

Management and Control of Cost and Risk for Tunneling and Infrastructure Projects, in China perspective, for the South to North Great Western Diversion

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Abstract

This paper presents a recently-developed risk-based approach to better estimate, and manage, the cost of complex tunnel and infrastructure projects. The method, called the Cost Estimate Validation Process (CEVP[®])¹ combines quantified risk and validated base costs to produce a “range of probable cost” for the project. This is necessary to correct the long history of world-wide problems in accurately estimating the final cost of these projects.

Such experience has been at times equally applicable to China infrastructures – therefore, to help improvements for the future, the authors have thought useful its presentation in the Beijing national symposium.

The method was developed and implemented by the main author and the Washington State Department of Transportation (WSDOT), working with key colleagues. It has now been used for a significant number of tunneling and infrastructure projects and it has been endorsed by the U.S. Federal Highway Administration and the U.S. Federal Transit Administration. The method, or an equivalent, is now required by these Agencies for major projects.

Such a track record and public endorsement reinforce the authors’ view of its suitability also for the South to North Great Western Diversion, due to the physical, environmental and technical difficulties and the potential high range of risks, intrinsic in such long and deep tunnels.

¹ CEVP[®] is registered to the Washington State Department of Transportation to recognize its development and application of this new process and to assure that, if the process is applied by others, that they acknowledge WSDOT and follow the basic requirements of the process. Hereafter CEVP will be used in the text.

The benefits of the method include:

- 1) Better estimation of “range of probable cost”
- 2) Explicit risk identification
- 3) Quantified risk management plans to reduce risk and cost.

Keywords: risk evaluation; cost implications of risks; reliable construction estimates time and cost-wise; Cost Estimate Validation Process (CEVP); applicability of method to Great Western Diversion-China; effective management control of cost and time from project feasibility to final commissioning.

1. Management problems – Poor cost performance

1.1 Examples of cost growth – International & Chinese projects

An Editorial comment in *Tunnels & Tunneling Journal* (2003 [27]) asked “Why can’t engineers prepare more reliable construction estimates?” This is because there are many examples of large cost over-runs for complex projects. The problem is world-wide and it has existed for a long time (70 years, according to Flyvbjerg research, 2002 [6]).

Cost growth is defined as the final cost of the project compared to the cost estimated at time of decision to proceed with the project.

Examples of large cost growth for tunnel projects include the Great Belt Link Tunnels (54% over budget), London’s Jubilee Line Metro Project (67% over budget), Boston’s Central Artery Tunnel (approximately 100% over budget) and the Channel Tunnel (80% over budget). These are all good and notable projects - with well recognized design and construction achievements.

Also in China there have been instances (such as e.g. Ertan, Xiaolangdi and Wanjiashai) of cost over-runs in complex mega-projects, risks all due essentially to unforeseeable geological circumstances.

1.2 Reasons for cost growth

An international survey by the main author (Reilly & Thompson, 2001 [17]) found that many owners reported significant cost and schedule overruns, suggestive of deficient management, for at least 30% and probably more than 50% of projects. These results were presented at International conferences. Discussion at those conferences identified the following as necessary for better management of cost and risk:

- Better Risk Identification and Quantification
- Better Cost Estimating process (which must include uncertainty, that is, Risk)
- A Strategy for better Cost Management and Management of Risk.

2. Risk identification and risk mitigation

Risk is always present in the design, contracting and construction of large, complex projects, particularly those involving underground conditions (ITA 1992 [13]; Jubilee Line 1993 [14]; Vrijling and Redeker 1993 [28]). Additionally, a significant number of projects overrun their budgets and schedules through what have been called “unforeseen events” – an excuse frequently given to Agency Boards of Directors when additional time and money are required.

Risk reduction through risk identification, analysis, mitigation and contingency planning is an essential management task. Risk identification and mitigation processes are well-established – and models exist to quantify the probable cost of risk (Einstein and Vick 1974 [5]; Roberds, 1996 [24]; Grasso et. al. 2002 [9]; Anderson et. al. 1999 [1]; Isaksson 1998 [10] & 2002 [12]; Reilly 1999 [16] & 2003a [20]). These models have been successfully applied to many tunnel and infrastructure projects (see previous references).

