RISK-BASED COST AND SCHEDULE ESTIMATION FOR LARGE TRANSPORTATION PROJECTS

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1. INTRODUCTION

Golder Associates has developed a Quantitative Project Risk Assessment (QPRA) process for assessing cost and schedule of large infrastructure projects. Golder’s QPRA process has been applied to over 100 large infrastructure projects to date worldwide, mainly for public sector transportation clients in North America.

During the last three years the authors have been involved in promoting and delivering Golder’s QPRA services to large transportation projects in Canada. At present there is a large amount of transportation infrastructure either planned or underway in Canada in both urban environments such as depicted in the first photograph but also in rural environments as depicted in the second photograph. Road construction in both of these environments faces different challenges; the QPRA process presented in this paper is quite general. It is flexible enough to be applicable to both environments. The authors believe that Golder’s QPRA process would be beneficial to managing infrastructure projects in European too.

In Golder’s QPRA process, cost and schedule are estimated probabilistically. Rather than using a single number to represent a project component a probability distributions is used instead. This allows uncertainty to be explicitly incorporated into the cost or schedule estimate for that component. The probability approach
gives both a range of cost/duration values and also an associated likelihood for each value within the range.

Inspection of the probability distribution for overall QPRA cost, provides a realistic expectation to project engineers and planners regarding the probability of meeting a target budget. For example, if the target budget comes in at the 50th percentile of the QPRA cost estimate (which is quite typical), engineers will know that they have only 50:50 chance of meeting the target budget. If planners want to be 80% confident that the budget will be not exceeded, they can use the 80% percentile of the QPRA cost and get buy-in from decision-makers for that amount.

The inputs to a QPRA assessment are provided by the engineers, planners and other knowledgeable people associated with a project. Elicitation of appropriate project information is performed by personnel from Golder’s QPRA team in a workshop setting. Members of Golder’s QPRA team have been intensively trained in the QPRA process and are experienced professionals with backgrounds in risk assessment, applied probability, simulation modelling and workshop facilitation. QPRA captures those uncertain (risk) events which contribute to cost and schedule uncertainty such as environmental, engineering and socioeconomic factors. Probability distributions are used to quantify these uncertainties as well as the associated consequences: impacts on cost and schedule. A simulation model is developed to capture the inter-relationship between these risks and the effects on cost and schedule, where significant. Analysis of the model outputs provides quantitative information which can be used for effective project risk management.

Golder’s QPRA was developed a few years ago by William J Roberds and co-workers of Golder Associates, Seattle, WA, USA at the request of Washington State Department of Transportation. A brief summary of the benefits of performing the QPRA process was given in (Maher, 2005). A detailed and definitive account of the QPRA process oriented to professional project managers is given in (Roberds and McGrath, 2006). In this paper we describe the QPRA process from the perspective of transportation engineers and planners and illustrate the method using results from a recent QPRA of a major highway expansion project in western Canada.

2. BACKGROUND

Large transportation infrastructure projects are often significantly over budget. This phenomenon has been dubbed in the media as the “Big Dig Syndrome” in reference to the Boston Central Artery system which was originally slated to cost
$3 billion and is now heading towards $15 billion, as it reaches completion. Not only is this syndrome solely a North America one; Europe’s Channel Tunnel and London Underground’s Jubilee Line were notoriously over budget. Budget overruns are common in other industries; almost all of Canada’s recent oil sands infrastructure projects have been reported as being significantly over budget. Note that these projects are owned and financed within the private domain.

Flyvbjerg and colleagues have studied the phenomenon of cost overruns on transportation mega projects systematically (Flyvbjerg et. al., 2002; Flyvbjerg et. al., 2004; Flyvbjerg, 2005). In a study of 258 transportation mega projects spanning 80 years and several countries, the authors report that

- costs are underestimated in almost 90% of projects,
- actual costs are on average 28% higher than estimated costs,
- cost overruns are independent of geographic location,
- percentage overruns increase with the size of project and
- cost estimation has not improved over time.

In addition to unfavourable media attention which ultimately ends up as public mistrust of the transportation industry, the consequences of going over budget and behind schedule can include poor decision making and scope reductions on a project, and competition among other projects within an organization because of dwindling resources.

