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TECHNICAL REPORT

Subjective Probability Distribution Elicitation in Cost Risk Analysis

A Review

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Prepared for the United States Air Force

PROJECT AIR FORCE

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Summary

It has become a truism of cost estimation that there is no "right" cost estimate; for any particular estimate, there is some inherent probability that the actual cost will exceed the estimate. A cost estimate is actually a forecast in which inherent uncertainties arise from changes in requirements, technology, the economic environment, and a multitude of other factors. One major approach to *cost risk analysis*—evaluating and quantifying the uncertainty in a cost estimate—has been probabilistic: to express the uncertainty in a cost estimate as a probability distribution over a range of possible costs. To get probability distributions for the characteristics and costs of new and untried technologies for which little data are available, cost analysts have often proposed tapping the resources of expert judgment and eliciting subjective probability distributions to quantify cost uncertainty.

Elicitation of subjective probability distributions as an area of research in its own right arose out of several developments in statistics and psychology and in demands from the field of general risk analysis. Experiments in elicitation indicated that human beings were subject to a number of serious biases, such as overconfidence in their ability to quantify uncertainty, which distorted their judgment about uncertainty.

How elicitation for cost risk purposes is actually practiced is difficult to determine. There is little information in the professional cost risk literature, and elicitation practices are very diverse—even in such disciplines as space systems acquisition, which involves a limited number of organizations and so is an area in which one might expect a high degree of methodological standardization. This, despite tutorial materials routinely recommending elicitation of expert judgment when data are scarce or when historical data might be irrelevant.

What practical advice can be given? A start can be made with the following procedure, which is synthesized from a number of sources:

- Use multiple independent experts.
- Ask an expert to provide, at a minimum, upper, lower, and most-likely values for cost elements under consideration.
- Fit a triangle distribution[1] to these three numbers, but using the upper and lower values to bound 90 percent of the probability (where reasonable, to counteract known biases in elicitation).

[1] For the triangle distribution, the probability is set to zero outside the endpoints, while between the endpoints the density rises linearly from the lower value to the most-likely value and then decreases linearly from the most-likely value to the

- In addition to the upper, lower, and most-likely values, elicit at least two more percentiles (perhaps the 25th and 75th, as recommended by several current authors).
- Provide feedback to the expert about the results of the elicitation, including the final range of nonzero probabilities, the median estimated cost, the probability that the final cost will exceed the most-likely cost, and so on.
- Carefully document the process and the results and archive the data obtained, for future retrospective studies.

The cost-estimation community is in general agreement that probabilistic methods of quantifying and reasoning with uncertainty are the most rigorous methods of cost risk analysis. What is needed is a systematic set of empirical case studies of elicitation in cost risk analysis to allow retrospective studies of the effectiveness and accuracy of different techniques. These case studies will provide cost risk analysts with a set of credible tools to do elicitation that can be compared and refined with further experience. Cost risk analysis is in a unique position to contribute to the development of elicitation procedures: It has a need for elicitation to quantify significant uncertainties, it has many different opportunities in government and industry to apply these techniques and test them, and it has quantitatively sophisticated practitioners who can help advance the field of elicitation.

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upper limit. The value of the density at the most-likely value is chosen so that the density integrates to one, as required for a probability density.