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Project Risk Analysis Using Simulation of Activity Networks: Is It Valid, Practical, and Teachable?

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Abstract

Recently, simulation-based methods for cost/schedule risk analysis using activity networks have begun to be used by some front-running companies in manufacturing, construction, power and other industries which require internal approval and/or external bidding for multi-million dollar projects. Interest in these methods is largely due to their availability as extensions to commercial project management software and cheaper/faster hardware capable of running the simulations in a timely manner. However, there is still skepticism among engineering managers regarding their validity and practical difficulties of model construction and data gathering. This paper presents some issues regarding development, use, and application of cost/schedule risk analysis software, and discusses related pedagogical concerns.

Introduction

Cost/schedule risk analysis extensions to commercial PERT/CPM-based software which use Monte Carlo simulation, intended for design-stage applications such as bid preparation, have only just become available in the past few years [1, 2]. Other network simulation packages have been available much longer [3], with use chiefly in government contracted projects, but without widespread commercial industry acceptance due to the time required for modeling and -- most importantly -- general skepticism about the underlying methodologies. However, many companies are revisiting project risk simulation using improved software and cheaper/faster hardware. Some companies have developed their own methodologies/software and are integrating them into the decision-making process for large capital projects. Others are experimenting with commercial software in pilot applications, and managers and developers are actively debating their legitimacy. There are strong incentives for companies to examine (or reexamine) simulation-based risk analysis methods. Large engineering projects are increasingly high risk, low margin ventures due to competitive pressures. Traditional methods of project cost and schedule estimation -- which rely strongly on parametric extrapolation from past production data and the intuition of experienced personnel -- are proving inadequate for the rapidly changing competitive/innovative production environments.

In this paper, we provide a brief overview of simulation-based project risk analysis by asking three questions relevant for educators in engineering economics: *Is it valid?* ; *Is it practical ?; Is it teachable?*

Is It Valid?

As defined here, simulation-based project risk analysis involves repeated random sampling of individual activity durations in a network and repeated quantification of the associated project cost and completion time. A PERT/CPM-based output file from commercial project management software is the usual starting point for developing the risk model. As typically created during pre-contract design phases, this initial data contains only precedence information and fixed time durations (and no cost information). Cost and other model-specific data, risk factor data, and uncertainty distributions for activity durations must then be assigned as preprocessing steps to a risk simulation. Issues related to methodological validity include: stochastic risk dependencies between activities; time-dependent cost modeling; proper abstraction of the activity network structure; and expert elicitation for activity duration uncertainties. Recent research by the authors has explored these issues and is described in detail in other publications [4, 5].

Stochastic Risk Dependencies. One significant methodological problem is the fallacious assumption of statistical independence for individual activities in traditional Monte Carlo simulation of project networks. Monte Carlo simulation approximates an assumed multivariate distribution of the uncertainty of total cost/time in a project by repeated random sampling of each individual activity duration in the network. However, Monte Carlo assumes *independent* marginal distributions for these activity durations. This assumption can potentially lead to serious underestimation of total cost/time uncertainty. As a hypothetical example from the shipbuilding domain, consider a new, unbuilt tanker hull design which would utilize identical hull sub-blocks for the full length of a constant-cross-section hull mid-body. As well as the new hull block design, a promising but not-yet-implemented type of robotic fabrication is to be introduced. If twenty-four such hull sub-blocks are required, the time to fabricate and erect each hull-block is uncertain, but each activity duration has in common factors which contribute to this uncertainty. These factors might include production efficiencies for robotic fabrication, alignment issues during erection, or even weather effects. A standard Monte Carlo simulation would generate the duration for each of these activities completely independently, ignoring any such risk dependency.

Expert Elicitation for Activity Duration Uncertainties. One criticism of activity network simulations for risk analysis is the difficulty of estimating probability distributions for activity durations. Most PERT/CPM-based project management software allows worst/nominal/best case inputs for activity durations, and network simulation packages typically use triangular, uniform, Normal, and other common theoretical distributions to characterize activity duration uncertainty. Techniques for subjective estimation of probability distribution parameters include the Normalized Geometric Vector method, the Modified Churchman-Ackoff Method, and the Delphi Technique. However, the choice of distribution type often appears to have a relatively small affect on the analysis results when fitted to the same parameters for upper bound, lower bound, mean, and standard deviation. Interestingly, recent research in eliciting expert judgment [6] found that "upper bound" and "lower bound" estimates of experts usually correspond to p-th quantile points in a triangular distribution rather than the actual upper and lower bounds of the distribution itself.