Different methods have been developed to provide realistic cost and schedule estimates over the years. Traditionally, contingency methods have been used in a deterministic way in which component costs and durations are summed and an overall contingency is then included for uncertainties in cost and schedule separately. Probabilistic approaches to project estimation were developed in the management science community for managing large projects as early as the 1950’s when PERT was invented for schedule estimation, (see Chapter 6 of (Hartman, 2000). PERT uses three values to demark a duration component: lower estimate, upper estimate which define the range of possible values coupled with a most likely value. These estimates are used to construct a series of triangular probability distributions which are fed into a simulation model which computes the overall duration.

Golder’s QPRA presents an improvement to traditional project estimation techniques because each project component and risk event is quantified separately and probabilistically. This allows prioritisation of risks in terms of their overall impact. Unlike PERT, cost and duration are treated in an integrated way so that the time-value of money is explicitly incorporated into each cost component. Also unlike PERT, which is a widely available project management tool, Golder’s QPRA approach is a risk assessment process in which the quality of project information is assured by use of project experts, independent experts and skilled facilitators. Finally, unlike traditional methods, project assumptions
are explicitly articulated during the workshop stage. Later these assumptions are tested systematically by using sensitivity analysis.

The theoretical underpinnings of Golder’s QPRA go back to the quantitative risk analysis (Morgan and Henrion, 1990) and decision analysis (Raiffa, 1968) literature. The methodology has evolved over time (Roberds, 1990) but was developed in its specific form (Roberds and McGrath, 2006) for the Washington State Department of Transportation following several high-profile project overruns. For several years, it has been used on all transportation projects over $25 million in Washington State and has also been used on a number of new start projects by the US Federal Transportation Administration (FTA). More recently Golder’s QPRA process has been used to assess large transportation projects in Canada: in Ontario, Saskatchewan and British Columbia. To date over 120 QPRA assessments have been completed by Golder worldwide.

The principal outputs of Golder’s QPRA assessment are a combination of probabilistic estimates of cost and schedule and a ranked list of main drivers of risk which significantly impact cost and schedule. Taken together this allows project engineers and planners to perform effective risk management by controlling cost and schedule on critical project components and selecting among viable alternatives.

Whilst the benefits associated with outputs of a QPRA assessment provide rich sources of information to project owners, engineers and planners, there are in addition also tangible benefits which arise from Golder’s QPRA process itself. These include:

- Benefits to the design team gained from enhanced project understanding gained from participation in QPRA workshops;
- Benefits of arriving at unbiased and trustworthy cost and schedule estimates from participating in a risk assessment process involving input from independent subject matter experts;
- Benefits from a methodology which is transparent, logical, consistent and defensible which promotes good communication with public stakeholders and the media;
- Benefits from performing model sensitivity analysis which can unearth possible ‘off-the-wall’ events that could occur and impact a project schedule or cost;
- Benefits of a participating in an innovative and rigorous process which properly takes into account the effects of inflation on the final cost calculation (which was a major problem on the Big Dig project) and
• Benefits from utilizing a process which is flexible and relatively low cost (typically a small percentage of the cost of the client’s own detailed budgets and schedules) because it builds upon the groundwork done by the design team in advance of the workshops.

3. METHODOLOGY

Golder’s QPRA process is carried out in series of separate stages usually involving two workshops. In the first workshop the project is first reviewed for understanding and a project flow chart is developed. Next the base cost and schedule, free of contingencies, are reviewed and re-computed. Then possible risk events are identified which could cause uncertainties in the overall project cost and schedule. In the second workshop insignificant risk events are screened out and the remainder are quantified in terms of probability distributions using risk elicitation techniques based on subjective probability assessment.

After the project and risk information is checked for accuracy, a simulation model of the project is developed. After the model has been debugged, tested and validated, cost and schedule results are generated. From sensitivity analyses of the simulation model, risks events are ranked in order of their impact to overall cost and schedule. Finally results of the assessment are presented to the client with recommendations for risk management strategies. The assessment methodology is described in detailed in forthcoming subsections.

3.1 Review of the Project

Before the QPRA can begin, it is essential that the whole QPRA team (comprising knowledgeable members of the client’s project team, independent subject matter experts and Golder’s QPRA assessment team) come to a mutual understanding of the most up-to-date version of the scope, status and delivery strategy for the project. The project details are usually communicated to the QPRA team members prior to the commencement of the first workshop by email.

