CEVP-RIAAT Process—Application of an Integrated Cost and Schedule Analysis

Philip Sander and Martin Entacher
RiskConsult

John Reilly
John Reilly International

ABSTRACT: Key processes necessary to identify and manage risks on complex tunneling projects have been developed over the last 20 years in order to implement risk-based approaches for better cost and schedule estimation. Cost and schedule, however, were mostly treated separately instead of integrating them in one model. This integration is highly relevant as schedule delays are very often the root cause for severe cost overruns. This paper presents a fully-integrated probabilistic cost and schedule model. The application is based on combination of two practice-proven approaches—the Cost Estimation and Validation Process CEVP® (Reilly et al. 2004/Washington State Department of Transportation) and the RIAAT (Risk Administration and Analysis Tool), creating a powerful tool for management of complex risk environments.

INTRODUCTION

Significant progress has been made over the last 20 years in the identification, characterization, mitigation and management of risk for complex projects. Risk guidelines have been developed (ITA 1992, 2004; ITIG 2006, 2012; Reilly 2001, 2003, 2008, 2013; Goodfellow & O'Carroll 2015) and are more routinely applied with increasing success, such that the general process and application of risk management principles are now generally clear. During this period, specific applications and detailed tools have been developed to assist with risk identification, characterization and mitigation, such as:

- Risk-based cost estimating, e.g., WSDOT's CEVP cost estimating/cost validation/risk management process (Reilly et al., 2004)
- Risk management processes and procedures (ITA 2004, ITIG 2006, Reilly 2008, Goodfellow & O'Carroll 2015)

Drawbacks in previous cost-risk processes were:

- A delay in obtaining results, since the model could only be run after completion of the cost-risk workshop, which frequently took several weeks
- A preliminary or approximate approach to the probable schedule element in terms of risk effects on the critical path and identification of the risk elements that contributed to those critical paths

RIAAT (RIAAT 2017. http://www.riaat.riskcon.at) solved both of these drawbacks since it is an integrated model which can be run in real time, during or at the conclusion of the workshop, to give results quickly. It allows efficient application of risk-based processes including risk characteristics (probabilities and consequences), correlations, interdependencies, linkage, risks occurring multiple times and schedule/critical path analysis (Sander et al., 2016).

Also added were full risk-based critical path schedule and cost integration in the risk-based cost and schedule estimating process and associated computer models. This is the subject of this paper.

DEALING WITH UNCERTAINTIES

Since empirical/historical data as input for risk analysis is often not available, risk probabilities and consequences can be difficult and complex to estimate. Normally, experts are involved in a workshop using, for example, Delphi technique. The risk-based method characterizes each risk with individual and specific distributions such as a large cost ranges for large uncertainties or a narrower cost ranges for smaller uncertainties. Using this approach, the uncertainty contributing to a particular cost estimate can be modelled more specifically and in greater detail than by use of a single-point deterministic estimate (Sander et al., 2009).

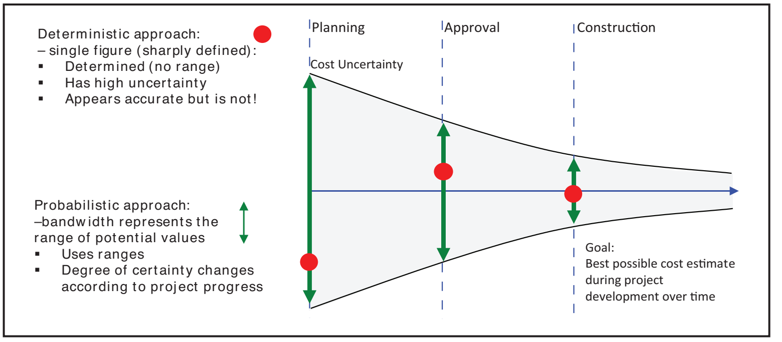


Figure 1. Deterministic versus probabilistic method in project development

Cost estimates, especially if only deterministic approaches are considered, can come with a high degree of uncertainty. This is especially true for early phases of projects when neither the exact quantities nor the exact costs or prices are yet known. Quantities will be determined for known project elements, but allowances must be made for unknown elements. Often a more detailed analysis is not yet available at this stage of the project due to a lack of precise information. With a deterministic approach, information about potential deviations (variability due to potential higher or lower values) for quantities and prices is not usually taken into consideration although this information is available or could easily be estimated (Figure 1).

At first sight, probability functions might seem more uncertain compared with what might seem to be a "totally defined deterministic value"—however, exactly the opposite is true (Rohr 2003) because the accuracy of a forecast is greater when the uncertainty component is included. The uncertainty is part of the answer and so not including it means that part of the answer is missing, therefore that answer is less accurate.

CEVP RIAAT PROCESS

Combining Both Approaches

CEVP is a Cost Validation and Risk Management process to address the concerns of:

- Why do project costs seem to always go up?
- Why can't the public and/or private owners be told exactly what a project will cost?
- Why can't projects be delivered at the cost you told us at the beginning?

