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MONTE CARLO SIMULATION FOR SCHEDULE RISKS

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ABSTRACT

Research was undertaken to assist practitioners in undertaking Monte Carlo simulation of project schedules. A probabilistic model was developed to translate project characteristics into schedule risk boundaries. This model has been tested in several projects and performed very well. Lessons learned during the application of Monte Carlo simulation to a large project are discussed.

1 INTRODUCTION

One of the barriers to the common use of Monte Carlo simulation in industry is the effort required to estimate multiple parameters. Development of a Monte Carlo simulation requires the user to acquire the parameters for a distribution of values instead of the usual single (generally, the mode or most likely value). The distribution parameters can come from data where they are available, or from educated estimates of domain experts. For this research, the focus was on the risks associated with schedules of building construction projects (Nasir 2000).

A model was developed to assist practitioners in translating project characteristics into a measure of risk for Monte Carlo simulation. The model was developed in the Bayesian belief network environment, which relies on nodes to represent variables in the problem domain, and directed arcs to indicate conditional dependence relationships between the variables. Probabilities are incorporated into the model to represent the strength of the relationship. For more information on belief networks, the reader is encouraged to read Jensen (1996) or McCabe et al. (1998).

Development of a model requires four steps. First, the variables and their states are identified. To achieve this, the scope of the problem domain and level of detail must be determined. This information may come from the literature or from domain experts. Second, the relationships between the variables are established. Because the literature seldom provides information that can be used directly, information about the relationships are often elicited from experts or extracted from data where they exist. These relationships represent more than correlation; they can imply causation, although caution should be used to distinguish correlation and causation. Third, a probability is incorporated for each conditional relationship. Again, where data do not exist, experts may provide the information. Finally, the model must be verified and validated.

2 MODEL DEVELOPMENT

It has been assumed that the practitioner already has the most likely activity durations as part of their schedule, and that those durations are reasonable estimates. To complete the simulation model, the user then requires a distribution to represent the activity duration variance based on the project risks.

AbouRizk and Halpin (1992) found that the beta distribution is suitable for representing construction activity durations. The beta distribution can be approximated with a triangular distribution, which requires 3 parameters for its definition: the lower or optimistic limit, the mode or most likely value, and the upper or pessimistic limit. The model developed through this research provides the user with the lower and upper distribution limits as a percent of the most likely value based on the risk factors identified for the project.

Briefly, a search of the literature provided relevant information on variables found to affect building construction schedules. The major sources of information were:

- Baldwin & Manthei (1971): US building projects on weather, labor supply, subcontractors;
- Friedrich et al. (1987): Revisions, repairs, rework;
- Okpala & Aniekwu (1988): Nigerian projects with focus on major causes of delays/cost overruns are shortage of material, financing, payments for completed works, and poor contract management;
- Laufer & Cohenca (1990): Labor issues, labor availability, weather, incomplete design, planning;
- Elinwa & Buba (1993): Nigerian projects with focus on poor project management, variations, late payment, change order, inadequate site investigations;

- Yates (1993): Project control, engineering, equipment, external delays, labor, management, materials, owner, subcontractor, weather;
- Christian & Hachey (1995): Productivity, waiting time delays especially for supervision;
- Hinze & Russell (1995): Productivity, labor injuries;
- Thomas & Napolitan (1995): Productivity, congested area, out of sequence working, weather, rework, disruptions, length of work day, material, equipment availability;
- Williams (1995):Fast track projects, design inadequacy, design error, qualified team;
- Ogunlana et al. (1996): Thailand projects with focus on material shortage, labor overwork, frequent design changes;
- Fisk (1997): Project administration, labor unions;
- Songer & Molenaar (1997): Owner staffing, budget;
- Majid & McCaffer (1998): Material, labor, equipment, financial, improper planning, subcontractor, poor coordination, inadequate supervision, improper construction methods, technical personnel shortage, poor communication;
- Ng et al. (1998): Singapore buildings with focus on change orders and weather.

