INTEGRATED PROJECT ENGINEERING CONGRESS (IPEC)

Please select category below:
- Normal Paper ☒
- Student Paper ☐
- Young Engineer Paper ☐

Digital Project Twin for Quantitative Cost, Risk and Schedule Assessment of Capital Projects

Philip Sander ¹, Markus Spiegel ², Taylor Burns ³ and John Reilly ⁴

¹ Institute of Construction Management, Bundeswehr University Munich, Werner-Heisenberg-Weg 39, Neubiberg, Germany.
² RiskConsult GmbH, Olympiaplatz 39, Innsbruck, Tyrol, Austria.
³ John Reilly International, 1101 Worcester Road, Framingham, MA, USA.

Abstract

Key processes necessary to identify and manage risks on complex infrastructure projects have been developed over the last 30 years to implement risk-based approaches for better cost and schedule estimation. Cost and schedule were mostly treated separately instead of being integrated into one model. This integration is highly relevant as schedule delays are often the root cause for severe cost overruns.

The Project Risk Twin (PRT) process discussed in this paper considers the correct application of risk correlations, dependencies and linkage. This allows project proponents to determine more realistic risk-based costs and risk mitigation strategies.

This paper presents a fully-integrated probabilistic cost and schedule model that provides a basis for better cost and schedule analysis on a management level. The application is based on proven approaches, i.e., the PRT process and RIAAT (software) resulting in a powerful tool for the management of complex risk environments.

Keywords: Project Risk Twin (PRT), RIAAT (Risk Administration and Analysis Tool), Integrated Cost and Schedule Analysis, Cost Component Structure, System Integration.
1. Introduction

In general, project management experts evaluate the cost, schedule and risk elements of a project separately, but it is clear that these elements are interdependent and therefore influence each other significantly. A probabilistic model that takes an integrated view of these elements, including their uncertainties, correlations and dependencies, can far more realistically replicate and predict project outcomes [1].

The Project Risk Twin process was created to ensure the correct creation and application of such a model using RIAAT (Risk Administration and Analysis Tool, RiskConsult). The Project Risk Twin is a process that results in a virtual model that connects the real and virtual worlds. This coupling of the virtual and real worlds enables the structured analysis of cost and schedule data and the monitoring of a project, e.g., understanding, analysing and counteracting risks before they even occur, avoiding construction delays, developing and seizing opportunities and using simulations to predict the future.

Digital twins, which accompany a project throughout the planning and construction phases, are a business necessity for large scale infrastructure projects. Being blindsided by project risks and incurring contractual penalties due to scope changes and schedule delays no longer needs to be the norm.

This paper presents the following subject matter (as seen in Figure 1):
1. Integrated Cost and Schedule Analysis.
2. Cost Component Structure.
3. System Integration.
5. A case study based on major European railway base tunnel projects.
2. Integrated Cost and Schedule Analysis

Formerly, cost estimates were primarily deterministic, using quantities and unit prices. Risk was accounted for based on the estimator’s experience and best judgment without fully identifying and quantifying risks. For example, project uncertainties were included in a general “contingency” and the judgment of the level of such contingencies was related to the level of definition in the estimate [2]. Deterministic estimates often rely on numerous assumptions and exclude information on uncertainty, simply using a mathematical addition to give the aggregated consequence for all risks. In doing so, a deterministic method can give equal weight to those risks that have a low probability of occurrence and high impact to those risks that have a high probability of occurrence and a low impact [3]. Conversely, integrated estimates that include information on uncertainty to produce probabilistic results based on thousands of coincidental but realistic scenarios are able to provide a greater depth of information, from which informed decisions can be made [3]. This difference of approach is depicted in Figure 2.

![Figure 2](image)

**Figure 2 – Left: Deterministic (not integrated) vs. Right: Probabilistic Integrated Cost-Risk-Schedule model**

3. Cost Components

Introducing a clear cost component structure allows for cost transparency and cost control. Cost components that need to be addressed in the estimate are:

1. **Base cost** – the cost if all goes according to plan without contingencies.
2. **Risk cost** – the cost resulting from threats and opportunities that might occur.
3. **Escalation cost** – additional costs resulting from inflation.