CEVP opens the "black box" of estimating, ensures cost transparency and provides a profound decision making basis for senior management.

CEVP® CEVP® RIAAT RIAAT

Figure 2. CEVP RIAAT process

The software RIAAT can fully implement the CEVP-Process. RIAAT combines a clear project structure and a convenient work flow with extensive modeling and simulation capacities. Key features include:

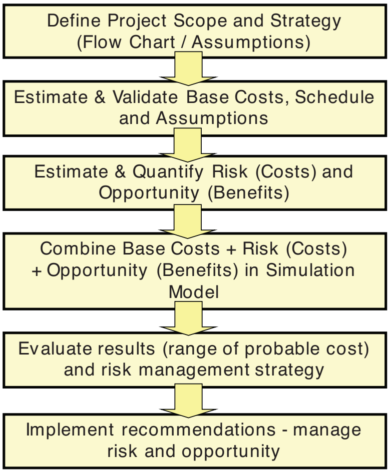
- Hierarchical project tree (WBS)
- Full integration of uncertainties for all cost components on all levels
- Live results and simulation updates within seconds
- Fully integrated cost and schedule model

Combining the CEVP Process with the simulation capacities of RIAAT (Figure 2) adds a powerful tool for the management of complex risk environments

CEVP—Cost Estimate Validation Process

In 2002, WSDOT, recognizing the need for a validated, integrated, cost-risk estimating process, developed the Cost Estimate Validation Process (CEVP®), to better estimate the range of cost and schedule for their complex megaprojects. The process has been described in detail (Reilly 2004, 2013)

In CEVP, estimates are comprised of two components: the base cost component and the risk component. Base cost is defined as the planned cost of the project if everything materializes as planned and assumed—the base cost does not include contingency but does include the normal variability of prices, quantities and like units. Once the base cost is established, a list of risks is identified and characterized, including both opportunities and threats, and listed in a Risk Register. This risk assessment



Principles

- Project team and CEVP team, including Subject Matter Experts, are brought together in workshops
- Promote openness to risks that may occur (culture of realism, not false optimism)
- Create mutual understanding of the project
- Integrate uncertainties in all phases
- Create clear project structure including cost components (Base Cost, Risk, Escalation)

Figure 3. CEVP process

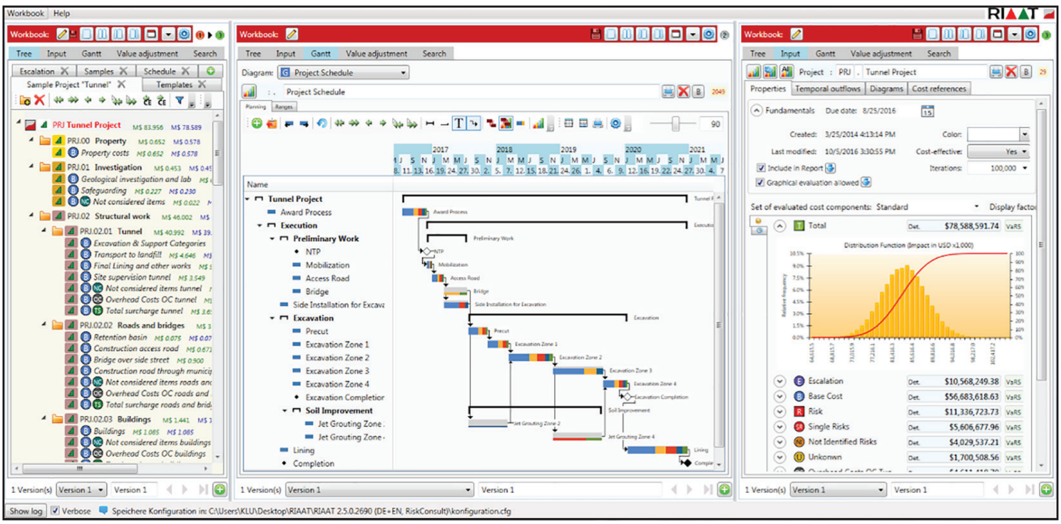


Figure 4. Sample main interface, RIAAT risk software

replaces general and vaguely defined contingency with explicitly defined risk events that include the associated probability of occurrence plus impact on project cost and/or schedule for each risk event. Risk is usually developed in a CEVP Cost Risk Workshop.

The validated base cost, base variability and the probable consequence of risk events are combined in a simulation model to produce an estimated range of cost and schedule, with probabilities of achieving a particular cost or schedule outcome (see Figure 3). The output is a rich data set of probable cost and schedule, potential impact of risk events, ranking of risks and risk impact diagrams.