2.1 Risks for tunnel projects

Tunnel projects are inherently complex with many variables including: uncertain and variable ground conditions; construction conditions and; contract assumptions. The type of risks that should be addressed for such projects include:

- Risk of injury or catastrophic failure with the potential for loss of life, and personal injury, extensive material and economic damage and, loss of credibility for those involved
- Risk of not meeting functional design, operational, maintainability and quality standards
- Risks of a significant delay to project completion and start of revenue operations
- Risks of significant increase of project and support costs

Reasons to identify, quantify and mitigate risks early in a project include:

- To reduce the risk to project goals and objectives - safety, schedule, budget.
- To demonstrate that options were comprehensively and rationally evaluated
- The process will reveal useful information even if the risks do not eventuate
- To clarify project goals, objectives and priorities (“alignment” of the project team)
- To estimate the probable ranges of cost and schedule
- To develop early Risk Mitigation Plans
- To develop and implement a strategic approach to the project

2.2 Risks specific for Great Western Diversion tunnels mega-project

The long tunneling at depth is made particularly complex by the environmental, climatic, location and physical conditions of the required work site (Arrigoni, 2005 [2]). The known problems encompass:

- Severe climatic conditions, with sub-zero temperatures for about 6 months, at high altitude
- Oxygen starvation, with consequent dramatic loss of human and engine performance, so maximization of mechanization and electrification is required
- Location problems, difficulties in access, supply, remoteness, adequate infrastructure provision for such extreme conditions
- Ventilation needs on such lengths & in such atmosphere
- High water inflows, so pumping required in all tunnels
- Finding excavation, muck conveyance and lining solutions, to minimize human toil, compatible with rock conditions and ventilation requirements
- Need to attract and preserve experienced human resources, in such conditions.

In addition to these known difficulties, more will eventuate to variable extents, due to a range of risks and hazards, examples of which include:

- Geological uncertainties, due to intrinsic difficulties of effective investigations at depths with covers in excess of 500 m
- Rock convergence phenomena, both short and long term, to be tackled for the constructability and ‘final lining’ aspects
- Many (over 20) fault zones requiring pre-treatment prior to conventional and TBM excavation
- Sudden water blows under pressure, due to highly fractured zones acting as aquifers (with or without gas inflow)
- Unstable tectonized areas, with risk of fall-outs and/or TBM blockage
- Earthquake zones, heavy fault zones, affecting permanent works
- TBM main bearing (and/or reduction gears) / main conveyor belt break-down
- Landslides / land mass movements, affecting either portals and surface works or interrupting supplies (including electricity)
- High ground temperature
- Rock bursts, tunnel fire, etc.

3. An Improved Cost Estimating Procedure

In meetings with colleagues and Associations in 12 countries between 1998 and 2002, the main author discussed the need for better management of complex projects and methods to better meet cost and schedule. Identification and management of risk was noted as essential to better manage projects - but this was recognized as one of the most difficult requirements. From these discussions, it was apparent that a new technique or process was necessary.

As noted above, the infrastructure community has consistently under-estimated the cost of complex projects for over 70 years. We have not corrected this problem, because, if we had, there would have been an equal number of cost estimates equally above and below the corresponding budget number – but this has not been the case (see Flyvbjerg 2002 [6], 2003 [7]).

The process of risk identification is well understood and has successfully been applied to a number of projects. Additionally, specialized examples of tunneling risk models, which predict probable cost and schedule ranges, have been developed and successfully used (references noted previously: [1], [5], [9], [10], [12], [16], [20], [24]). However, risk processes related to probable cost and schedule, have not been widely applied to complex infrastructure and tunnel projects. An example of such a process is given hereafter.

