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The most often heard reason given as an excuse for a job gone wrong is that construction is a risky business. It is true that one may encounter physical conditions or circumstances during the project which are exceptionally adverse or were not foreseeable, and therefore considered unavoidable. Nevertheless, their impact is often manageable.

This is the second time that the lead article of the Revay Report discusses construction risks. The first was in July 1993 (Volume 12, Number 1). Additionally, we have dealt with this topic a number of times at various seminars. Unfortunately, we could not have been very convincing, or our message fell on deaf ears. In any case, many contractors and buyers of construction services still embark on projects without analysing the risks involved and without implementing risk management techniques. One of the explanations one hears is that risk analysis is too complicated, and its cost outweighs its benefits.

In this article we are trying to lift the mystery surrounding risk analysis and show that it can be done inexpensively by most experienced schedulers. This type of analysis will help to evaluate eventual impact(s) — e.g. cost and time — which may result from unwanted or unpredictable events or circumstances. Knowing the potential impacts one can then decide on an appropriate response, such as: 1-possible prevention, 2- transfer or sharing of the consequences (e.g. insurance), 3- minimization of the eventual impact by selecting a suitable method of construction, etc.

Construction Risk

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Managing a construction project is often compared with fire fighting — problems that arise must be handled immediately. However, how many of those problems could have been avoided? The resources required to react to immediate problems takes away from effort that might otherwise be put toward a more proactive plan of avoiding difficulties. Risk analysis can be an effective tool to help identify where the problems can occur.

The Oxford Dictionary defines risk as *"a chance or possibility of danger, loss, injury, or other adverse consequences".* This article reviews risk analysis in construction and provides an example of how a PERT analysis could be undertaken.

Uncertainties have been classified as known, known-unknowns, and unknown-unknowns. Known risks have a range of potential outcomes that can be defined. Examples may include weather events and labour strikes. Known unknown risks are not expected and their outcome is more difficult to assess. Examples may include earthquakes, war, or terrorist acts. Unknown-unknown risks are unimaginable, and cannot be defined. The goal of risk analysis is to assess known risks. If the risks are unknown, then a crystal ball might be more cost-effective. Therefore, to make a risk analysis exercise meaningful, three conditions must exist. First, the risk must be known. Second, there needs to be some understanding of the effect the risk might have on the project. And third, the effects must be significant enough to worry about.

WHEN COULD RISK ASSESSMENT BE BENEFICIAL?

Risks are often defined by the probability that the problem happens and the cost that will be experienced if it does happen. The expected value of the risk is the probability multiplied by the cost. For example, if an equipment breakdown happens one day out of ten, the probability of breakdown is 10%. Assume the cost associated with the breakdown is $10,000. The expected value of this risk is 0.10*$10,000=$1,000 each day. If this amount is greater than the company is willing to risk, then ways for avoiding the breakdowns, such as earlier maintenance, should be developed.

If the projects undertaken by a company are all in the same geographic area, of approximately the same scope, if the problems are few and are easily solved when they do occur, then risk analysis may not be necessary. However, if any of these project characteristics change so that the change brings significant uncertainty, analysis might be beneficial. Changes in project conditions might include entering a new market, working in a different geographical area, encountering uncertain material or labour markets, or undertaking a project of larger scope than normally undertaken. Consideration of using a new construction method, having to work in a congested site, or looking at the effect of likely delays are also reasons to undertake risk analysis. New conditions may result from developing an innovative strategy for a project or crashing the schedule. Alternatively, if project conditions are stable, but the contractor regularly experiences problems, then risk analysis could be beneficial.

It is well known that decisions made early can have a greater impact on a project than decisions made after construction has started. Obviously, the earlier risk analysis is done for a project, the greater is the potential benefit.

ESTIMATING

To bid or not to bid, that is the first question. This decision is based on many factors including the likelihood of winning, the intensity of competition, the characteristics of the owner, the type of project, the strength of the market, and so on. Organizations often use a checklist to evaluate these decision factors. However, the temptation to bid is very strong, and more often than not, the decision is "yes". The risk associated with this decision is the cost of tender preparation for a project in which the bid is not successful. Although this is often considered a necessary cost of doing business, estimating can become a monster, consuming massive amounts of time and money. Careful evaluation of this item could substantially reduce overheads.