RIAAT—Risk Administration and Analysis Tool

The Risk Administration and Analysis Tool RIAAT (RIAAT 2017) is a powerful software that enhances CEVP principles by integrating them into a continuous workflow. RIAAT uses probabilistic modeling. In spite of advanced mathematics in the background, results can be updated live during workshops and easily understood due to RIAAT's clear work breakdown structure. RIAAT supports full MS Excel Import/Export, advanced risk modeling and numerous options for visualization. Figure 4 shows the main interface of RIAAT—the following figures in this paper were generated using RIAAT.

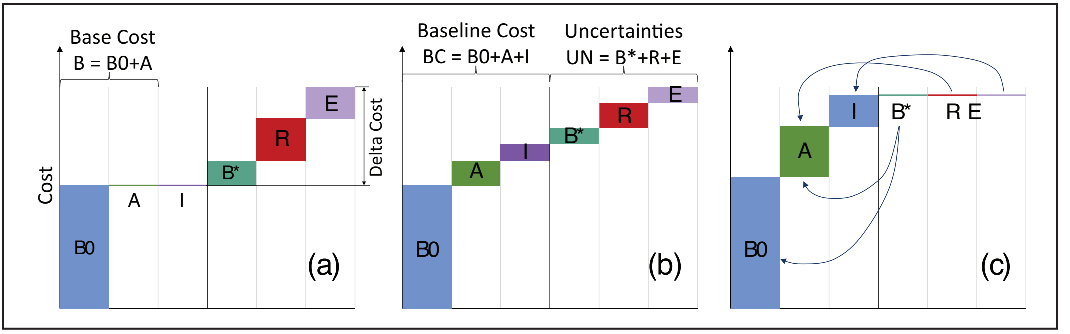


Figure 5. Waterfall diagram for cost component structure, planning phase (a), construction phase (b), project completion (c)

The RIAAT workflow is optimized, utilizing a normal estimating structure and well-understood elements such as base cost, risk and escalation which makes it a good fit to use in CEVP workshops. Cost components that need to be addressed in the cost estimate are:

- Base cost—the cost if "all goes according to plan" without contingencies
- Risk cost—the cost resulting from threats and opportunities that might occur
- Escalation cost—additional costs resulting from inflation

A best practice cost component structure for different project phases is shown in Figure 5. It consists of actual cost without uncertainties (left part of the waterfall diagram: B0—Base Value, A—Additional Cost, I—Indexation, B0 + A + I: *Baseline Cost*) and uncertain components (right part of the waterfall diagram: B*—Base Uncertainties, R—Risk Cost, E—Escalation, B* + R + E: *Uncertainties*). The sum of the uncertain cost components is also called *delta cost* and allows for inclusion of uncertainties in the project budget. While uncertainties are high in early project phases, they reduce to zero upon project completion. Escalation becomes indexation cost (contractual clause for compensation for inflation) and realized risks result in actual additional cost.

Construction schedules are fully integrated into RIAAT. Risks are assigned to tasks (elements) of the schedule from the project tree using drag&drop. Schedule results (e.g., completion dates, critical paths) are obtained using Monte Carlo simulation (since the performance of Monte Carlo simulation is no longer a problem, 100,000 iterations can be carried out in just a few seconds). Delays can be associated with time related cost which allows for an integrated cost and schedule analysis.

Process

The process used for the integrated cost and schedule model is shown in Figure 6. In the first step, Base Cost is estimated and validated, subjected to uncertainties, and integrated into the Work Breakdown Structure (WBS). Subsequently, identified risks and a markup for unknowns with cost and time impacts will be assessed and integrated into the WBS and the construction schedule. A probabilistic simulation of the construction schedule incorporates all risks with associated time impacts. The results include a construction completion date, delays with respect to specific milestones, critical paths and near-critical paths. The results of the construction schedule are linked back to the WBS, where the time impacts can be associated with time-related costs to evaluate the cost impact of program delays.

Figure 6 depicts the following steps:

1. Base cost estimate is reviewed, associated with uncertainties and integrated into the WBS.
2. Risks are assessed (probable cost & time impact) and integrated into the WBS.
3. Risks are assigned to tasks in the project's schedule. Subsequently, completion date, critical paths and delays from risks are simulated.
4. Cost impact from time delay is calculated with time-related cost and integrated into the WBS.
5. Project Cost including uncertainty is available an all WBS levels and for all cost components.