Unfortunately, very little was found about the relationships or interactions between those variables. A group of experts was gathered to provide the remaining information required for the model. They all had 15 or more years of experience in the construction industry. The experts were asked to review the variables from the literature and to add variables they believed to be missing. Table 1 provides the risk variables used in this model.

The relationships and probabilities required to complete the model were elicited from the experts, as data were not available. A sample of the model is shown in Figure 1. Although it appears messy, the modeling environment is very logical, allowing domain experts to understand the concepts of the model without having to understand the probability theory behind it. The model was tested on 14 completed projects with excellent results (Nasir et al. 2003).

Unfortunately, the belief network model was intimidating to most practitioners questioned. Therefore, a user interface software was developed to help the practitioner to implement the model without having to deal with its complexity. Figure 2 shows the opening screen, where the user is asked to enter only that information which is known with certainty. The variables for each category are provided on a separate page, as shown in Figure 3. The 'Evaluate Now' button is clicked when the project factors are all entered. The results are shown in Figure 4 and in more detail in Figure 5.

Table 1: Risk Variables and Description

Area Conditions	
Construction Area	On Site Congestion
Reconstruction Project	Traffic Permits, Approvals
External Site Activity	Intense Security
Traffic Conditions	Working Hour Restriction
Contractor	
Contractor Prequalified	Defective Work
Rework	Contr'r Ability, Experience
New Technology	Short Breaks
Contractor Non-Labor Resources	
Vendor Bondability	Damage to Equipment
Critical Items Import	Equipment Shortage
Equipment Quality	Theft of Equipment, Tools
Equipment Failure	
Design	
Fast Track Schedule	Innovative Complex Design
Design Team	Design Specifications
Multifunctional Bldg.	Design Quality
Project Definition	Design Changes
Environmental	
Earthquake	Precipitation
Seasons	Humidity
Geotechnical	
Geotechnical Consultant	Archeological Survey Done
Local Geotech'l History	Unexpected Subsurface Cond'ns
Labor	
Labor Union	Labor Skill Level
Labor Dispute/Strike	Potential for Adverse Activities
Labor Availability	Labor Injuries
Labor Wage Scales	Labor Productivity
Materials	
Material Procurement	Reliance on JIT Delivery
Secure Material Yards	Material Shortage
Material Theft/Fire	
Owner	
Owner Type	Owner Financial Stability
Decision Making	Progress Payment
Political	
Community Attitude	Potential of Delay by Others
Strong Dissenting Group	Project Stopped Abandoned
	Relevant Public Inquiries

The results are provided as categories of activities: de/mobilization, foundation/piling, demolition, labor intensive activities, equipment intensive activities roof/ exterior building, mechanical/electrical/plumbing, and, commissioning. The user can review the activities in their schedule, decide which category best describes the activity, and

