Cost and Schedule Estimates for Large Transportation Projects: A New Approach to Solving an Old Problem

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Cost and Schedule Estimates for Large Transportation Projects: A New Approach to Solving an Old Problem

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ABSTRACT

Estimating and managing the costs and schedules of complex infrastructure projects has been a challenge for decades. Recent publicity on this problem has focused attention toward developing different approaches that deal more explicitly with the uncertainty that is inherent in project estimating, not just of cost but also scheduling, safety and other issues. This paper includes a review of the 70-plus year history of large infrastructure cost estimating and summaries of studies conducted around the world. This is followed by an overview of the specific methodology used in the 'Cost Estimate Validation Program' (CEVP™) as implemented for the Washington State Department of Transportation. This risk-based cost estimation process described in this paper is a collaborative approach involving independent peer reviewers, independent experts, and project team members to validate estimates and conduct explicit assessments of financial and schedule risks and opportunities. With the potential for 'mega' civil-infrastructure projects in Toronto and Vancouver and other large transportation projects elsewhere in Canada, where significant public funds are at stake, the risk-based estimation process may be the means for owner agencies to understand the interdependent financial and technical risks early in the project. The structuring of risk-based cost and schedule estimating is described in detail and, finally, the results of applying this approach to two specific major projects are described.

1. INTRODUCTION

"In this world, nothing is certain but death and taxes." (Benjamin Franklin, 1789). In spite of this maxim, how many transportation and construction projects are planned on the notion of a unique budget value? Recent and large "mega" projects have highlighted the problems associated with notions of certain project budgets [1, 2]. In these projects and many others, the important concept of variability is often forgotten. In general, 90% of estimates for transportation infrastructure projects have been low and, on average, cost estimates for transportation projects have been 20% short of final costs [3]. This trend is be due to any number of factors including:

- overly optimistic assumptions about project costs early in the planning process;
- political, economic, or strategic misrepresentations;
- changes in economic conditions;
- changes in project scope;

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- poor planning or design; or
- unknown conditions (subsurface, environmental, etc.).

Cost over-runs for underground transportation projects were a large-scale industry problem in which final costs could range up to 80% or 100% greater than the original engineer's estimate at the time of bidding [4]. This poor record of cost variability was judged at the time to reflect the uncertainties associated with subsurface conditions and the use and abuse of the data provided within contract documents. This aspect of uncertainty was considered so important that the entire industry has shifted to using new contractual practices [5]. This type of cost escalation, however, does not consider the escalation in the project estimates that occur between the initial project planning and the final pre-bid estimate. The consequences of problematic cost estimates in comparison to significantly escalated final construction costs include:

- political disarray;
- budgetary disarray;
- increased taxes to cover unplanned expenditures;
- institutional reorganisation;
- misunderstandings and acrimony that eliminate future benefit;
- cancellation of projects;
- public perceptions of poor management; and, finally, the root cause
- project cost & schedule over-runs.

To avoid the plague of problems that this causes for public transportation departments, a process has been developed to incorporate financial and technical uncertainty in planning project cost estimates. The State of Washington has adopted a process it has titled the "Cost Estimate Validation Process" (CEVP™) [6, 7] to avoid the "sticker shock" of transportation infrastructure construction [8].

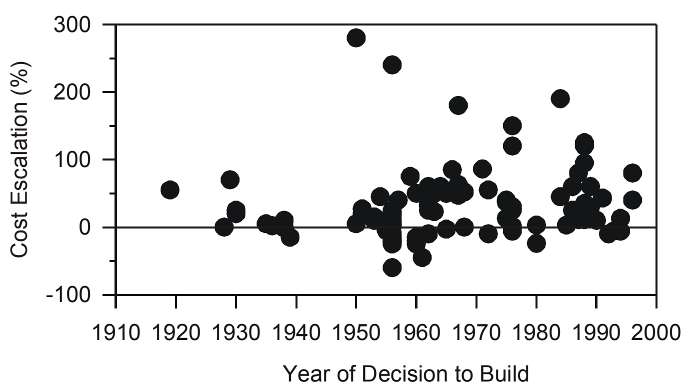


Figure 1. Inaccuracy of cost estimates in transportation projects over time [after 3].

2. BELEAGUERED HISTORY OF COST ESTIMATION

The risks involved in the processes of estimating costs and selecting valid bids for large transportation and infrastructure projects has been the subject of increasing scrutiny [9, 10, 3]. Although cost estimates can evolve during the course of planning and design, the most critical estimate is that completed at the time the decision of whether or not to proceed with construction is made. Using this basis, a number of recent and highly publicised projects have made the problems associated with misconceptions, misinterpretations, or misleading of the public related to final project costs all too apparent. This problem, however, is not new. The Suez Canal, when completed in 1869, cost more than 20 times the initial estimate at the time the decision was made to proceed with the project. Multiple contracts for the Panama Canal, at its 1914 completion, cost 70% to 200% more than estimated. The Sydney Opera House, completed at 15 times more than initially estimated, is a more recent example [3]. The Boston "Big Dig" is more recent still, where the final construction cost may be more than 480% of the estimate made at the time the decision to proceed was made [11]. Haven't we learned anything? A recent study of more than 258 transportation projects, completed in Europe, North America, and in a number of developing nations, found that over the past 70 years, there has been no statistically significant improvement in the performance of final cost versus estimated cost in inflation-adjusted values, see Figure 1. How problematic has cost estimation been? Using the 258 projects, the authors found that:

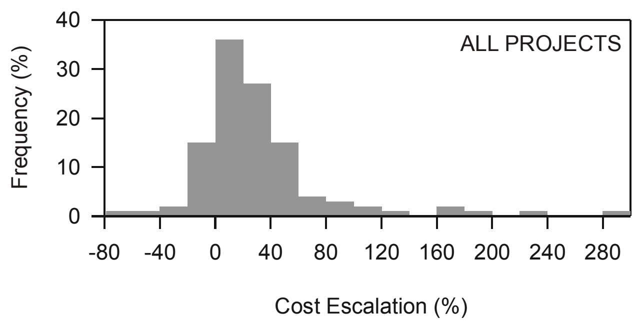


Figure 2. Historical performance of final cost versus estimated cost for 258 transportation projects [after 3].