As shown in Figure 6 RIAAT is an ideal tool to fully utilize the added value of CEVP. The optimized use of cost components (e.g., base cost, risk), the ability

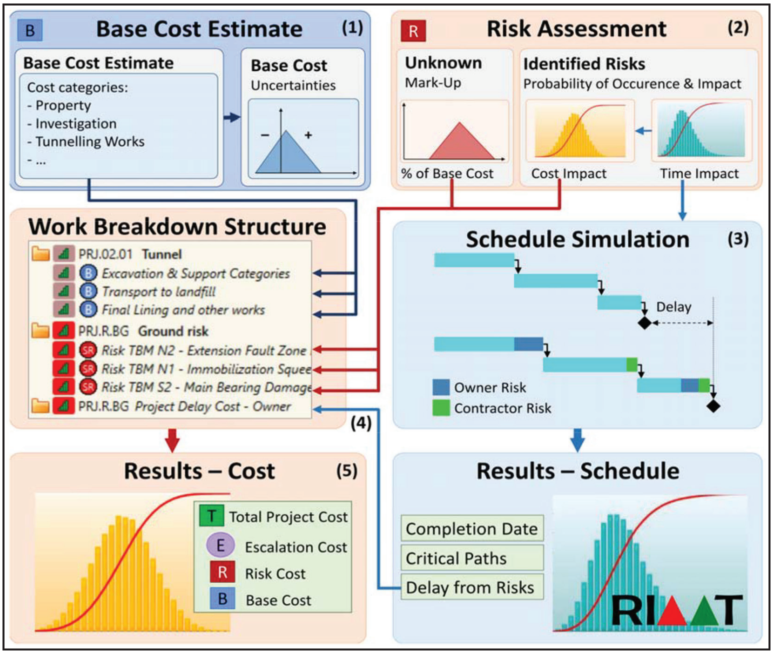


Figure 6. RIAAT—process for integrated cost and schedule analysis

for probabilistic simulation, the instant availability of results and the integrated cost and schedule analysis are very beneficial for the application of CEVP. The combination of CEVP and RIAAT is thus called the CEVP-RIAAT Process.

INTEGRATED COST AND SCHEDULE ANALYSIS—SAMPLE PROJECT

Project Description

A fictitious sample project is used in this paper to illustrate the process. It is based on experience from major European railway base tunnels. This 14-km twin-bore tunnel consists of several Tunnel Boring Machine (TBM) drives as well as Drill & Blast (D&B) drives in different geological formations, an access shaft, an emergency stop, various cross cuttings and (optional) inner linings. A linear project schedule is shown in Figure 7. In RIAAT, the base schedule is modeled as a Gantt diagram (Figure 8). The deterministic critical path is shown in red.

Base Cost and Risk Register

A deterministic base cost estimate is made by the design firm. It is reviewed, discussed and validated with the project team and a bandwidth is assigned to account for minor variability in the base cost estimate. Subsequently, risks are identified and assessed in moderated workshops with the project team and subject matter experts. The process is structured using “risk fact sheets” to gather and systematize information such as risk description, qualitative and quantitative assessment, risk strategy and risk mitigation measures. The quantitative assessment typically consists of either probability of occurrence (0–100%) or expected rate of occurrence (e.g., 1, 2, 3, etc., modeled with a Poisson distribution) and cost/time impact using a three-point estimate (best, most likely and worst case). Complex risks (e.g., including correlations or dependencies) can be modeled using event or fault trees (ETA, FTA). The risk register is updated during the workshops to give the project team a clear picture of the ongoing process.

Table 1 shows the quantitative assessment of the top 10 risks. The risks are ranked according to their respective VaR95 (95% of not exceeding the depicted value in days delay), which is depicted in the range impact diagram in Figure 9. Range impact diagrams are used to compare risks with respect to their cost or time impact (in this case time). The width of each bar represents the bandwidth of a risk impact from the best case (left end of bar, VaR5) to the worst case (right end of bar, VaR95). Each bar represents a probability of 10%. The left end of Risk No. 1 (TBM Main Bearing Damage) represents VaR80. This is because the probability of occurrence