Construction estimating is a process of predicting future events. Contractors are provided with masses of data in the form of plans, specifications and contracts. In a relatively short period, they are expected to submit a cost-effective *and* profitable tender price. The predicted costs are based on an evaluation of the most likely labour productivity, equipment availability, and project conditions. Risk analysis at this point can highlight the most uncertain costs, and provide an understanding of those costs.

SCHEDULING AND PLANNING

Scheduling can be an excellent risk analysis opportunity because costs are often related to time. Critical Path Methods (CPM) and bar charts are the most popular scheduling methods used in industry. CPM provides additional information related to the critical path and activity relationships. The critical path is the series of activities that define the total project duration. A delay in an activity on the critical path will delay the completion of the project. Activities not on the critical path contain float. This means that they can be delayed by the float amount without affecting the project completion date. Popular software systems perform their calculations based on the CPM, then show the information in a bar chart format.

The major problem with CPM is that the activity durations are estimated as the most likely duration, and do not consider other possible durations and their effect on the schedule. A delay in one activity, even if it is not on the critical path, can affect the overall schedule if the delay is sufficiently long. The risk, then, would focus on the likelihood of having the project completed late such that extra costs are incurred.

RISK ANALYSIS METHODS

Three available methods for risk analysis are Program Evaluation and Review Technique (PERT) analysis, Monte Carlo analysis, and discrete-event simulation modelling. Other methods exist, but only these will be discussed here. PERT is based upon the Critical Path Method but takes the analysis one step further by allowing the planner to consider not only the most likely activity duration, but also pessimistic and optimistic activity durations. An example of PERT is discussed later in this article. One of the limitations of PERT is that it assumes that all of the activities are independent. In other words, it assumes that the actual duration of one activity will not affect the duration of other activities in the project. In many cases, this is an acceptable assumption. The assumption may not hold where several activities use the same resource, and the resource is not available in sufficient numbers. Note that resource can refer to equipment, labour, materials, tools, space, or any other feature that is needed to complete the activity. The result of a PERT analysis is the mean and standard deviation of the project completion time. From this, the likelihood of completing the project within a certain time can be determined.

Monte Carlo is a method of simulating the construction of your project to decide how each activity could turn out. Duration ranges are required as for PERT. A duration or cost of each activity is chosen based upon the range of values provided for that activity. Once the duration for each activity is chosen, the critical path and the total project duration are calculated. This analysis is usually performed several hundred times with different outcomes, just as though there was the opportunity to build the project that many times. The idea is that each run of the analysis represents what *could* happen on the project. The results are shown as a distribution of the project duration, and like PERT, the probability of completing the project within a certain time can be examined. In addition, the number of times an activity falls on the critical path can be provided. Monte Carlo analysis is more powerful than PERT because it does not assume that all activities are independent of each other.

Discrete-event simulation modelling refers to the use of a simulation language and an environment specifically developed for experimenting with operations on the computer. Several software systems are available with varying degrees of complexity. (In most cases, developing these models is complicated, and requires a simulation expert.) Models can incorporate resource interactions, delays, and random events such as weather. The information that can be extracted from them is enormous including comparisons of construction methods, identification of bottlenecks, and resource utilization.

Of the three, PERT requires the least effort to do. Both PERT and Monte Carlo analysis can be performed using a spreadsheet. Discrete-event simulation modelling is more involved, but it can provide more information about the project. In the next section, PERT analysis is discussed and an example evaluation is provided.

PERT METHOD OF RISK ANALYSIS

There are many methods for assessing risk that require varying degrees of effort. The use of CPM in scheduling has been briefly discussed. Its shortcoming is that it does not consider uncertainty or risk. The activity durations are the best estimate or most-likely duration, shown as ML, for a particular activity given the known circumstances of that project.