During the first workshop the project team presents the details of the project. They then clarify how the project is defined for the purposes of risk assessment, including which project designs/alternatives will be evaluated, any alternative scenarios to be considered and the key assumptions for each. Note that in a QPRA, it is important to understand the project at the correct level of detail for a risk assessment. Because risk assessments are used primarily for decisions about the project including risk management, it is not necessary to analyze every line item in a work breakdown structure. On a project worth £100 million, we only consider project components equal or greater than £100K in magnitude.

During to the first workshop, usually prior to the project presentation by the client, the QPRA team presents an overview of probabilistic risk assessment. In
particular they instruct team members about what is required of the QPRA team members during the elicitation process.

3.2 Project Flowchart

The next step in the QPRA process is development of the project flowchart. The flowchart is the “backbone” of the QPRA model which will be used to compute cost and schedule information. It comprises the major cost components of a project, known as “activities” which are ordered in time sequence in the same manner as a standard software flowchart. Like a software flowchart, decisions are also included as are project alternatives. Milestones are included as in a project Gantt chart. The times between the project activities are included as are the times to complete each activity. Together all the information constitutes the integrated time-cost framework of the QPRA model. Figure 1 shows a flow chart for the first of five phases for a highway expansion project in Canada worth a total of approximately $50 million. We will use this project to illustrate the QPRA methodology in this paper. Note that the flow chart comprises of only 15 major activities. Typically a project flowchart is of the order of approximately 20 to 200 elements.

**Figure 1: Example Flowchart**

The flowchart provides the QPRA team with a visual summary of the project, including major milestones and schedule logic delivery which enables the team to a common validation. This in contrast to client’s schedules which often contain
thousands of line items, including incomplete information, and are understandable by only one or two individuals. Flowcharts reflect the time at which the QPRA is carried out within the project life-cycle. For example, during planning and early stages of project development, the focus may be on differences between project alternatives whereas during final design the focus may be on contracting, construction and bidding processes.

Types of activities included in flowchart activities and milestones include steps in the design process, environmental (Environmental Impact Assessments), funding and other political approvals, property/right of way access, utilities relocations and other pre-construction work, procurement and construction.

Windows for winter shutdowns should be included in northern climates and project constraints should be included such accelerated schedules when a certain threshold is exceeded. Also incorporated into the flowchart are lags and overlaps between activities and the correct sequencing of activities.

Table 1: Example Set of Base Factors

<table>
<thead>
<tr>
<th>Flowchart Activity Number</th>
<th>Project Activity</th>
<th>Base Cost (2005 $M)</th>
<th>Base Duration (months)</th>
<th>Average Escalation Rate (%/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Costs to Date</td>
<td>0.19</td>
<td>-</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Activity No.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Preliminary Design</td>
<td>0.00</td>
<td>0.50</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>Utility Communications</td>
<td>0.00</td>
<td>0.50</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>Railroad Communications</td>
<td>0.00</td>
<td>0.50</td>
<td>2.5</td>
</tr>
<tr>
<td>4</td>
<td>ROW Negotiations</td>
<td>0.00</td>
<td>2.00</td>
<td>2.5</td>
</tr>
<tr>
<td>5</td>
<td>Final Design</td>
<td>0.00</td>
<td>0.25</td>
<td>2.5</td>
</tr>
<tr>
<td>6</td>
<td>Utility Relocations</td>
<td>0.32</td>
<td>2.00</td>
<td>2.5</td>
</tr>
<tr>
<td>7</td>
<td>Railway Crossing Approval</td>
<td>0.00</td>
<td>0.00</td>
<td>2.5</td>
</tr>
<tr>
<td>8</td>
<td>ROW Purchase</td>
<td>0.18</td>
<td>0.25</td>
<td>2.5</td>
</tr>
<tr>
<td>9</td>
<td>Funding Availability - Grading</td>
<td>0.00</td>
<td>0.00</td>
<td>2.5</td>
</tr>
<tr>
<td>10</td>
<td>Grading Tendering</td>
<td>0.00</td>
<td>1.00</td>
<td>2.5</td>
</tr>
<tr>
<td>11</td>
<td>Grading</td>
<td>3.47</td>
<td>5.00</td>
<td>2.5</td>
</tr>
<tr>
<td>12</td>
<td>Final Surfacing Design</td>
<td>0.02</td>
<td>0.75</td>
<td>2.5</td>
</tr>
<tr>
<td>13</td>
<td>Funding Availability - Paving</td>
<td>0.00</td>
<td>0.00</td>
<td>2.5</td>
</tr>
<tr>
<td>14</td>
<td>Paving Tendering</td>
<td>0.00</td>
<td>1.00</td>
<td>2.5</td>
</tr>
<tr>
<td>15</td>
<td>Paving</td>
<td>4.07</td>
<td>3.00</td>
<td>2.5</td>
</tr>
</tbody>
</table>