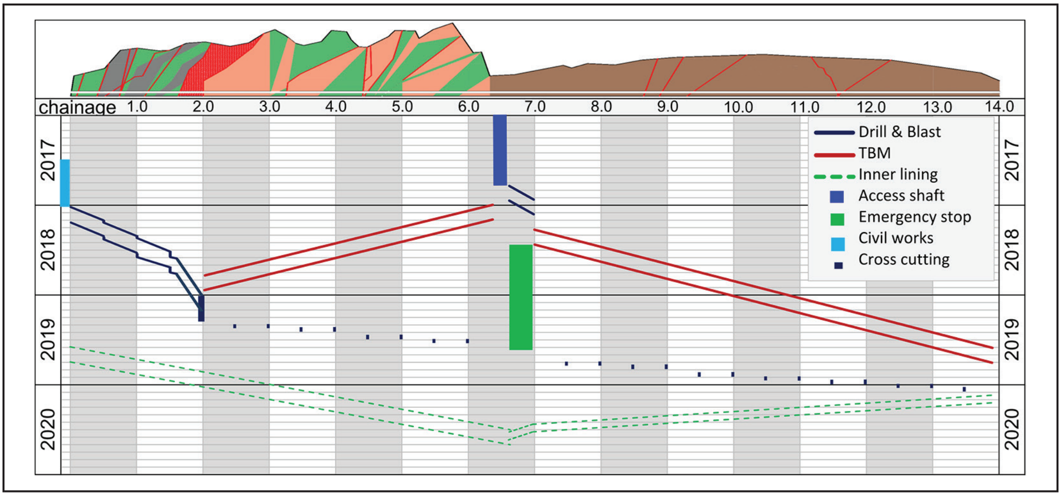


Figure 7. Linear base schedule—horizontal axis: station; vertical axis: time

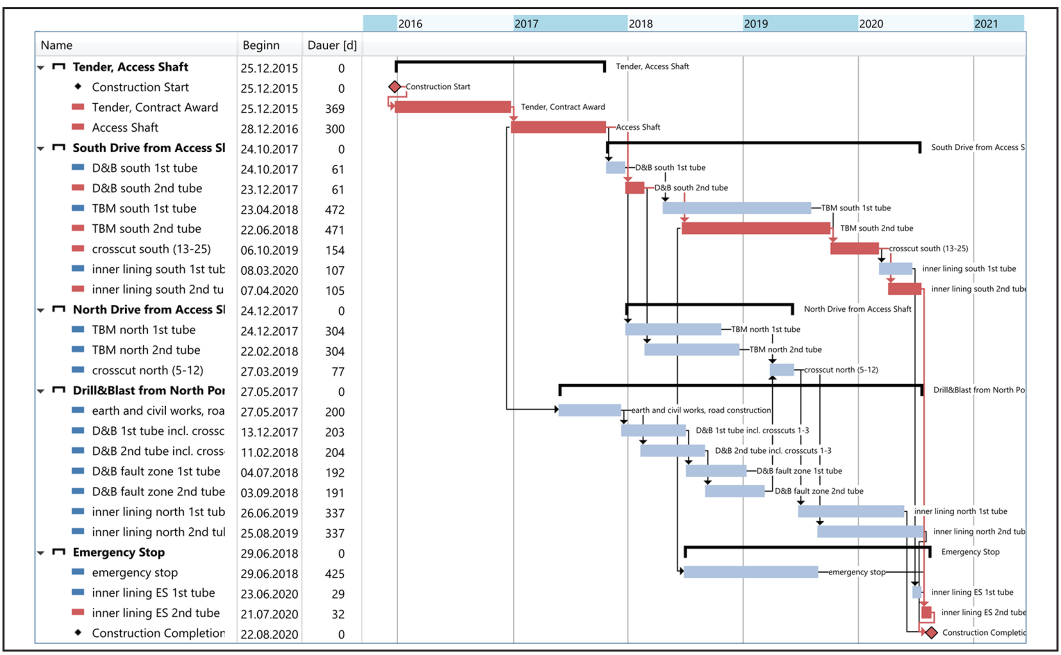


Figure 8. Base schedule in RIAAT, deterministic critical path without risks is shown in red

is as low as 20%. Hence, any probability lower than 80 equals to zero. Each of the top 10 risks has an associated % value. This value indicates the chance that the respective risk will be on the critical path according to the Monte Carlo simulation.

A single risk that is assigned to more than one task in the schedule will be dependent, i.e., the risk will impact both tasks if it occurs. The importance of the capability to model dependencies in schedules was explained by Dorp & Duffey (1999). In the following example, independent risks such as "Main bearing damage" for four different TBMs are modeled separately as four different single risks to ensure independency. For clarity, similar independent risk events are not displayed in Table 1 and Figure 9.

After the risk register is complete, all risks with time impact are assigned to the base schedule (Figure 10). Colors can be used to indicate the type

Table 1. Sample quantitative assessment of top 10 identified risks

#	Identified Risk	Probability of Occurrence	Rate of Occurrence	Cost Impact (USD × 1,000) Best	Most Likely	Worst	Time Impact (d) Best	Most Likely	Worst
1	TBM S2—Main Bearing Damage	20%	—	1000	2000	3000	90	180	400
2	TBM N1—Change in Exc.&Sup. Categ.	70%	—	500	3000	4500	20	120	180
3	TBM N1—Immobilization Squeezing	25%	—	1500	3000	5000	60	120	200
4	Contractor Appeal	50%	—	—	—	—	30	90	180
5	No Release of Design	30%	—	225	900	1350	30	120	180
6	TBM N—Delay installationon	25%	—	400	1200	2000	20	60	100
7	Extension Fault zone km 2.0	80%	—	0	840	1660	0	42	83
8	TBM S2—Extension of inner lining	—	3	150	200	250	5	10	20
9	Logistic Problems Crosscut S (13–25)	30%	—	150	375	600	20	50	80
10	CC N—Mountain water inflow >40l/s	—	3	222	886	1782	1	3	14

