

Cost Estimations for Large Scale Engineering Projects under Uncertainties

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Abstract

Cost estimation for large projects can be difficult because of many complex factors and uncertainties involved. It is often the case that only very rough guesses of actual costs may be provided. In this paper, we will examine the various types of uncertainties in the cost estimation problem of the Myrrha project. We will then use a few examples originated from the conceptual phase of the project to illustrate the practical use of a software package, IDS Cost Estimator, in cost analysis of nuclear systems. It is demonstrated that IDS Cost Estimator can take care of several types of uncertainties in cost estimation and provide user friendly interfaces for data collection, reporting and display.

Keywords: interval uncertainty, probability uncertainty, decision support systems, fuzzy logic, cost estimation, Myrrha.

1 Introduction

Myrrha is an Accelerator Driven System (ADS) under development at the Belgian Nuclear Research Centre (SCK•CEN) in Belgium. It is aiming to serve as a basis for the European experimental ADS to provide protons and neutrons for various R&D applications. It consists of a proton accelerator delivering a 350 MeV * 5 mA proton beam to a liquid Pb-Bi spallation target that in turn couples to a Pb-Bi cooled, subcritical fast core. The project started in 1997. After a conceptual period of two years, a pre-design has been launched and is to be completed by 2005. After a detailed engineering design phase and construction of the components, Myrrha will be put in service around 2016 (<http://www.sckcen.be/myrrha>).

2 Cost estimation for Myrrha with Intelligent Decision System

The possible cost for the Myrrha project at this stage might include: (1) the construction of the Myrrha machine and its related components, (2) R&D activities, (3) Feasibility and pre-design studies, and (4) Licensing.

Just for the item (1), all possible expenses are far from detailed at this stage and the expenses are those that would be incurred after the decision to construct the Myrrha machine (around 2008). This means that all problem areas (spallation source, problems related to the accelerator, LBE connected problems, robotics, fuel, and instrumentation) are given a reasonably satisfactory solution and that the pre-design has come to a point that no technical major problems are to be expected any more.

There are many ways to estimate the cost of the machine [1-2]. Classically, the costs of the above-mentioned item (1) are separated in a coarse way into: (i) material cost, (ii) engineering cost, (iii) manufacturing costs, and (iv) other costs (e.g., costs for transport, quality assurance, special treatments, purchase of small components,...).

It is not always clear when this distinction is to be made and this separation can be used in a more arbitrary way to facilitate the cost estimation of a particular item. E.g., the reactor vessel is not a complex component and one can (more or less) easily estimate its cost by adding the material, the engineering and the manufacturing costs and if necessary some other costs (e.g., ultrasonic control of welds, thermal treatment, ...). On the other hand some components (e.g., bearings, motors, drives, ...) are industrially available and for those components the cost separation is useless. In those cases, only the expected purchase price is considered as "other costs."

However, it's very difficult to estimate the price all at once as we are just in the pre-design phase without any detailed technical drawing of any part of the machine. So, all estimations are more or less rough guesses under various uncertainties. Especially estimating the input parameters may be difficult at early stages of the design due to lack of data or insight. In addition, historic data for construction are not always accessible and more importantly are often unreliable. To overcome data difficulties, a probabilistic technique, usually the Monte Carlo simulation (MCS) [3], may be employed, where it is required to determine a probability distribution function (PDF) for every uncertain variable to carry out a MCS. Such functions are best derived from statistical analysis of significant data. But, as mentioned previously, historic data are sparse; therefore it is questionable whether statistically meaningful PDFs can be derived.

With the help of the Intelligent Decision System (IDS), a software package designed to assist multi-attribute decision analysis under uncertainties, a better cost estimation for the Myrrha machine is being carried out as a result of the cooperation between SCK•CEN and The University of Manchester.