3.3 Review of Cost & Schedule Estimates

Once the structure of the flowchart is in-place, the QPRA team assigns cost and duration values to the project activities and duration values to the times between activities as show in Figure 1. The information is reviewed by project personnel and the independent experts to confirm that the cost and schedule estimate matches the project scope and design is reasonable. In the process, the group
identifies and removes all contingencies and conservatism. These components are accounted for separately and later in the QPRA using probability distributions.

After review of the project flowchart, the set of project activity costs and durations are compiled into a set of base factors. Included in this list are a set of escalation rates which account for the effect of inflation over time. Table 1 shows a set of base factors for the same project shown in Figure 1.

The base costs are quoted in currency values at the time of the QPRA. Conversion to year of expenditure currency will be performed later by taking into account the effects of inflation.

3.4 Identification of Risk Events

The effect of risk is handled in two steps in Golder’s QPRA. First risk events are identified which can be performed during the first workshop if there is sufficient time. Next the impact of risk on specific project activities and durations is assessed. This process is undertaken in a second workshop.

By risk we understand it as an event which has an uncertain outcome on project cost and/or duration. A risk event has both a range of consequences on cost and schedule and associate set of likelihoods. A risk event can have either a negative or positive impact, i.e. risk is used to include opportunity events which are included explicitly in Golder’s QPRA.

As in the development of the base activities, identification of risk events follows a systematic procedure. An initial set of risks can be generated through a brainstorming session using the flowchart as guidance. Risk events should include all credible technical, environmental and socioeconomic issues. Once the initial set of possible risks is complete, the QPRA facilitator leads the process of refining the set of risks to make sure it is all encompassing and mutually exclusive. Then the risks are categorised according to whether they are associated with activities which are classified as design, environmental, funding, right-of-way, political, and so on. Included in the categories are risks which hitherto are unidentified to account for risks which have been missed. Typically of the order of 100 risks are usually identified by this process. During the facilitation process, risk events are documented to form the project risk register. Once the risk register is complete, the QPRA team reviews it and screens out risks which are deemed on greater reflection to be of insignificant impact in terms of cost and schedule.

3.5 Quantification of Risk Events

The next step in the QPRA process is to put numbers around the risks in the risk register so that a simulation model can be built. For a particular risk, the QPRA team must estimate the consequences of that risk changes in cost to specific activities in the flowchart and similarly, with durations. For risks which have only a minor effect on cost/schedule changes are labelled as such and no further
quantification is necessary. Some risks will affect only one activity whereas other risks such as the price of oil may affect several activities. Risks must be assessed at the appropriate level of detail; for example, if a risk affects an activity which contributes a very small amount to overall project cost, this risk should not be assessed in great detail. The converse is also true.

Table 2: Example Quantified Risks

<table>
<thead>
<tr>
<th>Risk or Opportunity</th>
<th>Affected Project Activities</th>
<th>Probability of Occurrence</th>
<th>Cost Change (current $M)</th>
<th>Duration Change (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Construction</strong></td>
<td>6. Utilities 11. Grading 15. Paving (apply independently to each section)</td>
<td>Grading: A. 70% B. 20% C. 10%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Rainfall Delays</td>
<td></td>
<td>Paving: A. 80% B. 15% C. 5%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Utilities: minor</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>• start of construction or causes other construction problems</td>
<td></td>
<td></td>
<td></td>
<td>Utilities: minor</td>
</tr>
<tr>
<td>• experienced during the summer in both 2003 and 2004, resulting in construction delays.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Uncertain Market Conditions</strong></td>
<td>11. Grading</td>
<td>A. 10% B. 80% C. 10%</td>
<td>A. -0.1 B. 0 C. 0.1</td>
<td>0</td>
</tr>
<tr>
<td>Excludes cost-escalation issues captured separately. Includes:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• competitiveness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• tender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Elicitation of the appropriate probability distribution of a risk event requires a significant amount of care. If data are available, statistical fits to those data may be used using standard (frequentist) probability theory. Most of the time, however, empirical data are not available. In this case subjective probability notions must be applied. The subjective or Bayesian approach to probability was pioneered in the 20th century by British physicist and mathematician Sir Harold Jeffreys (Jaynes, 2003). It has been adopted by the risk and decision community (Morgan and Henrion, 1990; Raiffa, 1968) and more recently the consulting engineering community (Ang and Tang, 1975; Vick, 2002) because of its practical usefulness in quantitative risk assessments. In the subjective approach, probability is interpreted as a degree of belief or uncertainty. It relies on engineering judgement and experience.
When eliciting probability distributions balanced viewpoints are usually obtained from three to five individuals which is why the QPRA team comprises personnel from the project team and outside experts. Use of the latter helps with removing bias from the estimates produced. More details of how to assess complex risks using decomposition techniques are given in (Morgan and Henrion, 1990; Roberds and McGrath, 2006) as is how to account for varying opinions.