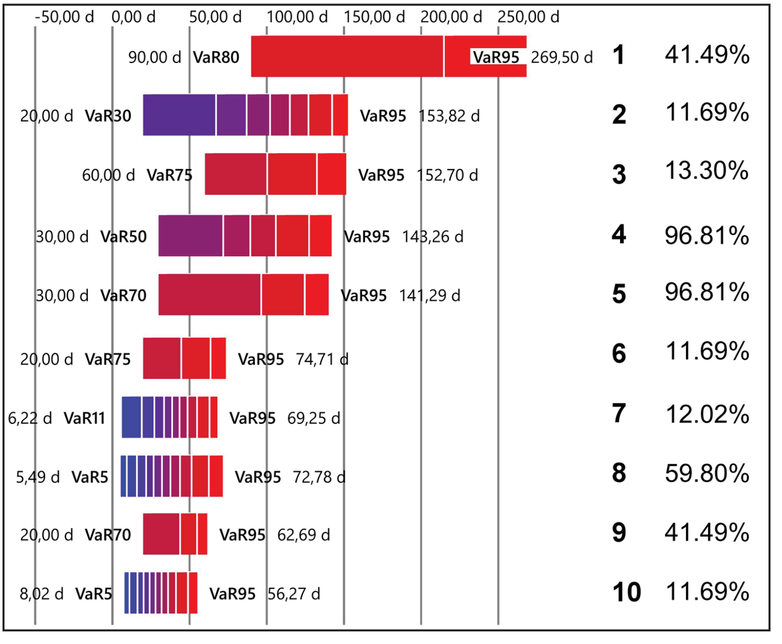


Figure 9. RIAAT range impact diagram for top 10 identified risks, bandwidth: VaR5–VaR95

of assigned risks, e.g., for owner risks, contractor risks and tender risks (pre-contract). The length of each task is not a deterministic number anymore, it contains uncertainties and is thus represented with a distribution function. Due to the assigned uncertainties, different critical paths become possible. The probabilities of occurrence for various critical paths are calculated using Monte Carlo Simulation.

RESULTS

Simulation results for the critical paths are shown in Figure 11. Different colors can be used to indicate alternative critical paths. A task with more than one color would be more than one critical path, e.g., in this example, the task "Tender, Contract Award" would be made up of all relevant colors and would be part of all possible critical paths. A graphical example for interpretation is given in Figure 12. In this example, there is a 60% chance that the completion date will be determined by the TBM south drive, but there is also a 30% chance that the TBM north drives will become critical. The D&B drive from the north portal only has a 12% chance of becoming critical.

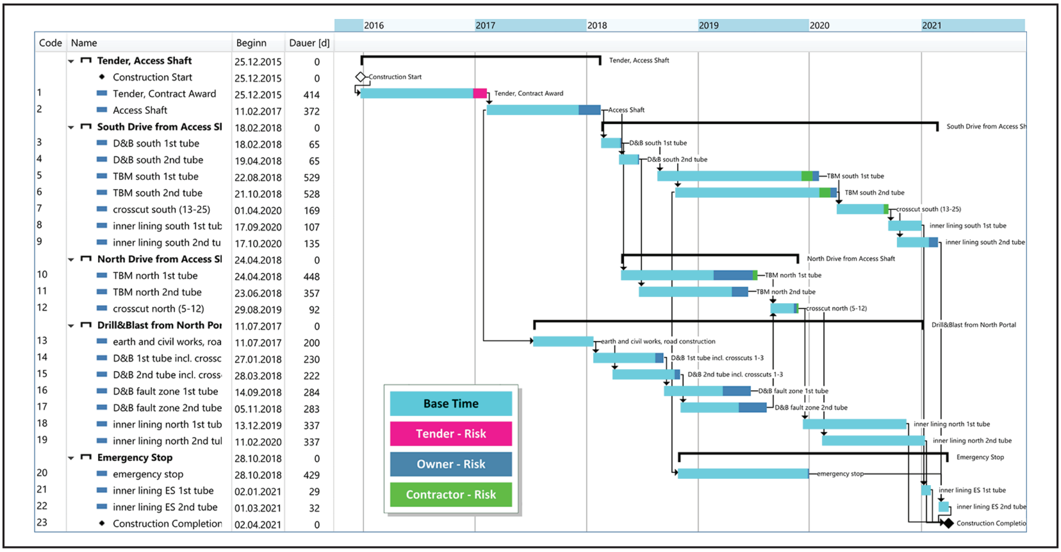


Figure 10. RIAAT schedule with assigned risks, colors can be used to indicate risk impact