IDS is based on a new methodology called the Evidential Reasoning (ER) approach [4-7] and helps to make a decision process more transparent and informative. It provides an unprecedented capability in handling uncertainties and friendly user interfaces for problem structuring, information collection, and data presentation in both graphical and text formats. During the past few years, the authors and their colleagues have applied IDS to support multiple criteria decision analysis under uncertainties, in the areas of:

Supply Chain Management [8-12]

- Supplier assessment
- Contractor selection
- Investment project evaluation

Design Decision Support [13-15]

- Engineering product design (cargo and container ships, ferries, offshore structures)
- Consumer product and service design (financial services, food and drinks)
- Cost benefit analysis

Risk and safety analysis [16-19]

- Offshore structures
- Marine systems
- Nuclear plants
- Food and drinks

Quality Management [20-25]

- Business performance assessment and improvement
- Customer satisfaction survey
- Audit

Government policy consultation [26-27]

- Whether UK should join Euro zone or not

The results show that the decision making approach and IDS have significant advantages over conventional methods in handling uncertainty and helping to improve consistency, transparency and objectivity in making a decision.

However, the information aggregation approach in the original IDS software, the ER approach, is a nonlinear process and not suitable for cost information aggregation. Therefore a linear aggregation process is adopted and the original IDS modified. To distinguish the two, the new package is called IDS Cost Estimator while the original IDS based on the ER approach is named as IDS Multicriteria Assessor. Demo versions of both packages are available from the web site www.e-ids.co.uk. In the following description, IDS and IDS Cost Estimator mean the same and they are used interchangeably.

In this paper, a case study on the cost estimation of the Myrrha project is given to illustrate how the IDS Cost Estimator can be used to carry out the cost analysis of large scale engineering projects under uncertainties.

3 A case study of the Myrrha cost estimation using IDS

As a case study for modelling cost estimation for Myrrha project using IDS Cost Estimator, we only consider item (1) the construction of the Myrrha machine and its related components, and do not include the costs for: (2) R&D activities; (3) Feasibility and pre-design studies, and (4) Licensing. In IDS, many dialog windows are designed to

support model building, data input, result analysis, reporting and sensitivity analysis.

IDS helps cost estimate process by decomposing costs into categories and subcategories or items. It then organises the decomposition into a category hierarchy in an interactive graphical interface. The main window of IDS Cost Estimator is a model display window. Using IDS, one of the Myrrha cost estimation model is shown in Figure 1. It has a menu bar, a toolbar and a model display window. The hierarchy of the cost elements can be readily constructed using the modelling menu or the related short cuts in the toolbar.

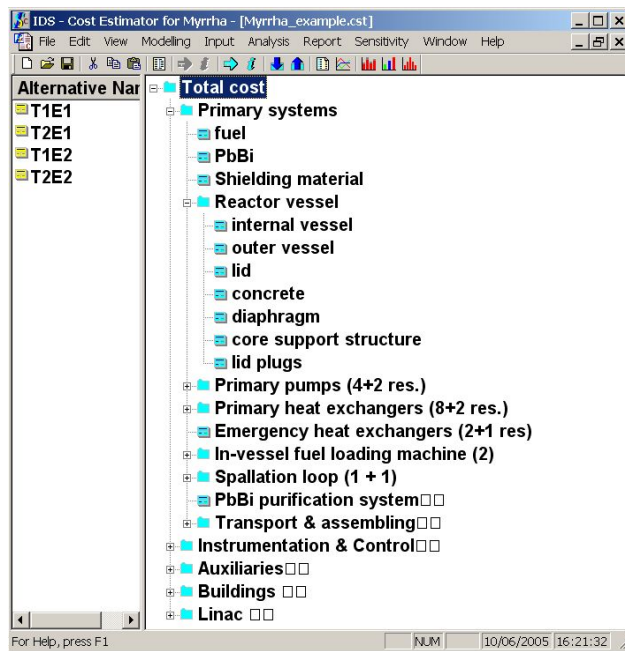


Figure 1. IDS main window for the Myrrha cost model hierarchy

The criteria hierarchy can be fully expanded in the same way as in Windows Explorer. The structure of the hierarchy can be modified and new options can be added if necessary. The information can be accessed and modified at anytime. The cost information and the aggregated results of the possible options can be displayed graphically.