In order to consider such a process, the following considerations apply:

1. The final cost of a project is subject to many variables, assumptions and conditions
2. These variables significantly influence the range of “probable projected cost”
3. A single cost number represents only *one possible result* and is dependent on these variables
4. The variables are not all directly controllable or absolutely quantifiable
5. Cost estimates must include the effect of potential risks and opportunities

Managing a project within an established budget means two things:

1. The budget must be realistic in terms of the project, its environment and its characteristics
2. Management procedures must be capable of controlling the project with respect to budget

Traditional methods for dealing with risk, in terms of potential cost, rely on the use of “contingencies”. These contingencies usually lump together the consequences of an unspecified number and type of possible problems. While based on the “expert” judgment of the estimator, these contingencies do not allow for explicit identification and management of uncertainties and risk. Additionally, control of long-term factors - environmental, political, technical - which significantly affect the final cost is very difficult.

Therefore, as a result of all these considerations, an improved cost estimating process to better forecast cost, including risk and long-term factors was developed by the main author with key colleagues and the Washington State Department of Transportation. It is described below.

3.1 The Washington State Department of Transportation's Cost-Risk process (CEVP)

In 2000, public concern regarding the ability of a U.S. transit agency, Sound Transit, to reasonably estimate the cost of a long tunnel project, the North Extension Light Rail Line, was confirmed when the contractors' bids were substantially higher than the cost estimate.

At that time, The Washington State Department of Transportation (WSDOT) was about to initiate several very large and complicated Highway projects, including two with tunnels. Concerned about the cost estimating problem, WSDOT decided to apply a new, experimental cost estimating process including cost validation and risk assessment.

The WSDOT "Cost Estimate Validation Process" (CEVP) was conceived by a small team of Agency Managers and Consultants (Reilly, McBride, Dye and Mansfield, 2002 [19]). The process included cost validation and inclusion of the probable cost of foreseeable risk (and opportunity) events. The process was directly applied to 9 large complex, transportation projects, with a collective value about \$US 25 billion (Brown, 2002 [4]).

The CEVP process estimated new cost-ranges for these projects which were significantly higher than previous cost estimates – due to the inclusion of a comprehensive list of risk events, including potential political and long-range management problems. WSDOT released the results to the public, the press and political decision makers on 2002, June 3rd (MacDonald et. al. 2002 [15]). The initial negative public reaction to the increased costs quickly turned to public acceptance of this new way of estimating, as shown by several following newspaper articles, editorials and letters.

The concept that an estimate of future costs is not a single number but a "range" was quickly understood by the public and political decision makers. The Department was commended for producing more realistic cost estimates. The editorial in one paper said: *"Shocking or not, the Department of Transportation has performed an unprecedented public service with these latest cost estimates. It is a much-needed dose of fiscal reality. The department offered realistic cost-range estimates."*

3.2 A summary of the CEVP process

CEVP is conceptually simple, although complex in application. It consists of the following steps:

1. Examine, in detail, the project estimate and determine the "base costs"(those costs that would occur if the project goes "as expected") removing all risk elements ("contingencies") in a concentrated workshop with the project team plus independent (external) subject matter experts. Address any significant variability in the "base costs".
2. Identify and quantify all identifiable potential risks and opportunities including their probabilities and consequences (potential impacts and benefits)

3. Statistically combine base costs and risk plus opportunity events to develop the “range of probable cost and schedule”.

The essential concept is shown in the following figure 1.