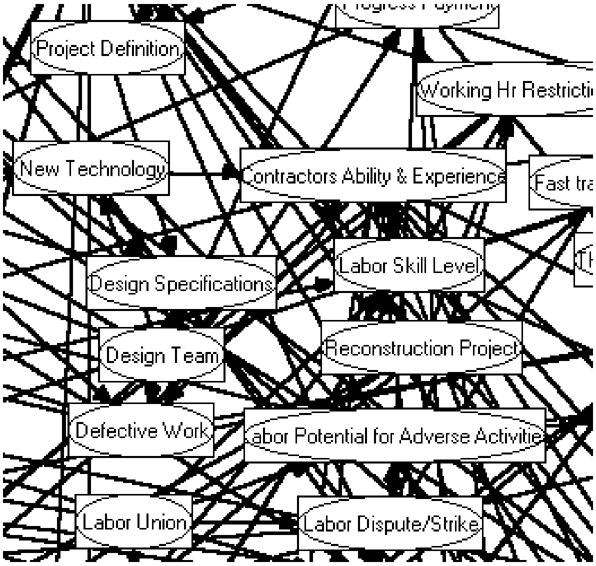


Figure 1: Sample of the Belief Network Model

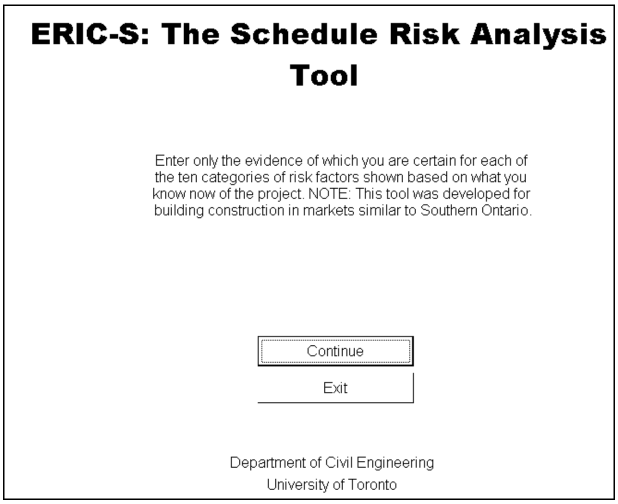


Figure 2: The Opening Screen

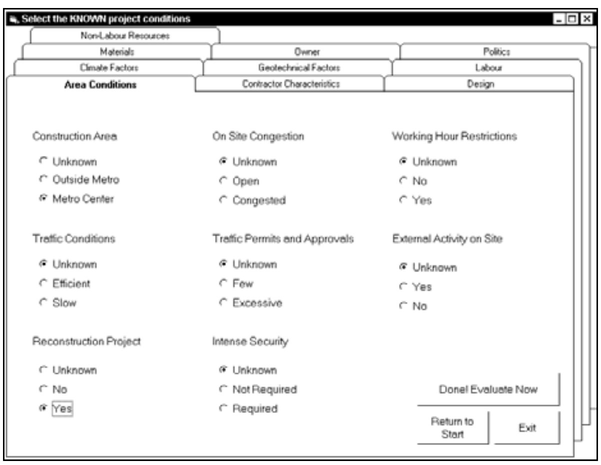
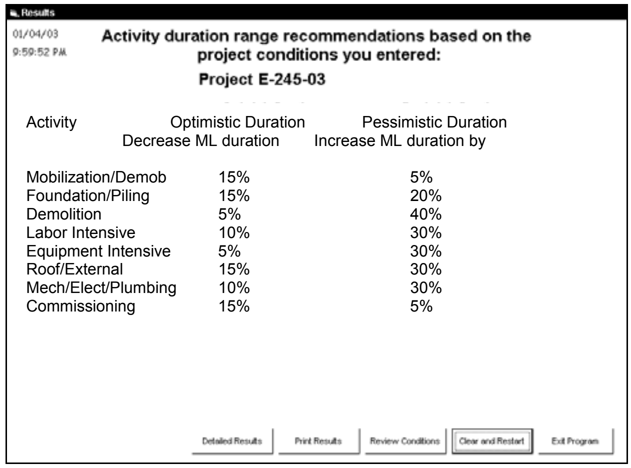


Figure 3: Entering the Project Characteristics



Results

01/04/03
9:59:52 PM

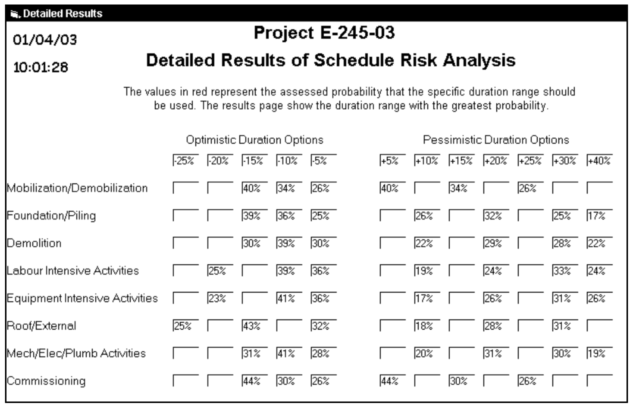
Activity duration range recommendations based on the project conditions you entered:

Project E-245-03

Activity	Optimistic Duration Decrease ML duration	Pessimistic Duration Increase ML duration by
Mobilization/Demob	15%	5%
Foundation/Piling	15%	20%
Demolition	5%	40%
Labor Intensive	10%	30%
Equipment Intensive	5%	30%
Roof/External	15%	30%
Mech/Elect/Plumbing	10%	30%
Commissioning	15%	5%

Detailed Results | Print Results | Review Conditions | Clear and Restart | Exit Program

Figure 4: Analysis Results



Detailed Results

01/04/03
10:01:28

Project E-245-03

Detailed Results of Schedule Risk Analysis

The values in red represent the assessed probability that the specific duration range should be used. The results page show the duration range with the greatest probability.