A best practice cost component structure is shown in Figure 3. It consists of actual cost without uncertainties in the left part of the waterfall diagram, namely **Cost Estimate (CE)** and **Additional Costs (A)** due to scope changes. In the right section of the diagram are the uncertainty components, specifically **Uncertainty (U)**, **Risk Cost (R)** and **Escalation (E)**. The sum of the uncertain cost components is also called the **delta cost** and is used for allowing the inclusion of uncertainties in the project budget.
4. System Integration

In order to have an agile risk management system that provides synergy, an effective digital project twin for cost, risk and schedule needs to easily integrate within the project management digital ecosystem and act as a source of truth for the entire project. Having a process that allows for effective integration is crucial to ensuring that expertise from all disciplines of the project team can be collected, validated, analysed and then the results further distributed to upper management.

As shown in the (Figure 1), the Project Risk Twin process allows for this system integration, with the ability to import data from existing systems (i.e., excel, MS Project, P6) and export via excel and PDF. Once imported, the information in the RIAAT model allows it to be a source of truth while also increasing efficiency by removing the need to refer to multiple software platforms for cost, schedule and risk management information.

The first step to ensuring complete system integration is to gather, validate, assess, and collate the data in accordance with the Project Risk Twin process. The Project Risk Twin process is as much about integrating the project team’s knowledge and experience via risk management workshops as it is about integrating the cost, schedule and risk impact information into a digital model.

5. Project Risk Twin Process

In the Risk Twin process (Figure 4), estimates are comprised of multiple components: the key components being base cost, risk and escalation (also see Figure 3). In the context of this research, the project team were involved in:

Figure 3 – Waterfall diagram for cost component structure
cost does not include contingency but does include the normal variability of prices

and quantities, the same applies for the base schedule. The base cost and base schedule are initially developed by the project team/estimator and then validated by an experienced cost estimator, subjected to uncertainty and integrated into the Work Breakdown Structure (WBS).

Secondly, a list of risks are identified and analysed (probability, consequence) including a markup for unknowns by a set of workshop participants including the project team, subject matter experts and experienced risk workshop facilitators. The resulting risk register contains opportunities and threats relating to both cost and time impacts, these results are also integrated within the WBS and Schedule allowing calculation of delay costs. This risk assessment replaces general and vaguely defined contingency with explicitly defined risk events that include the associated probability of occurrence and impact on program cost and/or schedule for each event. This information can then be further employed to work out the potential delay cost.

Thirdly, a valuation of the unknown risk is carried out using a predefined risk fact sheet. The fact sheet assesses the project for factors such as the degree of maturity, degree of complexity, geological conditions, the market situation and other individual project risks. The unknown risk is calculated as a percentage of the base cost.
Finally, cashflows are produced, escalation is added for the project duration and analysis of the initial model results is carried out (i.e., sensitivity analysis, what if etc.). This often results in risk mitigation measures being put in place to address high impact cost and time risks. The perceived benefits of these mitigation measures are updated within the model and then the final results for the process can be reported.

6. Case Study

A virtual model is an essential part of the Project Risk Twin process, it ensures assessment of project cost and schedule and enables further analysis possibilities (e.g., what-if) for decision making at the management level. Figure 5 shows the main interface of RIAAT.

![Figure 5 – Sample main interface, RIAAT risk software [4]](image)

6.1 Project Description

A fictitious sample project is used in this paper to illustrate the process. It is based on experience gained from major European railway base tunnels. This 14 km twin-bore tunnel consists of several Tunnel Boring Machine (TBM) drives as well as New Austrian Tunneling Method (NATM) 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 6. In RIAAT, the schedule is modeled as a consolidated Gantt diagram (Figure 5).
Integrated Project Engineering Congress (IPEC)

Figure 6 – Linear base schedule – horizontal axis: station, vertical axis: time

6.2 Risk Identification

The identification process is structured using risk fact sheets to gather and systematise 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, 5, 10, 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., 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 in our example base tunnel project.