- costs were underestimated in 90% of the projects (see Figure 2);
- actual costs were 28% above the estimate, on average;
- for a randomly selected project, the likelihood of costs being greater than estimated was 86%; and
- costs that were underestimated were wrong by a substantially larger margin than those that were overestimated.

The projects that formed the basis of this comprehensive study were subdivided into three subcategories including (see Figure 3):

- rail and urban transit projects;
- fixed-link (or bridge) projects; and
- roadway projects.

The evaluation of these projects, on a project-type basis is illustrated in Figure 3. It can be seen that there is some distinction in the performance of cost estimation for these various project types, reflecting the project complexity and the unknowns associated with each.

These data and examples illustrate the disturbing problems that often occur within many transportation agencies or large private or public-private consortia that deal with infrastructure planning and construction. What, then, is the problem? The sources of the difference between final cost and estimated cost, can be broken into several categories [3] including:

- technical explanations such as imperfect design, inadequate subsurface data, mistakes, lack of experience, bidding methods, and other forecasting errors;

- economic explanations such as economic self-interest (of planners, engineers, and construction firms, and other stakeholders) and the public interest where costs may be deliberately stated to be low to encourage cost-cutting and competitive bidding;

- psychological explanations in which biases lead to "appraisal optimism"; and

- political explanations such as "monument building" or jobs creation;

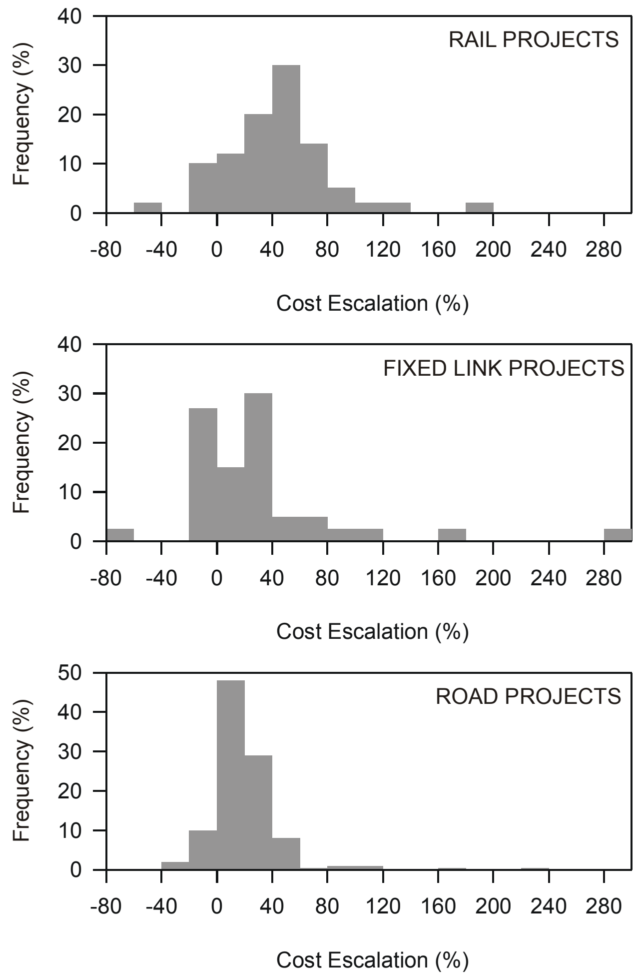


Figure 3. Historical performance of cost escalation separated by project type [after 3].

The combined results of the explanations produce overly optimistic forecasts of project costs or, as Flyvbjerg et al. [3] assert, a "...highly, systematically, and significantly deceptive..." evaluation of cost-benefit and decision-making processes related to transportation infrastructure projects.

A number of agencies have focused on technical or economic explanations, examining a number of points. The Ministry of Transportation Ontario (MTO) examined the history of cost over-runs associated with roadway and bridge construction with contract values greater than $1 million [12]. The MTO undertook the study to examine the underlying factors for cost over-runs and focused primarily on the design aspects associated with each contract with a subsequent study to be undertaken to examine potential administrative flaws. They found that over a six-year period, the final costs for about 14% of their contracts exceeded the bid prices by 20% or more. On the projects that experienced cost escalation, over-runs or extras on earth or rock excavation estimates led to an average 10% cost escalation with a range of cost escalation of up to 25% from these items alone [12]. Though this comparison of final cost versus bid cost is somewhat different than a comparison of decision-planning estimates, it is nevertheless a measure of cost control concern and is consistent with the trends illustrated in Figure 3.

In 1996, the Florida Department of Transportation (FDOT) was authorised to establish a program of alternative techniques to, among other goals, control and limit the effects of transportation project cost increases [13]. Within the framework of this program, the FDOT examined general project delivery and contracting methods such as Design-Build (DB) and the Bid Averaging Method (BAM). The purpose of each of these methods is to:

- DB: reduce the length of time of project from concept to completion; and
- BAM: achieve bids closer to a true and reasonable cost where a low-bid system was perceived to be a significant problem.