Table 2 shows part of a risk register with probability distributions for risk shown. The risk rainfall delays affect three of the activities in the flowchart: Utilities, Grading and Paving, numbered 6,11 and 15 respectively. There is no effect on cost change for grading and paving (inflation is taken account separately) and Utilities are deemed to have a minor cost change. In the case of grading, there is an estimated change in schedule as follows: 70% change of no change, 20% chance of a 1 month delay and 10% chance of a 2 month delay. Similarly for paving, there is an 80% chance of no delay, a 15% chance of a 1 month delay and a 5% chance of a 2 month delay. For Utilities, the delays are deemed to be minor.

In Table 2, the uncertain market conditions risk affects just cost. Furthermore this risk affects only one activity in the flowchart: Grading, numbered 11. There is a 10% chance of a $100,000 decrease in cost, an 80% chance of no change in cost and a 10% chance of a $100,000 increase in cost. These types of probability distributions are called discrete distributions in the literate. Other common distributions used in cost and schedule risk assessment of projects are normal distributions, log-normal distributions and triangular distributions.

Note that in the table under risk or opportunity a brief explanation of the why the risk occurs is described. Because the summers of 2003 and 2004 were wet and did affect construction during that time period, the QPRA team decided to include rainfall as a risk factor during the year of assessment which was 2005.

3.7 Simulation Modelling

The logic of the flowchart, the values for cost and duration for the project activities and the durations between activities are programmed into a MS Excel spreadsheet. This information enables us to calculate total base cost and duration. To incorporate the effects of risk events into the simulation, risk probability distributions are then programmed into the spreadsheet by using suitable Monte Carlo add-in software. The authors' preference is @RISK developed by Palisade Corp. (Pallisade, 2006). The outputs of the simulation, which are now probability distribution functions, are computed by the Monte Carlo engine of @RISK. So far all computations have been performed in current currency values. Account of cost escalation compounded over the appropriate durations is made in the spreadsheet to year of expenditure currency (YOE) which is usually preferred by client organizations. Whilst the total cost of the project is just the sum of the activities corrected for risk events, the total duration must take into account overlap of activities. After the model is built by one of Golder's QPRA team members it is validated and verified by another Golder
employee who is trained in QPRA modelling. For a more comprehensive account of simulation modelling, consult (Roberds and McGrath, 2006).

3.8 Results

Two of the most outputs from a QPRA simulation model are the probability distributions for total cost and total schedule. These reflect the aggregate uncertainty caused by all the risk events. Figure 2 shows the distribution functions for overall cost in YOE dollars. The LHS of Figure 2 shows the probability distribution (mass) function for total project cost which we can see is centred close to the mean value of $42.2 million. An equivalent but more useful representation of the cost uncertainty is provided by the RHS of Figure 1 which shows the cumulative distribution function. This plot enables us to see percentile values. The median (50th percentile) value of the cost is $42.1 million. This number is useful to project engineers and planners. What this number means is that based on all the information elicited during the QPRA workshops there is a 50:50 chance of mean the project budget meeting $42.1 million. Usually government planners work at about the 80% percentile value, i.e. they want to be 80% confident that their budget meets its target. The 80% value of cost is $47.2 million which is an increase of just over 10% from the median value. If the project planners want to be 90% sure that their budget is going to be met, the QPRA assessment estimates that $49.8 million will be required.