Table 1. Sample quantitative assessment of top 10 identified risks

<table>
<thead>
<tr>
<th>#</th>
<th>Identified Risk</th>
<th>Probability of Occurrence</th>
<th>Rate of Occurrence</th>
<th>cost impact (USD x 1000)</th>
<th>time impact (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>best</td>
<td>most likely</td>
</tr>
<tr>
<td>1</td>
<td>TBM S2 - Main Bearing Damage</td>
<td>20%</td>
<td>-</td>
<td>1000</td>
<td>2000</td>
</tr>
<tr>
<td>2</td>
<td>TBM N1 - Change in Exc.&amp;Sup. Categ.</td>
<td>70%</td>
<td>-</td>
<td>500</td>
<td>3000</td>
</tr>
<tr>
<td>3</td>
<td>TBM N1 - Immobilization Squeezing</td>
<td>25%</td>
<td>-</td>
<td>1500</td>
<td>3000</td>
</tr>
<tr>
<td>4</td>
<td>Contractor Appeal</td>
<td>50%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>No Release of Design</td>
<td>30%</td>
<td>-</td>
<td>225</td>
<td>900</td>
</tr>
<tr>
<td>6</td>
<td>TBM N - Delay installation</td>
<td>25%</td>
<td>-</td>
<td>400</td>
<td>1200</td>
</tr>
<tr>
<td>7</td>
<td>Extension Fault zone km 2.0</td>
<td>80%</td>
<td>-</td>
<td>0</td>
<td>840</td>
</tr>
<tr>
<td>8</td>
<td>TBM S2 - Extension of Inner lining</td>
<td>-</td>
<td>3</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>9</td>
<td>Logistic Problems Crosscut S (13-25)</td>
<td>30%</td>
<td>-</td>
<td>150</td>
<td>375</td>
</tr>
<tr>
<td>10</td>
<td>CC N - Mountain water inflow &gt;40l/s</td>
<td>-</td>
<td>3</td>
<td>222</td>
<td>886</td>
</tr>
</tbody>
</table>

7. Results

7.1 Schedule Results

Once the risk time-impacts have been integrated into the schedule and Latin Hypercube Sampling (i.e., simulation) has been completed, it is now possible to select milestones within the model and visualise the distribution functions for
deviation against target dates. This information can be used to produce S-Curve diagrams as seen in Figure 7. The blue curve in the example shows the basic schedule deviation due to uncertainties. The red curve is obtained by adding identified risks (IR) which impact the critical path. The comparison with the target date (in the example 22/08/2023) results in a schedule security of 1% (P1). Hence, the target date can be kept at the current date with a 1% probability of success. It will be exceeded with a 99% probability. In order to achieve an 80% certainty (P80) of the target date in accordance with the current status, we will need to use 3/02/2025 as the target date.

![Milestone deviation](image)

**Figure 7 – Milestone Deviation**

### 7.2 Cost Results

After including time-related cost, a probabilistic cost forecast for all cost components can be made. The results are shown in Figure 8. The total project cost, including bandwidths is broken down into cost components at each level of the project, these include base cost, risk and escalation. Also shown are the deterministic costs (initial costs) of each level, the deterministic base cost in the example is show by the vertical blue line and is $748 million. The blue curve shows the initial costs including quantity and price uncertainties. The red curve shows the base cost + risk and the green curve displays the total cost estimate for the project including escalation. The comparison of the total project costs with the budget shows whether the project is sufficiently budgeted at the current point in time, whether it is underfunded or whether budget funds can even be released. In the example, the budget of $1,100 million corresponds to the P28 value, i.e., 28% of the budget is under-budgeted and 72% is over-budgeted. To achieve a budget security of 80%, the budget would have to be increased by $72 million.
8. Conclusion

A software-supported Project Risk Twin process was presented on a sample tunneling project that has the capability to enhance risk-based project management in Australia and internationally. The main conclusions are:

1. A fully integrated, virtual, cost-schedule model is available that enables the structured analysis of cost and schedule data and the monitoring of a project, e.g., understanding, analysing and mitigating risks before they even occur, avoiding construction delays, developing and seizing opportunities, and using simulations to predict outcomes.

2. Being blindsided by project risks and incurring contractual penalties due to scope changes and schedule delays no longer needs to be the norm. A Project Digital Twin can help prevent this by providing insights in the early phases of a project.

3. Probabilistic schedule simulations can be used to determine possible deviations from the completion dates of major milestones and their respective probabilities.

4. Model results can be used to set realistic budgets in the planning and design phases and P-values can be selected base one’s risk tolerance.
10. References


Integrated Project Engineering Congress (IPEC)