Based on the reviewed literature, there is no statistical conclusion on the results of this study as yet; however, it has been noted that the contractors involved in the BAM projects were less likely to request more money for changes to the project [14]. This conclusion is consistent with the findings of other research [9, 15, 16, and 17] in which unusually low bids are eliminated from the pool of bidders, and the mean bid price is factored into the decisions. Such alternative bidding practices have evolved to address the risks associated with cost growth related to the low-bid system of contract award.

These two agency studies, and the variety of research publications related to technical and bidding method cost control and associated risks do not address all economic, psychological, or political reasons for cost escalation. Key to cost control in these aspects of the problem, as Flyvbjerg et al. [3] point out, is transparency in the cost estimation process. Good decisions can only be made on the basis of good information and part of developing good information is a thorough, systematic, and unbiased understanding of the financial risk.

3. TRADITIONAL COST ESTIMATION

Traditionally, estimating project construction cost has been based on a combination of listed items with quantities and unit rates, usually with some degree of conservatism built in. Using a system of measurable units, whether they are cubic metres of concrete, kilometres of highway pavement, or kilometres of subway tunnel, the total project cost is based on assigning a unit cost to each of the planned items involved in the final construction. Having defined the "base" project cost estimate, a "contingency" value is added to the estimate to take some account of the unknowns. Typically, the contingency value is a percentage of the total unit cost estimate, or base value. This contingency is often based solely on judgement or limited experience with a history of similar projects. In any traditional cost estimate, there is some implicit degree of variability that is considered where costs below the selected value represent opportunities and costs above the sum of the base value and contingency represent risk. Because of concern about project cost escalation, conservatism can be built in to the average unit costs and quantities to develop cost estimates that are biased above the true mean values. Conversely, if the end goal is to achieve political approval to proceed with the project, low-end estimates can also be made, but this practice may be deliberately deceptive [3]. Rarely, except on some very large projects, are the individual risks and opportunities quantified explicitly.

4. RISK-BASED COST AND SCHEDULE ESTIMATION

The risk-based estimation processes are based on explicitly identifying and quantifying uncertainty. The risk analysis methods have been more commonly applied to technical and safety issues associated with large dams, flood control structures, and tunnels [18, 19, 20, 21]. In its fundamental form, the risk-based cost estimation methods:

- identify major system variables and relationships among those variables (e.g., major project activities and the dependencies among these activities);
- quantify uncertainty for each of the variables (e.g., uncertainty in the cost and duration for an individual project activity including discrete risk and opportunity "events"); and
- combine these uncertainties with a model of system performance (e.g., a critical-path cost and schedule model) to quantify the total uncertainty in the measure of interest (e.g., total project cost and/or schedule).

Some of the variables typically considered in this process include:

- unit prices and quantities for project components or activities;
- duration of project activities – for example pre-construction activities such as design or permitting, or construction activities such as earthwork or paving)
- alignment changes forced by property or social issues (e.g., expropriation or legal costs, costs associated with physical changes in geometry);
- project "add-ons" - scope creep (e.g., additional on/off ramps, pedestrian bridges, safety improvements);
- economic changes (e.g., inflation, interest rates, revenue streams, labour shortages or unrest);
- unknown subsurface conditions (e.g., geotechnical, environmental, or buried structures);
- materials performance and costs (e.g., selection of different pavement types – long term costs versus short-term costs, variable material unit costs);
- errors and omissions in planning or design;
- bidding method (low-bid, design-build, bid averaging method);
- project completion stage (initial planning, preliminary design, final design, bid)

Each of these variables can be characterised in terms of risks associated with schedule or physical costs, though in the total cost risk, both are interdependent.

The risk-based estimation process is interactive and generally built of four sub-processes including project definition, assessment, analysis, and revision to reflect risk-management activities and project evolution. A flow chart of the process is illustrated in Figure 4 with the terms used in this chart defined as follows:

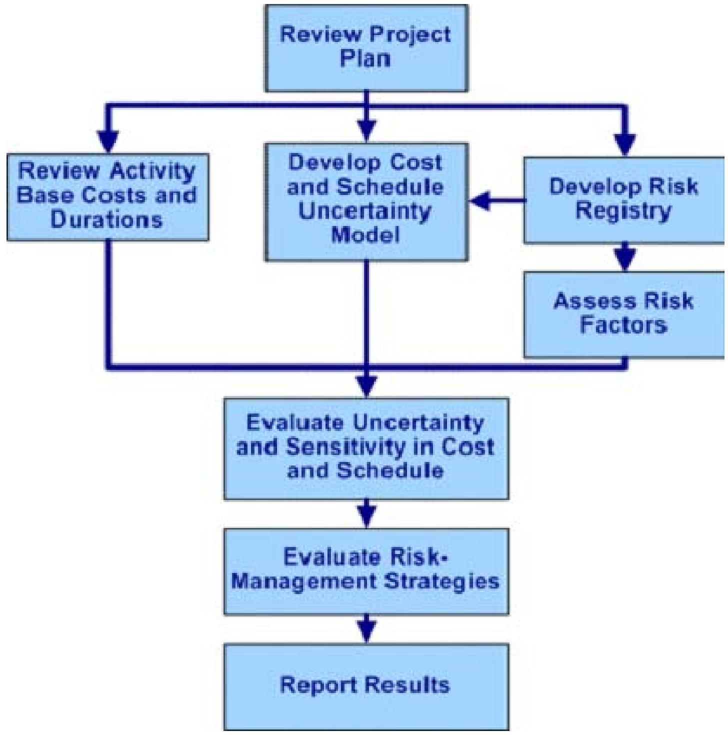


Figure 4. Risk-based cost and schedule estimation process.