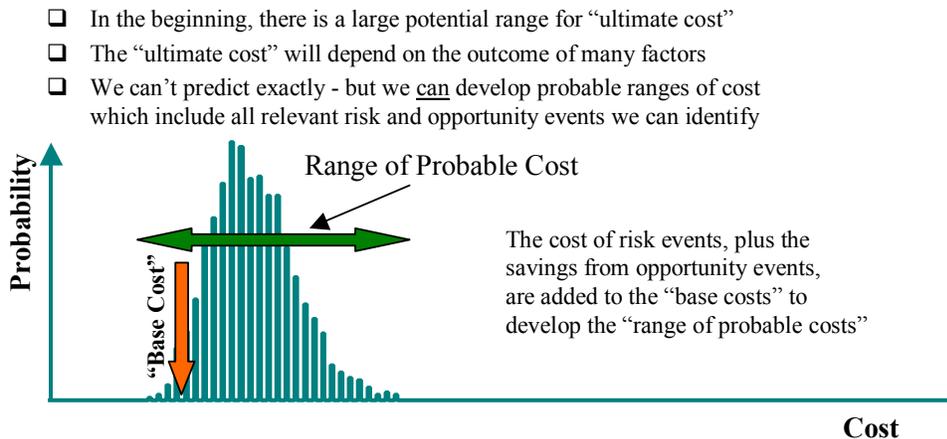


Figure 1 – Base Cost + Risk and Opportunity Costs gives the Range of Probable Cost

3.3 US National Acceptance of the CEVP Cost Estimating Procedure

The CEVP process, or a simpler process called Cost-Risk-Assessment (CRA), are routinely applied to projects in Washington State. The CEVP process is now well understood in Washington State as the way that most cost estimates should be produced. The exception is for small, routine well-understood projects with low risk (uncertainty) in their construction.

The process was presented, by the main author and the Secretary of Transportation to the Transportation Research Board in Washington, D.C. (Reilly, 2003a [20]) with briefings to representatives of the U. S. Federal Highway (FHWA) and Federal Transit Administrations (FTA). Following this presentation, in July of 2003, the U.S. Federal Transit Administration evaluated the CEVP process by applying it to a transit project in Pittsburgh. Subsequently, FTA and FHWA have adopted as policy that cost estimates for large complex projects must use a risk-based approach and FTA has developed a comprehensive cost-risk methodology manual (U.S. Federal Transit Administration 2004 [8]).

3.4 The International Extent of the Cost Estimating and Management Problem

Following implementation of the WSDOT CEVP process, Flyvbjerg et. al. published a study of 258 projects world-wide (Flyvbjerg 2002 [6]) which showed the cost estimating problem to be more extensive and chronic than many had believed.

Subsequently they stated that “A main cause of overruns is a lack of realism in initial cost estimates.” (Flyvbjerg et. al., 2003 [7]) and noted that it is inevitable that there will be management and cost over-run problems if the real scope of a project (including the effects of risk events) is greater than that envisioned by the estimator. Under these conditions, no manager, however excellent, can successfully complete a project which has an unrealistically low estimate (budget). China mega-projects also have had, at times, to face similar kinds of problems, which it would be preferable to avoid altogether by adopting an appropriate risk evaluation process

This leads to the third topic of this paper – a better strategy for management of complex infrastructure and tunneling projects.

4. A strategy for better cost management, including risk

After the London Jubilee Line Metro project was complete, the Oversight Consultant’s report, to the UK Secretary of State regarding cost and schedule overruns (Arup, 2000 [3]), noted that the project was a “...safe achievement, bringing significant benefits.” but that “...time and cost overruns could have been minimized with a more established strategy at the very beginning of the project”. The Agency agreed.

Many will agree that an early, comprehensive strategy is necessary for successful management of cost and risk for complex and tunnel projects – but, how can such strategies be explicitly developed? It has been demonstrated that one of the benefits of the CEVP approach is that it forces the project team to think about all risks and, in particular, long-range risks that may not be technical in nature (like e.g. some economics redistribution inherent in the subsequent stages of the Great Western Diversion, China) – such as politics, environmental, local and national policies, governance issues and management continuity – all of which were major contributors to Boston’s ‘Big-Dig’ cost and schedule overruns (Salvucci, 2003 [26]).

Following are the general risk mitigation steps which will produce a more strategic approach to risk and successful project management earlier in a project’s life-cycle – for which CEVP provides explicit and quantified risk information (see also Reilly, 2003a [20] and b [21]).