IDS can accept input data (cost estimate for each decomposed item in the hierarchy) with or without uncertainties: quoted costs from suppliers, rough guess with a range, cost estimate from a group of experts whose estimates may not agree with each other, and cost estimates with probabilistic uncertainty or subjective uncertainty.

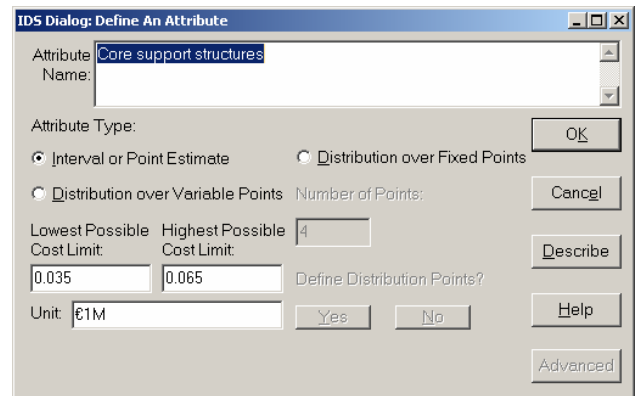


Figure 2. Attribute definition window

For example, Figure 2 is the cost attribute definition window for “Core support structure.” At the early stage of the project, the estimates are most likely to be a rough guess in a range. The Lowest and Highest Possible Cost Limits define the ultimate range of the estimate for the cost element, which are provided by the user (based on experience and/or history data) and in which an estimated value or value range can be assigned.

Figure 3 shows the data input window for the cost attributes with interval uncertainty. Initial estimate and its uncertainty range can be entered using the window.

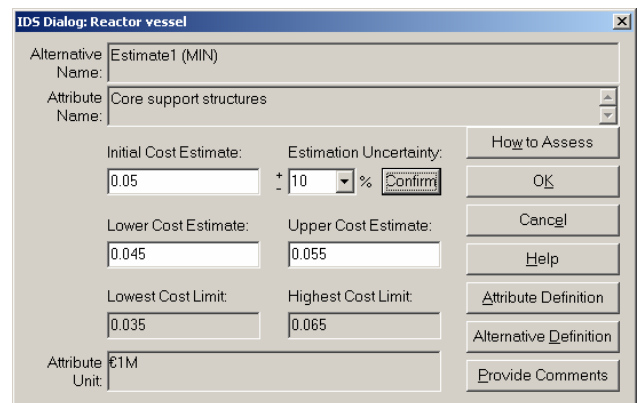


Figure 3. Enter numerical data using IDS dialog

Random numbers with various probabilities can also be defined and both possible values and their likelihoods can be entered as well, as shown in Figures 4 and 5, where the likelihoods are expressed as belief degrees.

In the absence of historic data, rough guess may also be made using a few critical points, such as Quarter Million Euro, Half Million Euros and so on. IDS can also accept information presented in such a format. For example, Expert E1 thinks that the cost of the

Beam Line could be around €3m and the estimate can be entered using the interface as shown in Figure 6. If the cost estimates are from a group of people having different views, belief degrees can be used to represent such a variation.