- *Activity Base Cost:* best unbiased estimate of cost and duration associated with each project activity;
- *Risk Registry:* list of all possible problems and opportunities that could lead to significant changes in cost and duration for each activity, and for each of these define the likelihood and consequence(s) of occurrence;
- *Cost and Uncertainty Model:* a computer model that incorporates uncertainty in individual input factors into the overall cost and schedule estimate to quantify overall uncertainty – this model is also used to identify sensitivity to input factors;
- *Risk Factor Assessment:* detailed assessment of each risk factors (e.g. probability of occurrence, consequence of occurrence) for events listed in the registry.

When constrained by time, two separate groups of individuals are gathered for the workshop phase of the process: one for a “cost” group; and a second for a “risk” group. These two task-oriented groups, however, can consist of the same individuals and the tasks completed sequentially if time permits. Each of these task groups focuses on identifying either cost and schedule factors in a deliberately unbiased approach. Typically, the individuals in each of the groups are assembled from the owner, designers, cost estimation groups (in-house or consultants), and outside specialists (e.g., contractors, technical specialists) or review panellists. The resulting risk registry, risk factor assessment, and activity base cost data are input into the cost and schedule uncertainty model. The cost and uncertainty model is then used to simulate project completion through Monte Carlo or other suitable techniques. Probability distributions for both cost and schedule are developed for the total project as illustrated by the examples shown in Figure 5.

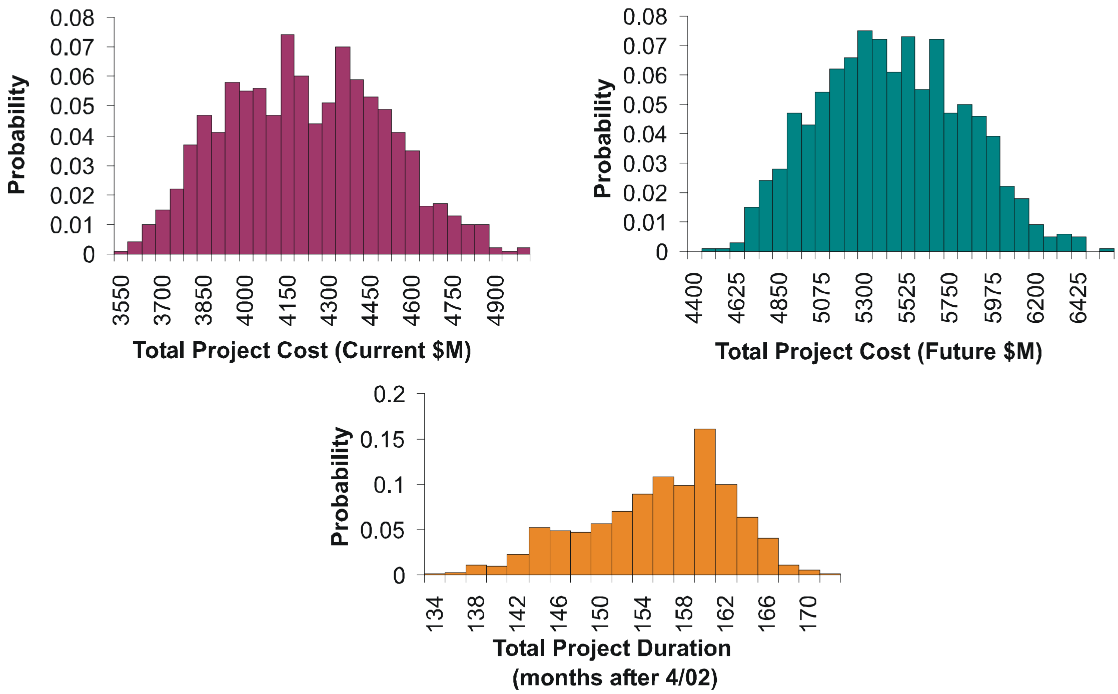


Figure 5. Probabilistic (risk-based) estimates of total cost and schedule for SR 520 project in Seattle Washington.

The choice of what project cost is selected for financial budgeting purposes is then dependent upon a selected level of risk. This question can be more troublesome to answer, depending upon the owner or financing agency. Some projects in the mining industry, for example, are accustomed to proceeding with projects with a relatively high level of accepted risk. Many public agencies, however, are highly risk averse, and would prefer to select budgets that provide more assurance that there will be more money left at the end of the project than more project left at the end of the money. With some examination of historical performance and owner or agency preferences, an appropriate risk level can be chosen such that a consistent basis for all project-specific decisions can be established.

5. COMPARISON OF TRADITIONAL AND RISK-BASED COST AND SCHEDULE ESTIMATION METHODS

Both traditional and risk-based methods of cost estimation are subject to GIGO (garbage in = garbage out). Both methods also rely on judgement from experience, though in differing levels of detail and scope. Therefore, effort is required to make sure that the input information is clear, defensible, documented, as unbiased as possible, and detailed. A brief comparison of the two approaches is summarised in Table 1 and Figure 6. One of the significant benefits of risk-based cost and schedule analysis is that through a sensitivity evaluation, the efforts of "value engineering" can be more effectively focused. Otherwise, value engineering exercises may be focused on large cost items with small potential uncertainty, while missing cost items that while initially small on a per-unit basis, may have a very large effect on the final project cost if their risk for change is potentially large. For example, on a large highway project with earth and rock cuts, retaining walls and bridges, significant total costs may be associated with units of relatively high unit-cost reinforced concrete. During design and value engineering, efforts can be made to minimise this cost through alternative designs. The potential for variation of these costs, however, may be relatively low. The unit cost for rock excavation and disposal may be relatively low but the risk for variation high because the earth-rock interface may be poorly defined. If decisions are to be made on the basis of cost and schedule, then it is clearly important that the risks accepted with any decision are clear and understood by all stakeholders including project managers, owners/agencies, and the public. This is one of the most significant benefits of the risk-based method of cost estimation.