Program Evaluation and Review Technique (PERT) is a similar scheduling method to CPM with one important distinction — it incorporates uncertainty. Along with the most likely duration, two other values are required — a pessimistic duration and an optimistic duration. PERT is based upon the Central Limit Theorem (CLT). This means that if you can estimate the mean (average) and variance for each activity cost or duration, then you can use this method to assess risk of the total project. However, the variance is not intuitively understood. Variance can be looked upon as a measure of risk — the greater the variance, the greater the uncertainty. Luckily, there are simple ways of estimating it using our three duration estimates: the optimistic (Opt), pessimistic (Pess) and most likely values (ML). From these three estimates, one can calculate the mean and the variance (Var) as follows:

$$\text{Mean} = \frac{\text{Opt} + 4 * \text{ML} + \text{Pess}}{6} \qquad \text{Eq. 1}$$

$$\text{Var} = \left(\frac{\text{Pess - Opt}}{6}\right)^2 \qquad \text{Eq. 2}$$

According to the Central LimitTheorem, the total project duration can be calculated for each path by adding the means and the variances for each path. The longest duration path becomes the critical path. But we want to know about the risk or uncertainty in the schedule, so let's consider this simple example. In the CPM network shown in Figure 1, activities B and C follow A.

Figure 1: Example Network

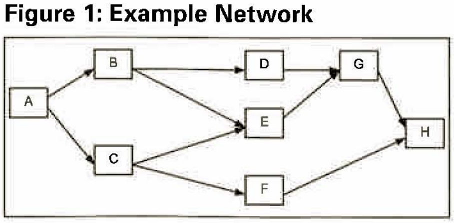

Table 2 : Activity Paths Analysis

Path	Mean	Var	SD	Low Range	High Range	75% Probability Duration
1-ABDGH	77.51	2.31	1.52	74.52	80.48	78.52
2-ABEGH	99.67	2.89	1.70	96.34	103.00	100.81
3-ACEGH	98.00	3.67	1.91	94.25	101.75	99.29
4-ACFH	63.67	2.72	1.65	60.43	66.90	64.78

Activity D cannot start until B is complete, and E cannot start before B *and* C are complete. This network has four paths that connect A to H i.e. from the starting activity to the last. These paths are ABDGH, ABEGH, ACEGH, and ACFH.

For each activity, the optimistic, most likely, and pessimistic duration is required. These values are shown in Table 1. The Mean and Variance are calculated using Equations 1 and 2, respectively. Note that the mean and the most likely values are not identical in all cases. If the difference between the Opt value and the ML value is the same as the difference between the Pess value and the ML value, then the Mean will be the same as the ML. This is the case in Activity B. The ML value is exactly midway between the Opt and Pess values. Therefore, the Mean is equal to the most-likely value.

It is assumed that the duration of Activity F is known with certainty, that is to say, it will take exactly 7 days to complete. Therefore, there is no difference between the optimistic, most likely, and pessimistic values. As there are more things that can go wrong than things that can go right, the difference between the Pess and the ML values is usually greater than the difference between the ML and the Opt values.

Therefore, each path in the network is analyzed to determine the total project duration, as shown in Table 2. The mean and variance values are the sum of individual values of the activities on the particular path. For example, the first path to be evaluated contains activities ABDGH. The mean duration of the path is the sum of mean durations shown in Table 1 of each activity. The mean path duration is 15.17+25.00+9.00+10.17+18.17=77.51 days. The standard deviation (SD) is calculated using Equation 3, which shows that the standard deviation is the square root of the variance.

Equations 4, 5, and 6 are used to calculate the low and high range values, and the 75% probability duration. The low and high range values indicate the shortest and longest duration for the project to be completed given a high level of certainty[1]. One may state with high certainty that the project will be completed within the low and high range values.

$$\text{SD} = \sqrt{\text{Var}} \qquad \text{Eq. 3}$$

$$\text{Low Range} = \text{Mean} - (1.96 * \text{SD}) \qquad \text{Eq. 4}$$

$$\text{High Range} = \text{Mean} + (1.96 * \text{SD}) \qquad \text{Eq. 5}$$

The importance of the low/high range is that the critical path(s) can be identified. To do this, look at the path with the greatest mean value, in this case, path ABEGH with a mean duration of 99.67 days. Then look at the low/high range values for the same path. These values are shown in bar chart format in Figure 2. If the range values for any other path fall within these two values, then the

1 For the statistics enthusiasts, the term 1.96 used in equations 4 and 5 relates to a level of certainty of 95%. This level of certainty is commonly used for range estimates.