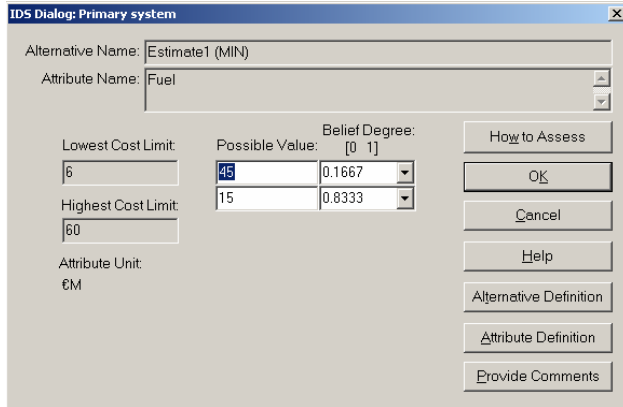


Figure 4. Enter numerical data with probability using IDS dialog

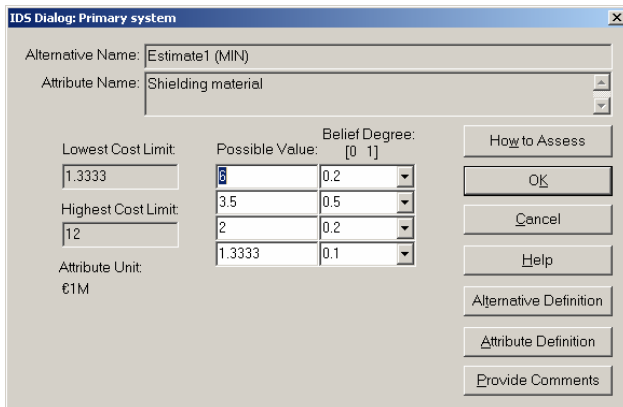


Figure 5. Enter numerical data with probability distribution using IDS dialog

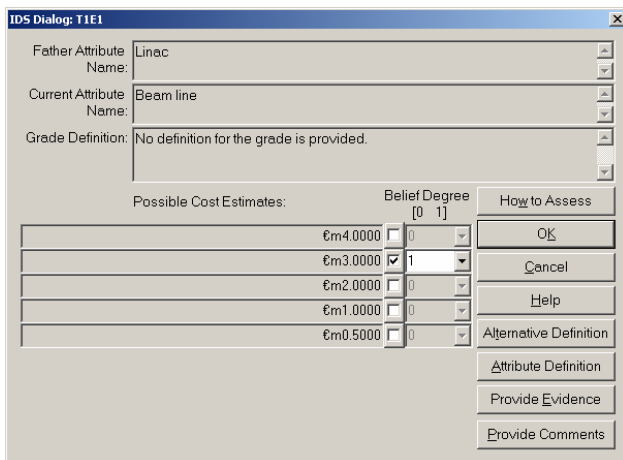


Figure 6. An interface for subjective inputting assessment information

From the input data, IDS can generate an overall total cost estimate and cost estimates in any category or subcategory. When there are uncertainties in input data, a range (lower bound and upper bound) of the estimate can also be provided at any level of the category hierarchy. If necessary, a distributed cost structure in each category can also be provided, which shows diversity in cost estimation. All the outcomes can be displayed graphically.

If there are different design options, or different estimates for the same options given by different experts at different time, IDS provides side by side comparison for all the cost estimates at any level of the category hierarchy.

Figure 7 illustrates the overall cost estimates provided by certain experts at different time as t_1, t_2 and so on. As time goes by, more information will be collected or become available. At the same time, the cost estimates will be with less and less uncertainties. For instance, at the two points of t_1, t_{16} , their cost estimates are completely different, i.e., the former has an estimate with large uncertain range whereas the later has an estimate with nearly no uncertain range at all. IDS may provide a visual aid to see such trend, which could help to guide the real cost estimation for large scale engineering projects under uncertainties.

Such visual comparisons and trends can be carried out for all or selected options in any category or a group of categories in the hierarchy. For example, the cost estimates for the lower level category, reactor vessel, is shown in Figures 8. Figure 9 displays the indicative total cost estimate and its break down in lower level categories, which indicates that Linac is the biggest cost contributor in this case.

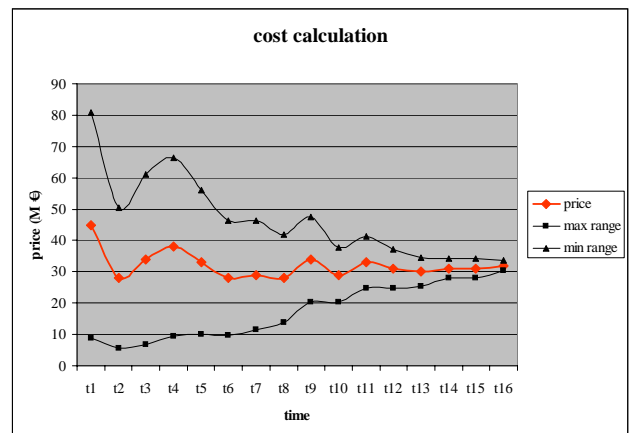


Figure 7. The overall cost estimate at different time.