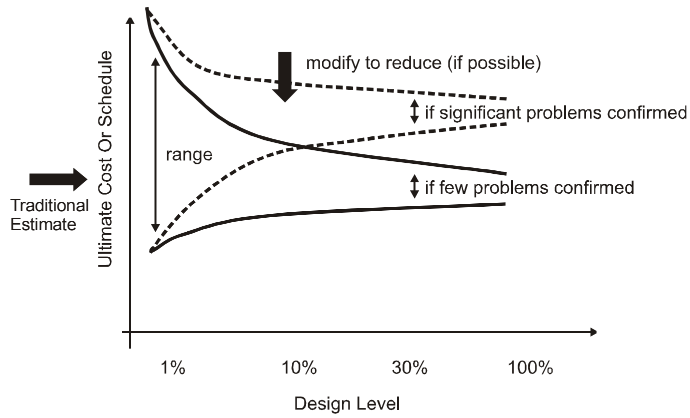


Figure 6. Illustration of risk-based cost-estimation in comparison with project evolution and traditional methods of estimation.

Table 1. Comparison of Cost Estimation Methods

Traditional	Risk-Based
Estimate is a single value	Estimate is a range
Risk and uncertainty are modelled as a lumped "contingency"	Risk and uncertainty are explicitly and quantitatively evaluated
Risk management is ad-hoc	Risk management is formalised and explicit
Financial and schedule risk are unknown	Financial and schedule risk are explicitly evaluated and documented
Relies on judgement from experience	Relies on judgement from experience

6. COMMUNICATION OF RISK-BASED COST ESTIMATION

Clearly communicating the costs and risks associated with large transportation infrastructure projects can be a daunting task, particularly since the audience may have a diverse background of experience and education. Figure 7 illustrates a simple one-page project summary used for the Washington State Department of Transportation [22]. Though this one-page summary captures a single project at a single point in time, similar pages can be developed if there are several potential options for constructing a transportation project and other summaries developed as the project evolves. For example, if a project to divert traffic through an urban area is being planned and two of the potential options being considered include either a viaduct or tunnel, each of these options can be examined through the risk-based estimation process. The end results of the cost-schedule-risk analyses can then be readily compared such that clear decisions can be made. By such effective communication, all stakeholders can be fully and clearly informed, thus avoiding potential acrimony, blame, and misunderstanding should project conditions or cost evolve or change.

7. APPLICATIONS OF TECHNIQUES

This risk-based cost and schedule estimation process is generally applicable to all construction projects. The cost of completing the work, however, limits its applicability to projects in the range of costs greater than about $5 million. Overall, the process is flexible to accommodate differing levels of detail, but the process itself remains the same. To date, the process discussed in this paper has been applied to projects including:

- highway reconstruction;
- new highways or extensions;
- lane additions;
- high-occupancy-vehicle (HOV) and bus transit lane construction;
- bridge replacement;
- new bridges;
- rail transit lines and tunnels; and
- water supply pipelines and tunnels.

The benefits of the risk-based estimation process have been recognised within the WSDOT as one of the first public agencies in North America to adopt this approach as standard practice. Other public agencies that have applied this process on a project specific basis or are considering adopting the process for multiple projects include: the US Federal Transit Administration, the US Federal Rail Administration, the San Diego County Water Authority, and King County (Washington). To date, the process has been implemented on over fifty individual projects. The current database available to compare predicted ranges of cost with final project cost is too small to provide a detailed numerical evaluation of the methods. The communication benefits, and effectiveness in other decision-making processes, however, have already proven beneficial in themselves on a project specific basis.

SR 520 Trans -Lake Washington Project (Seattle to Redmond, 6 -Lanes)

10 Year-Project in Full

6-lanes

Description:

- Reconstructs and expands SR 520 to six lanes between Seattle and Redmond (adds one HOV/bus rapid transit lane each direction)
- Replaces SR 520 floating bridge, approaches, and Portage Bay bridge
- Adds expanded roadway shoulders, bicycle and pedestrian lanes
- Includes five 300-500-foot lidded sections of freeway

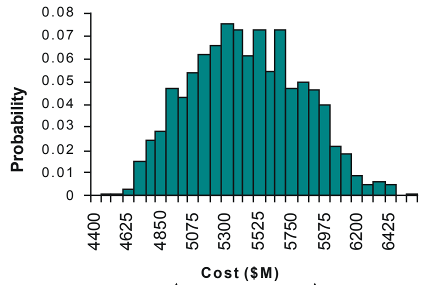
Schedule:

Begin Construction Range: 2005 - 2007

End Construction Range: 2014 - 2016

Inflation escalation is to 2011, approximate midpoint of construction

CEVP Result:



Project Cost Range

There is a 10% chance the cost is less than $ 4.9 Billion

There is a 50% chance the cost is less than $ 5.4 Billion

There is a 90% chance the cost is less than $ 5.9 Billion

Benefits this project would provide:

- Expands current highway capacity by adding an HOV/bus rapid transit lane in each direction
- Increases safety and reliability with added standard shoulders and lane widths
- Decreases seismic and storm damage risk exposure significantly
- Improves speed and reliability of transit and HOV through direct access, dedicated lanes, and better freeway connections at I-5, University of Washington, 108th NE, 31st, and I-405
- Improves freeway flow and improves safety with removal of traffic weaves at SR 520/I-405 interchange
- Adds noise walls and improves water runoff quality
- Improves environmental quality by combining ramps in Arboretum area, reducing water pollution from stormwater, and adding noise walls
- Creates a new link for bicycles and pedestrians across Lake Washington and to existing trails
- Expands commuter choices by expanding the vanpool fleet and expanding employer commute trip reduction programs
- Reconnects neighborhoods with 300-500-foot lids at I-5, Montlake, Evergreen Pt. Rd., 84th Ave. NE, and 92nd Ave. NE southbound I-5 Ship Canal weave
- Addresses southbound I-5 Mercer weave

Risk issues that could impact project cost or schedule:

- Changes to national seismic design criteria increase structure costs.
- Limited number of contractors are qualified and available to pursue a project this large, increasng contract costs and project delays.
- Catastrophic failure of floating and fixed bridges occurs before replacement, which results in a more expensive emergency replacement.
- Changes to environmental regulations increase project time and cost.
- Special stormwater treatment facilities for the floating bridge increase complexity and expense.
- Legal challenges and delays in obtaining environmental permits result in project delay.
- Early stage of project development increases project scope uncertainty.
- Restrictions on when work in and around water can occur increases time to complete project.

Level of Project Design: Low — Medium — High

June 3, 2002

Washington State Department of Transportation

Figure 7. Summary of risk-based cost estimate for viaduct and seawall replacement project in Seattle (courtesy of WSDOT).

It has been contemplated that one of the additional benefits of the risk-based estimation methods could be in better managing overall funding and budgeting programs within public agencies concerned with construction. If individual projects go over budget by unknown amounts, in both duration and cost, managing a portfolio of projects can become increasingly difficult, whether the revenue is from a fixed public allocation or from variable revenue streams (e.g. tolls). If the probability of particular project being completed on schedule and on or under budget can be identified, then applying cost uncertainty modelling to overall capital works budgets becomes a more explicit exercise. This then could also lead to better transparency, financial tracking, risk management, and back-analysis of public or private spending on transportation infrastructure.

8. EXAMPLE PROJECTS

WSDOT SR 520

To improve traffic solutions for Seattle motorists crossing Lake Washington on State Route (SR) 520, WSDOT is studying potential bridge replacement and HOV lane construction projects [22]. Parts of the existing transportation corridor are nearing the end of their design life, and need replacement. The project includes a number of variables that must be considered during the decision-making, permitting, and design processes including options for:

- storm-water management related to fish and wildlife habitats;
- noise pollution control measures for adjacent neighbourhoods;
- replacement of the existing floating bridge with new lanes and shoulders or safety pull-out areas;
- potential for seismic-event-induced failure of the existing structure and consequent effects on alternative roadways;
- revised seismic design criteria;
- possible full or partial funding from county, State of Washington agencies, US federal agencies, and user fees;
- involvement of local Native American tribal communities related to land issues;
- involvement of multiple levels of government regulatory agencies;
- additional interchanges or modifications to interchanges to permit improved traffic flow;
- lane configurations ranging from four lanes to eight lanes;
- possible addition of high-occupancy vehicle (HOV) lanes; and
- differing methods of project delivery (design-bid-build (DBB), or design-build (DB).

Each of these options has uncertainty associated with both cost and schedule, and as the existing corridor is reaching the end of its design life and the potential consequences of a seismically induced bridge failure could be significant, both cost and schedule are of great importance. The project was divided into twelve geographic design/construction/contract segments including major bridges, interchanges, and