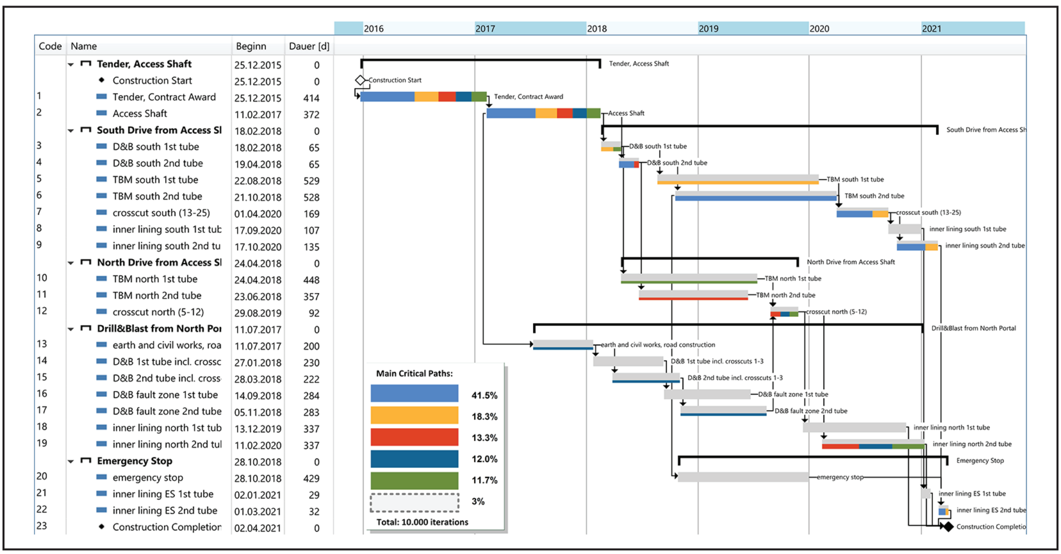


Figure 11. Results of critical path simulation in RIAAT, each color indicates one possible critical path

This will be the case when the fault zone turns out to be much longer than expected (risk 7).

The construction completion date and the deviation to the original construction completion milestone of the base schedule are shown in Figure 13. Direct time-related cost that is caused specifically by one risk event is calculated within the risk itself (see Table 1). In addition to that, a delay on the critical path causes additional time-related cost. This cost is now calculated using the overall project delay on the critical path. In this case, this was done by taking into account only the portion of the critical path delay caused by the owner's risks (see Figure 14).

After including time-related cost, a probabilistic cost forecast for all cost components can be made. The results are shown in Figure 15. The vertical line represents the deterministic base cost without uncertainties. Taking into account uncertainties related to the base will result in the curve to the right of the vertical line. Adding risk cost results in the next curve.

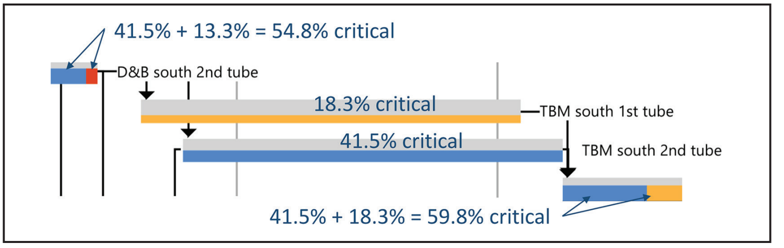


Figure 12. Interpretation of critical path simulation results

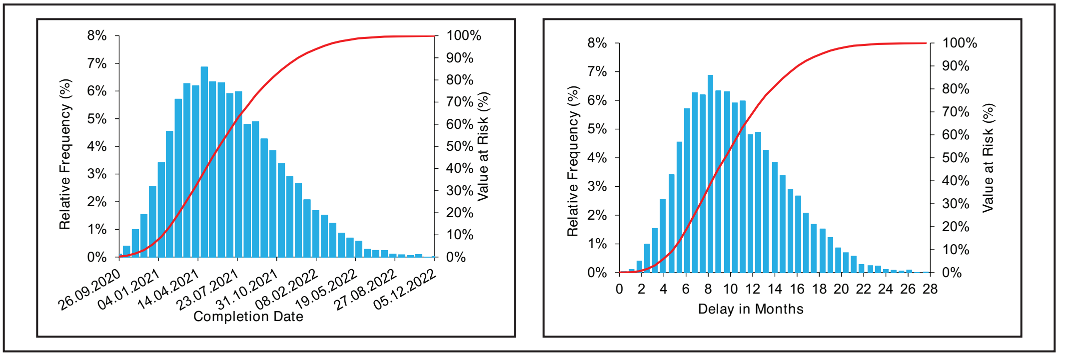


Figure 13. Construction completion date (left), and deviation to milestone (right)