Time-Dependent Cost Modeling. Risk for commercial profitability for many engineering projects is highly schedule-dependent. Aside from increased direct labor costs, delays in delivery time can tie up capital resources and often require payments for liquidated damage clauses in owner contracts. Also, discounted cash flow effects can be significant because production spans many months and involve large cash outflows for equipment and material deliveries, complex financing arrangements, and payments based on percent completion. Therefore, a risk analysis method should ideally integrate activity network information into the cost model. Direct labor rates, material costs, and subcontractor payments are relatively simple to assign as cost attributes for each activity in the network representation. However, determining the best way to represent indirect costs and certain other financial effects is more difficult. Indirect costs and the way they are organized for overhead allocation will vary according to firm practices and circumstance. However indirect costs are assigned in the model, the total project cost estimate resulting from the network simulation should be compared with results of other cost estimation procedures in the firm.

Configuration of Activity Networks. Users must determine the appropriate *level of detail* to model in the activity network. For example, shipbuilding networks for schedule estimation prior to contract signing used about 250 activities in several observed cases (versus ~10,000 activities in later, on-going project management). Understanding the correlation between network size and validity of analysis will require trial-and-error experimentation; there is obviously some point of diminishing returns for increased model complexity. Also, the PERT-type network assumed in most methodologies has an acyclic graph structure. That is, it assumes that all activities in the network will be realized one time and only one time during the project. This assumption is reasonable for well understood construction methods, but may be questionable for highly concurrent processes which include both product and process design innovations. One possible enhancement to the stochastic network might be conditional branching to model alternative possible paths which have non-deterministic realization probabilities. However, introducing conditional branching would add another dimension to subjective uncertainty estimation which would complicate but not necessarily improve model validity.

Is It Practical?

The authors have observed the practical application of simulation-based project risk analysis, particularly among civil construction firms. Practices at one such firm, Ballast Nedam Engineering (based in the Netherlands, with $1.8 billion revenues in 1994), were documented in the course of a recent project [7]. Their risk analysis department has been using simulation-based risk analysis in project planning and budgeting for over seven years. Typically large projects exceeding an overall budget of $30 million are candidates for a risk analysis, however smaller projects may be considered as well. The method used by Ballast Nedam consisted of five main steps:

1. Model Building. Using the tendering documents of a project, drawings, planning and personal communications with the engineers, an initial system description is formulated. The system description consists of two main components: a) a list of activities to be executed, including their interrelations and completion time and b) a cost matrix which indicates costs associated with each activity. Each cost is classified by a cost type. In addition, liquidated damages are set and milestones are selected. A construction project may consist of more than 1000 activities even in the tendering phase. However, partly due to time constraints in the tendering phase of a project and difficulties with estimating all the parameters in case of large projects, for risk analysis purposes a large network is collapsed to a network of no more than 100 "Main Activities."

2. Qualitative Uncertainty Assessment. During the tendering each project team member has been assigned a specific task: estimators develop a cost estimate, planners develop the schedule, the purchase department obtains price quotes on materials, etc. A Risk Item List (RIL) is prepared and distributed among all team members who write down what they consider the project risks or uncertainties. In addition, the RIL contains possible countermeasures in the case of a bad event happening. Using the RIL, it will be decided by the project team in the tendering phase which risks will be insured and which risks will be accounted for in the cost price by budgeting the counter measure. The remaining risks should be accounted for in a quantitative risk analysis.

3. Quantitative Uncertainty Assessment. For each activity one determines sources of uncertainty. The RIL generated in the former step is used as a guideline. Sources of uncertainty are divided into two groups: Normal Uncertainties (in completion time, price, and quantities) and Special Events (discrete events identified in the RIL). Experts are asked to provide a lower and upper bound for the duration of an activity. The value used to calculate the cost estimate in the planning and budgeting documents is used as the most likely estimate. The lower bound and upper bound are interpreted as 5% and 95% quantile respectively. From this, a triangular distribution is used to model the activity duration uncertainty. The price of labor, equipment and materials are considered to be a separate uncertainty source. Again, lower bounds and upper bounds are determined. Together with the price estimate in the cost estimate, a triangular distribution is used to model the overall uncertainty. The amount of materials used is considered a separate source of uncertainty. The uncertainty in these quantities are modeled as above. For special events, the project team estimates the probability of occurrence of this event and the consequence of this event with respect to cost and duration. Usually, multiple people give their estimates after which their opinions are combined in a consensus estimate.