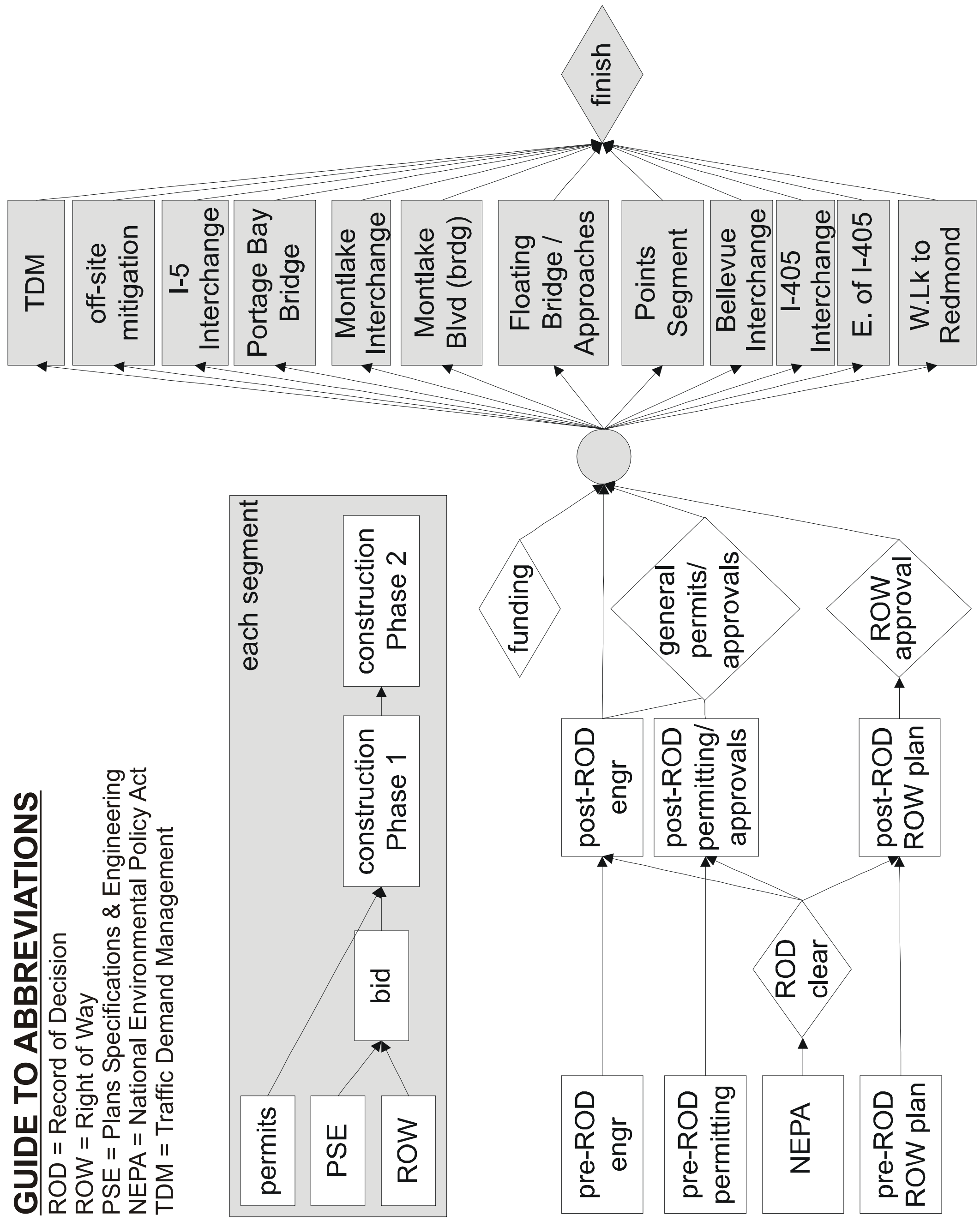


Figure 8. Project flow chart for 6-lane option with full funding, SR 520 project, Seattle Washington, using design-bid-build project procurement.

highway sections between bridges and interchanges. Figure 8 illustrates the project flow chart for one of the options considered in the risk-based cost and schedule estimate.

Table 2. Top Ten Risk Events and their influence on project cost and schedule, SR 520 project.

Rank	Relative Contribution to Risk Cost[1]	Risk Registry Number	Risk Event
1	35	12	Seismic design criteria
2	17	30	Project delivery method
3	13	22	ROW
4	11	3	Market Conditions (high bids)
5	9	31	Other (low risk items)
6	3	26	Local access improvements
7	2	28	TDM
8	2	16	Construction staging areas
9	1	1a	floating bridge failure before replacement
10	1	21	parks and recreation zoning/code issues

Rank	Relative Contribution to Risk Delays[1]	Risk Registry Number	Risk Event
1	30	15	Work windows
2	20	6	Legal challenges to Environmental Impact Statement
3	10	14	Constructability of I-405 Interchange
4	9	8	Environmental Site Assessment
5	7	11	Tribal issues
6	5	29	WSDOT Management
7	4	31	Other (low risk)
8	3	21	4F Issue
9	3	7	Permitting
10	2	4	Work zone traffic control (local)

Note: 1) Cost risk in current dollars, delay risks are due to individual events and do not reflect the critical path.

Figure 5 illustrates the final probabilistic cost and schedule estimates for the one option described above. The process was completed for a total of four different project configurations so that the range in costs could be adequately characterised in a cost-benefit evaluation and for decision making purposes. In addition, the project alternatives and their associated costs were made directly available to the public using summaries such as the one illustrated in Figure 7 [22] and summarised in Table 3. Although the particulars of this project as described above represent a single point in time of the project evolution, decisions may be made to isolate selected project items that are particularly risk prone relative to either cost or schedule to optimise the design and potential project benefits.

Table 3. Final probabilistic cost estimates as made publicly available [19] representing 10th and 90th percentile costs.

Option	Cost Range (Billions)
4-lane	\$1.8 – \$2.1
6-lane (modified)	\$1.8 – \$2.0
6-lane	\$4.9 – \$5.9
8-lane (not including improvements to I-5 to make option feasible)	\$6.0 – \$7.4

Seattle Monorail Risk Management

The Seattle Monorail Project is a proposed transit solution to serve an initial 14-mile route through downtown Seattle. Given recent local and international experience with major cost overruns on large transportation projects, the City of Seattle in July 2002 engaged a consultant team to review the cost estimates that had been prepared for the project. The team evaluated the planned project using the previously described methods that explicitly incorporated uncertainty in the assessment and which described the estimated cost and schedule for the project in terms of ranges and expected distributions. Key findings of the July 2003 review included a list of ranked risks for the cost and schedule estimates as summarized in Table 4.

The management team for what is now formally called the Seattle Monorail Project undertook an aggressive risk management program immediately following the July 2002. project evaluation. Following an affirmative and supporting vote from the Seattle citizens in late 2002, they began to plan for implementation of the project while continuing their aggressive risk management activities. The principal objectives and targets of these risk management efforts were those cost and schedule risks identified in the estimating uncertainty evaluation and applicable to the early stage of project development where policy and management variables are most important. Specific risk management targets, from Table 4, included:

- future monorail leadership and management;
- delay to the EIS;
- transportation systems delivery schedule; and
- agreements with other entities, especially permitting through the City of Seattle.