Figure 2: Bar Chart of Duration Ranges for Paths

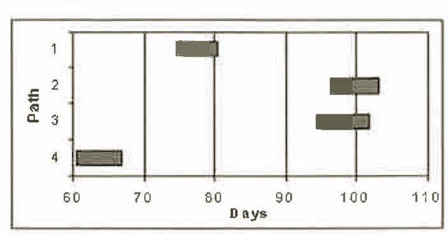

Table 1: Activity Durations

Activity	Optimistic (Opt)	Most Likely (ML)	Pessimistic (Pess)	Mean	Variance (Var)
A	13	15	18	15.17	0.69
B	22	25	28	25.00	1.00
C	20	23	28	23.33	1.78
D	8	9	10	9.00	0.11
E	29	31	34	31.17	0.69
F	7	7	7	7.00	0.00
G	9	10	12	10.17	0.25
H	17	18	20	18.17	0.25

overlapping path has the possibility of being the critical path. In this example, only path ACEGH overlaps, and could, therefore, also be a critical path depending upon how the project proceeds. Because the mean and low/high range values for these two paths are very similar, one could assume that they are both critical. Simple CPM calculations would not have shown this important information because it is only focused on the calculation of one critical path. The other two paths, ABDGH and ACFH do not have durations that overlap with the critical path durations, and will not affect the total project duration unless they are significantly delayed. Significant delay in this case means the difference between the Low Range value of the critical path (94.25) and the High Range value of the non-critical path (80.48). In other words, 14 days.

The 75% Probability Duration is calculated using Equation 6. A 75% confidence level means that 75 times out of 100, the activities can be completed in that time or less.

Table 3 shows the values of z_c for various confidence levels. Note that z_c for 50% confidence has a value of zero, and the Probability Duration is equal to the mean. In other words, if your calculations only consider the mean or average values, then you have only 50% confidence that you can complete the project within that time. As the level of confidence increases, the Probability Duration also increases because less risk is being accepted.

$$\text{ProbabilityDuration} = \text{Mean} + z_c * \text{SD} \quad \text{Eq. 6}$$

Table 3: z_c for Confidence Levels

Confidence Level	z_c
50%	0.00
60%	0.25
70%	0.52
75%	0.67
80%	0.84
85%	1.04
90%	1.28
95%	1.64

Where the cost of exceeding the schedule is very high, the analysis can be done backwards to find the probability of meeting that schedule. Then the contractor can assess his comfort with that probability. For example, assume that the contract states that the project must be completed within 102 days. Using Equation 6 with the Probability Duration=102, the Mean=99.67, and the SD=1.70 (taken from Path 2-ABEGH in Table 2), the value of z_c is 1.37. From Table 3 one sees that the level of confidence is between 90% and 95% that the project can be completed in that time. If the specified finish date is less than the Mean duration, then there is less than 50% chance of completing the project by that date.

CONCLUSION

Although this is a simple example, the information that can be gained through a PERT analysis is evident. By looking at the confident levels, the risk of accepting a schedule or budget can be calculated. The PERT method also identifies multiple critical paths in the network if they exist. The same technique can be used to evaluate costs except that no critical path exists - all costs will be experienced. Therefore, the total cost is the sum of all of the mean costs, and the variance is the sum of the variance of each cost.

Risk analysis methods discussed here include calculating expected values, PERT, Monte Carlo, and discrete-event simulation. As the method becomes more complex, there is more concern whether the effort is worthwhile — one must be reasonably sure that the benefits will outweigh the costs. If the analysis is performed, then the cost is related to the effort required to do it. The benefits would be an early understanding of the problems that may arise and the foresight to deal with them. The cost of not doing a risk analysis depends on what actually happens and what could have been avoided. However, it is not often that everyone agrees that doing a risk analysis is a waste of time. The biggest problem is understanding *how* to do it. PERT is an effective method for evaluating schedule or cost risk.

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