1. Identify all possible high-cost and schedule risk events
2. Quantify the probability and consequences of these risks
3. Identify a risk mitigation plan for the high-cost and schedule risk events
4. Formalize the Risk Management Plan (adopt by top management).
5. Implement the risk mitigation strategies to reduce potential impacts – leaving “residual risk”
6. Decide how to handle the “residual risk” – e.g. accept, allocate contractually or insure.

It is the authors’ opinion, on their experience in major projects world-wide, including China, that the application of the above ‘structured approach’ to the Great Western Diversion mega-project would maximize management and economic (both cost- and time-wise) benefits for all the project aspects of feasibility, budgeting, engineering,

financing, construction and operation. It will also help all “main actors” (YRECC, TBM manufacturers, specialist suppliers, contractors, MWR, Central Government) to focus as early as possible on the ‘technically’ best contingency plans for risk mitigation, schedule maintenance and budget restraint, all aspects of paramount interest for the government planning and the people benefit.

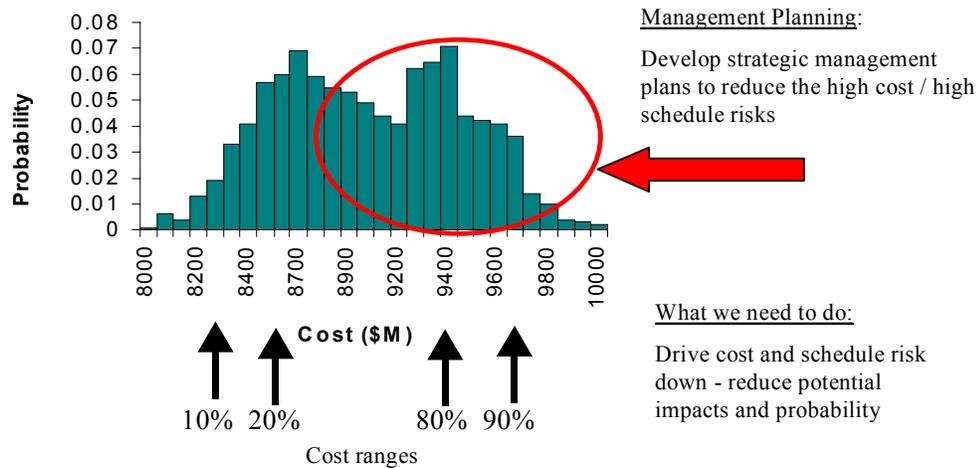


Figure 2 – Range of probable cost with risk mitigation targeted to the high-cost risk events

5. Conclusions

1. The final cost of a project is subject to many variables, assumptions and conditions which significantly influence the range of probable cost.
2. A single cost number represents only *one possible result* and is dependent on variables which are not all directly controllable or absolutely quantifiable
3. Cost estimates should produce a “range of probable costs”
4. To do this it is necessary to use a process incorporating quantified risk (probability and consequence)
5. A new approach – the Washington State Department of Transportation’s Cost Estimate Validation Process (CEVP) and a simpler Cost-Risk-Assessment (CRA) process, have been successful in producing more realistic ranges of probable costs for complex projects
6. The CEVP process explicitly quantifies potential risk events and their contribution to “probable cost” – allowing explicit risk management plans to be developed early in the project
7. The more realistic cost ranges have increased public confidence in the Agency’s ability to estimate and manage complex, infrastructure projects
8. Cost-Risk processes, following CEVP, have been adopted by the U.S. Federal Transit and Federal Highway Administrations. Policy memoranda have been issued to this effect.

9. In the China context, the development of the above ideas, techniques and innovations will take time and experience, but will require most encouragement and willingness by top management to endorse such new “paradigms”. If top Chinese leaders and managers will progress along these lines, much value and capability will be realized within China and for this ambitious Great Western Diversion project.
10. Applied jointly with a ‘dispute avoidance’ contractual scheme, such as “partnering” / “alliancing”, it could lead to a ‘contract arrangement’ more akin to the Chinese culture and tradition, than what is presently adopted under the FIDIC / World Bank (+DRB/DAB) form.

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