By March 2003, the Monorail management team and staff had begun preliminary engineering for the project and had made significant headway with their risk management program. Consistent with their plans for overall project management, they requested a second project evaluation to assess the effect of the work to date and to provide a new base for future risk management and project development planning. The March 2003 assessment was done by the same team and using the same approach as in July 2002.

Table 4. Top Ten Risk Events and their influence on project cost and schedule, Seattle Monorail project.

Rank	Relative Contribution to Risk Cost[1]	Risk or Opportunity Event
1	23%	Future Monorail Leadership & Management
2	18%	O&M Subsidy Risk
3	9%	Contracting Process
4	7%	Additional Parking Required
5	7%	other risk items
6	7%	Urban Design Risk
7	6%	Utility Relocation Issues
8	5%	Other Scope Risk
9	3%	Power Systems Cost Uncertainty
10	3%	Foundation Design Risk
all others	12%	

Rank	Relative Contribution to Risk Delays[1]	Risk or Opportunity Event
1	31%	Future Monorail Leadership & Management
2	18%	Delay to EIS
3	12%	Transportation Systems Delivery Schedule Uncertainty
4	12%	Ballard Bridge Construction Schedule Risk
5	9%	Agreements with Other Agencies
6	7%	other risk items
7	5%	ETC Governance Transition
8	4%	City Permitting Issues in Design
9	1%	Not Allowed to Use W. Seattle Bridge
10	1%	City Permitting Issues in Construction

The effect of the Seattle Monorail risk management program is illustrated in Figure 9 where the presentation has superimposed the July 2002 and March 2003 results for a cost estimate (future dollars) and for the estimated project duration. These results clearly illustrate the effect that risk management has achieved. For the estimated cost, the influence of risk management has been primarily at the upper end of the estimated cost range rather than a general reduction in the estimate. This is shown by the relatively depleted probabilities between \$1.8B and \$2.3B and the higher probability of the cost estimate in the modal centre of the distribution. In contrast, the influence of the risk management actions on the estimated schedule has been a large shift of the estimated range downward. In fact, the mean value of estimated project duration decreased from 99 months in July 2002 to 77 months at the time of the March 2003 evaluation. Both the change in the estimated cost range and the decrease in expected project duration were viewed as significant positive impacts on the Seattle Monorail plan.

The changes (reductions) in estimated cost and duration for the Seattle Monorail project are directly linked to success in addressing the list of targeted risks defined previously. For example, the uncertainty about continuity in project leadership and management was reduced by a supportive policy decision to maintain a core of the original governing board and, in turn, their success in retaining key executives. Similarly, the importance of establishing appropriate agreements and policies among several key agencies and the City of Seattle was a priority in the risk management program and had been accomplished by March 2003. Another example of successful risk management was a set

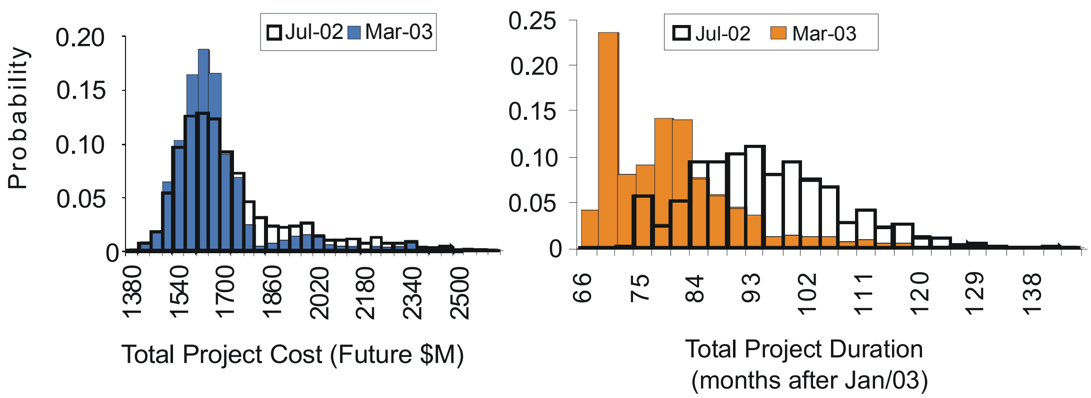


Figure 9. The effect of risk management in changing estimated cost and duration, Seattle Monorail project.

of agreements and lead agency commitments to a 12-month EIS process. In each one of these three examples, the success in getting the positive result was attributed to being able to identify the critical risk issue and being able to communicate to decision-makers how significant the effect of these decisions could be on the plan.

In summary, the Seattle Monorail management, board and staff used the results of a risk-based estimate evaluation in an effective risk management program. They used the initial assessment results to target appropriate management and policy risks where early actions to mitigate the risks could have significant impact. They then targeted these critical risks in a strategic program to bring about change. A re-evaluation of the project after eight months documented significant positive results.

9. CONCLUSIONS

A risk-based process for cost and schedule estimation using (including risk management) has been described in this paper. Versions of this process are now used routinely by one major state agency, several US federal transportation departments, and by consulting groups on other major public infrastructure projects. The probability-based cost estimation process offers significant advantages over traditional processes related to:

- explicitly understanding the financial and schedule risk associated with infrastructure construction projects;
- focusing project decisions and value engineering on high-risk items;
- capitalising on the strengths of the entire project owner, design, and advisement teams; and, most importantly
- communicating the direct links between cost and risk to the public and significant stakeholders.

Significant qualitative and quantitative benefits have been gained in the management and communications for new transportation projects. Further use of such risk-based cost estimating techniques may assist public agencies, private transportation groups, or combinations of these, and the general public in understanding both the risks of undertaking such projects and in the development of better policies and practices for renewing and improving our transportation infrastructure.

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