.
    – Analysis of historical data to create cost models.
  – Forecasting
    – A long-term prediction of future funding requirements using conceptual costing techniques.
    – Few technical requirements and limited understanding of project scope.
    – Results in rough order of magnitude cost predictions with wide tolerance levels.
    – Pre-contract phase.
  – Estimating
    – The skill of translating current technical requirements into financial predictions for immediate budgetary and approval purposes.
    – Estimating looks into the short to medium term future.
    – Verify contractor claims.
Summary

• Do cost practitioners have access to high-quality data sets?

• Do cost practitioners have access to appropriate tools to analyse and utilise data to generate a cost forecast?

• Are cost practitioners trained in costing tools, and are they working on projects commensurate with their skills and experience?

• Do cost practitioners follow a standard and agreed cost modelling process, incorporating the use of high-quality data sets and tools?