When there is missing or partially missing data, and uncertainty in input, it is only rational to expect a certain degree of uncertainty in the output. When the cost estimates for each element is provided as a range, the overall estimate provided will also be in range. The IDS tool indeed demonstrates such rationality and reflects a certain degree of uncertainty in the output as shown in Figure 7.

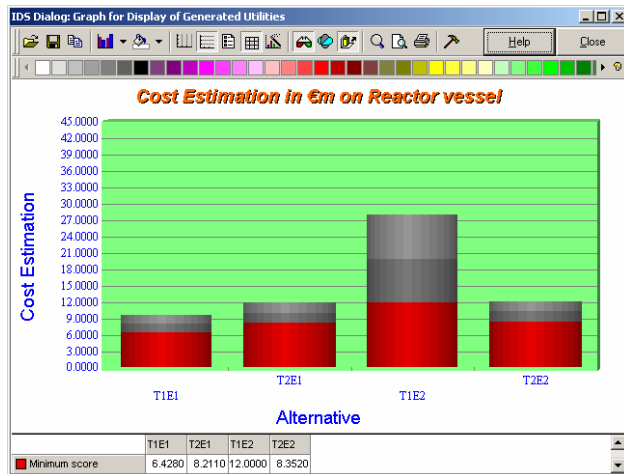


Figure 8 The cost estimate on reactor vessel

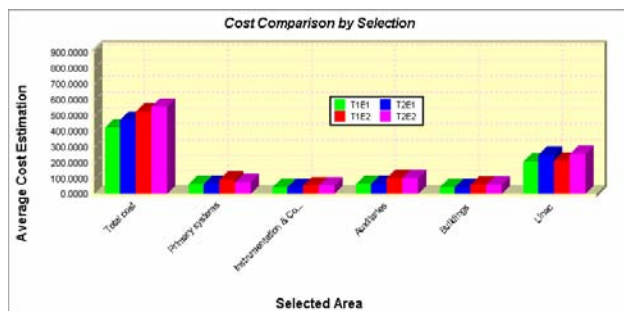


Figure 9. Cost comparison for a selected group of attributes

There are many other functions in IDS Cost Estimator. For example, the Text Report Generator can output the cost hierarchy model and the cost information to a text file so that such information can be easily incorporated into a report. It can also import other cost model and estimates into another model so that information collected previous can be used repeatedly.

In summary, using IDS for cost estimation has the following main features:

- There is no need to convert probability distributions into average numbers
- Uncertain or incomplete information can be used so that loss and distortion of available information are minimized.

- It can also be used for benefit analysis and cost-benefit trade off analysis.

The main advantages of using IDS for cost estimation are that:

- It provides a structured, flexible and natural framework for analysing complex cost estimation problems,
- it supports more consistent, reliable and informative cost estimations and comparisons between different options, and
- It facilitates more effective and efficient knowledge management and communication.

4 Conclusion

IDS helps cost estimate process by decomposing costs into categories and subcategories or items. It then organises the decomposition into a category hierarchy in an interactive graphical interface. It can accept input data (cost estimate for each decomposed item in the hierarchy) with or without uncertainties: quoted costs from suppliers, rough guess with a range, and cost estimate from a group of experts whose estimates may not agree with each others, cost estimates with probability uncertainty or subjective uncertainty.

From the input data, IDS can generate overall total cost estimate and cost estimates in any category or subcategory. When there are uncertainties in input data, a range (lower bound and upper bound) of the estimate can also be provided at any level of the category hierarchy. If necessary, a distributed cost structure in each category can also be provided. All the outcomes can be displayed graphically. If there are different design options, IDS can compare cost estimates for all options at any level of the category hierarchy. In this paper, we provided a case study on the Myrrha project to illustrate how IDS Cost Estimator can be used for cost estimations of large scale engineering projects with various uncertainties. We strongly believe the IDS tool will be useful for the cost-benefit analysis of nuclear systems in particular and for any large scale engineering projects in general.

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