Alternatively, we can look at what the planners and engineers originally estimated the overall cost to be. The original estimate was $47 million which corresponds to the QPRA estimate of about 80%. Therefore we can conclude that based on the information gathered during the QPRA workshops, the original estimate has about an 80% chance of being met.

We now turn to the probability distributions of total project schedule given in terms of completion date which are shown in Figure 3. Inspection of the RHS of the Figure 2 shows that the probability mass function has two peaks which reflect the lack of construction during the winter season when ground is frozen. The
mean completion date is September 2011. The median completion date (50:50 odds) is August 2011 and the 80 percentile value is September, 2011. From the information gathered in the QPRA workshop we can conclude that there is over a 90% chance that the project will be completed before the end of the constructions season in 2011.

Figure 3: Example Probability Distributions for Total Project Completion Date

3.9 Risk Ranking

Whilst the information provided by the cost and schedule probability distributions is useful for engineering planning purposes, what is more useful for project risk management is what is the relative importance of each risk to impacting the overall cost and schedule. By performing sensitivity analysis on the simulation model, we can rank the risks in order of importance. Tables 3 and 4 show the rankings of risk events in decreasing importance for overall cost and schedule respectively. The first 3 risks in Table 3 contribute most of the risk to the project as far as cost is concerned – almost $3 million on average. Therefore any management actions which could mitigate these risks would be expected to have a significant effect on controlling costs on the project.

Table 3: Risk Rankings for Cost

<table>
<thead>
<tr>
<th>Risk Rank</th>
<th>Contribution to Expected Cost Risk</th>
<th>Risk Event</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>Current $M</td>
</tr>
<tr>
<td>1</td>
<td>26.7%</td>
<td>0.99</td>
</tr>
<tr>
<td>2</td>
<td>23.7%</td>
<td>0.88</td>
</tr>
<tr>
<td>3</td>
<td>21.0%</td>
<td>0.78</td>
</tr>
<tr>
<td>4</td>
<td>7.9%</td>
<td>0.29</td>
</tr>
<tr>
<td>5</td>
<td>6.7%</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Uncertainty in Soft Costs / Consultant Design
Issues related to haul / haul roads for surfacing material
Relocation of Borrow Pits
Right Of Way Acquisition Cost
Cost Penalties paid to paving contractor due to delays in grading contract
### Table 4: Risk Rankings for Schedule

<table>
<thead>
<tr>
<th>Risk Rank</th>
<th>Contribution to Expected Time Risk (Months)</th>
<th>Risk Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.3</td>
<td>Significant wet year delays start of construction or causes other construction problems</td>
</tr>
<tr>
<td>2</td>
<td>2.3</td>
<td>ROW Acquisition Schedule</td>
</tr>
<tr>
<td>3</td>
<td>1.2</td>
<td>Relocation of Borrow Pits</td>
</tr>
<tr>
<td>4</td>
<td>0.3</td>
<td>Uncertainty in Horizontal Alignment</td>
</tr>
</tbody>
</table>

#### 4.0 CONCLUSIONS

In this paper we have shown how cost and schedule risk assessment using Golder’s QPRA method is performed and illustrated the main results of a PQRA. There are many benefits to performing Golder’s QPRA on a large infrastructure project. There is the benefit of having probabilistic information on cost and schedule which can be used to manage public expectations. There is also the benefit of having the main drivers of risk identified which can be used to manage cost and schedule effectively in today’s uncertain market conditions. The QPRA process itself and results generated from it are useful as a communication tool to the public because the process is transparent and the results are realistic. Also because Golder’s QPRA process is performed in a workshop setting with project personnel and independent experts, it provides greater project understanding to the project team and decision-makers. Moreover by performing regular updates, a PQRA can be used as an effective monitoring tool which can be used to track progress over time on a project and demonstrate the efficacy of risk mitigation efforts.

In conclusion, the cost of performing a Golder QPRA on a major infrastructure is relatively low compared with that of preparing the detailed budget and schedule. This is because Golder’s QPRA builds on a client’s current project information and uses their design team. Typically the cost of a PQRA on a $50-100 million project ranges between about $40-50 thousand. In PQRA in general, it is our experience that return on investment is usually much greater than 10:1.

#### 5.0 ACKNOWLEDGEMENTS

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6.0 REFERENCES