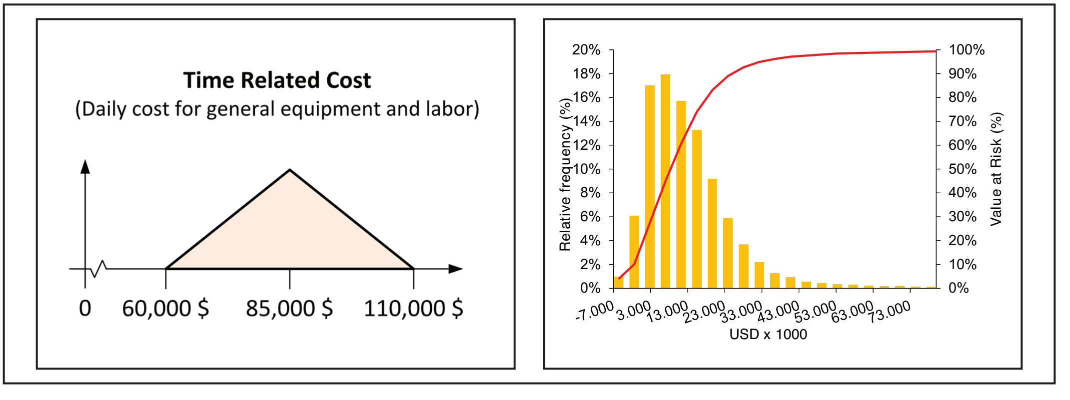


Figure 14. Delay on critical path from owner's risks is multiplied with time related cost and added to the overall risk cost of the project

Finally, escalation cost is added to obtain the total project cost (far right curve). Delta cost is obtained by comparing the total project cost with the deterministic base cost. In this case, a certainty level of VaR80 was chosen to determine the project's budget.

DISCUSSION AND CONCLUSIONS

This paper describes an integrated risk-based cost and schedule estimation, modeling and management process that has been used by a significant number of US and International projects and Agencies in the planning, design and construction phases of a significant number of complex projects. The process can be used to establish a transparent and realistic budget e.g., setting the budget for a program of projects at a probable outturn cost level e.g., a P80 level—an 80% chance that the projects will be delivered at or under this number (which also means that there is a 20% chance that they will be delivered over this number). The P-level will depend on the historical experience

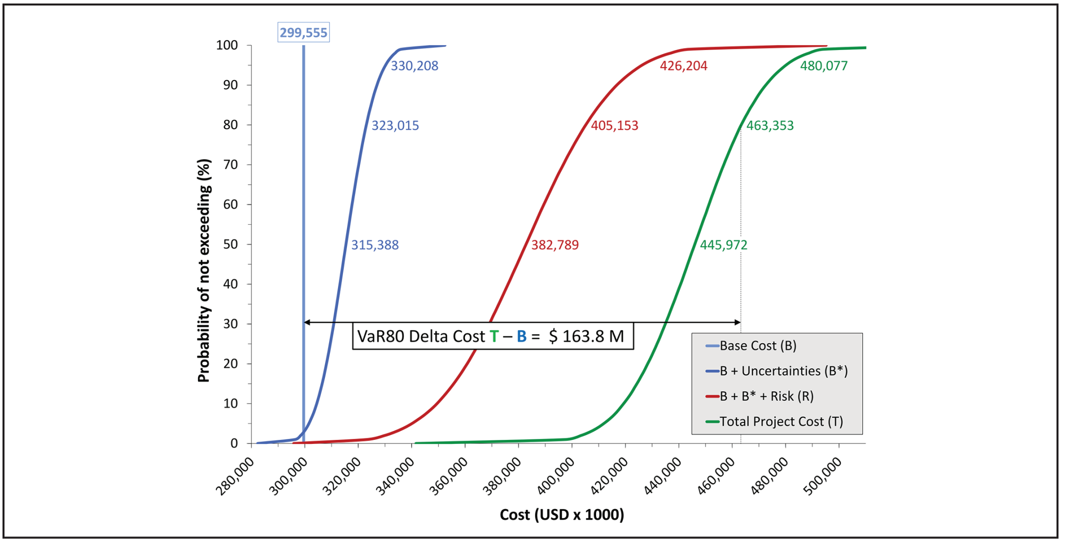


Figure 15. Probabilistic project cost (base cost, risk, total project cost)

of the Agency, its risk tolerance, and if the project is a large complex project—where perhaps P80 is appropriate, or a set of smaller more routine projects—where perhaps P60 is more appropriate.

Beyond the planning and design phases, the use of RIAAT can enable a risk-based approach to progress tracking and reporting and, management of construction change orders and cashflow. Integrated change order management can be applied, and probabilistic look-aheads can be used to update the project's budget certainty (or uncertainty).

These advances in risk-based cost and schedule estimation and project management are being implemented due to more widespread recognition of the need to apply risk-based methods, the advantages of using such processes and the publication of risk guidelines by international associations (ITA, ITIG, UCA), as well as U.S. Federal and State Agencies. In Summary we now have routine access to:

- Model results which can be used for budgeting in the planning and design phases.
- Budget control with integrated risk/change order management in construction.
- A fully integrated cost-schedule model that can analyze probabilistic risk impacts on programs (costs and construction schedules) and can enable an integrated probabilistic risk analysis and mitigation of potential delay and delay cost.
- Probabilistic schedule simulations can be used to determine major critical paths and their respective probabilities.

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