4. Simulation. A software package developed in-house is used to simulate the network. The software package generates uncertainty distributions for total completion time and total project cost. Attempts have been made to model statistical dependence between the uncertainty in the input parameters. However, the results have not been satisfactory. Therefore, independence is assumed. No discount factor is used, and only non-discounted cost is calculated in the package. Learning curve effects are incorporated directly in the duration estimate for repeated activities. Finally, the number of simulations used was 10,000, which is the maximum number of simulations the program can generate.

5. Interpretation. The generated distribution of the total completion time and the total cost of the project are used to help determine a price proposal for the project. If the initial simulation results are not considered meaningful (e.g., cost and time distributions are inconsistent with the fixed estimates of other analyses), several reasons could be given e.g.: the system description is incorrect; one forgot to identify a risk source; the quantification of the uncertainty in the project is not realistic. If such is the case, one has to go back to Step 1 and redo the analysis. Once a satisfactory result is obtained, several procedures are available to aid the decision-making in the price proposal. Typically, one uses average cost with profit margin as a starting point. However, usually this criterion does not satisfy one or more of the risk criteria such as the probability of losing a particular amount of money. The difference between the average cost with profit margin and the price compliant with the risk averseness in one of the other risk criteria is termed risk overhead. The price proposed is then presented as an average cost with profit plus the risk overhead. The resulting price proposal from the risk analysis is only one of several inputs for the decision-making process. Sometimes, for example, external strategic or political concerns can drive a bid price more than the actual project data. The risk team acknowledges many areas for improvement in both theoretical modeling and integration with procedures in other departments, and some managers in other departments are still skeptical of its benefit. However, it has strong support from upper management and is an increasingly accepted part of the overall estimating and bid process for large projects.

Is It Teachable?

If methodologies such as described above become increasingly used in industrial practice, might there be a role for them in the curriculum? First, students would first need a solid grounding in both engineering economics fundamentals and project management basics to introduce activity network concepts. Second, they would need to learn more than just the mechanics of the activity network cost/schedule simulation. It would be most beneficial to introduce them to the full "life cycle" of the project risk analysis process including expert elicitation and the types of qualitative judgment needed to construct realistic, complex models, such as cited above. One way to do this might be to introduce a graduated set of three case studies. The first would require students to construct, simulate, and analyze a small, ~10 activity network to introduce modeling particulars, software familiarity, and data gathering concepts. A second case study might involve simulation and analysis (but not construction) of a larger, pre-existing network model adapted from an actual project. Such a teaching case would be best if enhanced with multi-media graphics to 1) quickly familiarize students with the project domain (e.g., video clips of different ship production activities); 2) allow graphical manipulation of complex network structures and related data, particularly "roll up" of activity subsets at higher levels of abstraction. These first two cases would involve individual student assignments. A third, final case study would be team-based, requiring students to construct a model from multiple sources using team roles similar to those found in industry.

In an on-going master's thesis that has followed the research cited in [4, 5], the participating graduate student is an experienced shipbuilding cost analyst. He has found, as have other research participants, that modeling a project activity network under uncertainty greatly improves one's understanding of engineering project cost and schedule behaviors. We are currently investigating extending this learning experience to a graduate-level course. However, the curriculum development issues are formidable.

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References

[1] Primavera Systems, Inc., *Monte Carlo for Primavera: Project Risk Analysis Software* . Reference information at http://www.primavera.com/products/products.html, 1995.
[2] Welcom Software Technology, *Guide to OPERA* (Open Plan Extention for Risk Analysis). Reference information at http://www.wst.com/products/opera.html, 1995.
[3] Cockerham, Hohn M., "RISNET Analyst's Guide," John M. Cockerham & Associates, Huntsville, AL, 1972.
[4] Duffey, M.R. and van Dorp, J.R., "Risk Analysis for Large Engineering Projects: Modeling Cost Uncertainty for Ship Production Activities," *Journal of Engineering Valuation and Cost Analysis*. Accepted May 1997, forthcoming.
[5] van Dorp, J.R., and Duffey, M.R., "Statistical Dependence in Risk Analysis for Project Networks Using the Monte Carlo Method," Technical Report, George Washington University.
[6] Cooke, R.M., Experts in Uncertainty, Oxford University Press, New York, 1991.
[7] Koenig, P., Duffey, M., Rosen, D. and Singh, P., "Design Infrastructure in Shipbuilding and Other Heavy Industries, *Transactions of the Society of Naval Architects and Marine Engineers* (SNAME), vol. 104., pp. 191-217, 1996.

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