	Optimistic Duration Options					Pessimistic Duration Options						
	-25%	-20%	-15%	-10%	-5%	+5%	+10%	+15%	+20%	+25%	+30%	+40%
Mobilization/Demobilization			40%	34%	26%	40%		34%		26%		
Foundation/Piling			39%	36%	25%		26%		32%		25%	17%
Demolition			30%	39%	30%		22%		29%		28%	22%
Labour Intensive Activities		25%		39%	36%		19%		24%		33%	24%
Equipment Intensive Activities		23%		41%	36%		17%		26%		31%	26%
Roof/External	25%		43%		32%		18%		28%		31%	
Mech/Elec/Plumb Activities			31%	41%	28%		20%		31%		30%	19%
Commissioning			44%	30%	26%	44%		30%		26%		

Figure 5: Analysis Detailed Results

enter the analysis results directly into model as a percentage of the most likely value. The detailed analysis results are provided for those practitioners wanting detailed information about the estimates.

3 MODEL APPLICATION

The model was applied during a risk analysis at a large infrastructure project in parallel with eliciting the range limits from 8 project managers. In this project, Primavera Project Planner © and Primavera Monte Carlo © were used.

The schedule had over 2000 activities, and the activities were allotted to them based on their area of expertise (e.g. structural, mechanical). It took over 6 weeks to collect all of the information. There appeared to be 2 main reasons for the delay. First, they were overwhelmed by the number of activities that had to be reviewed; on average, they each had to provide duration limits for 250 activities. Second, they were not experienced in providing this type of information, therefore, they were not confident in their estimates and needed time to think about it. In general, they found the process tedious and non-productive.

The probabilistic model provided a second opinion of the limits for each activity. It took approximately 2 hours to determine the project risks, enter them into the software, get the results, and enter the duration ranges into the Monte Carlo model. The two methods for providing the activity duration limits provided similar distributions, with the probabilistic model providing a slightly wider distribution. The Monte Carlo simulation results were almost identical.

4 LIMITATIONS TO MONTE CARLO SIMULATION

A few lessons were learned during the previous application. First, the CPM schedule to be used as the basis for analysis must be complete and correct. In this context, complete refer to having all activities properly tied in with predecessors and successors and lags where appropriate. Correct refers to using durations that do not include float, that reflect the activity scope, and reflect the construction plan. Negative lags should be avoided as they do not represent the way activities are undertaken in the field.

Second, experts are very comfortable estimating the most likely values of an activity duration, but are not as experienced at estimating the lower and upper limits. The collection of real data to support these estimates would be very beneficial; however, the estimates provided by the probabilistic model did offer some confidence.

Third, there is a lot of skepticism in industry of the value of the results. This skepticism appears to be based on unfamiliarity with the technique; however, the author believes that it can provide both owners and contractors with valuable information about their risks. It is hoped that the probabilistic model will help to bring Monte Carlo simulation to wider use.

Fourth, it is quite difficult to accurately represent correlation between activities, so approximations are developed to simplify the process. The effect of these approximations are not known with certainty.

5 CONCLUSIONS

This paper discussed the development of a probabilistic model to assist in estimating lower and upper duration estimates required in the preparation of a schedule risk analysis using Monte Carlo simulation. The model was tested in 14 projects with excellent results. The application of the model to an ongoing project was discussed along with lessons learned.

The author believes that Monte Carlo simulation can provide valuable information to the owner and the contractor. Unfortunately, lack of common knowledge about the technique is a major barrier to its use.

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