Schedule Risk Analysis for a Rail Decarbonisation project

***Abstract*:**
This paper provides a case study of Schedule Risk Analysis (SRA) for a Rail Decarbonisation project in the mining sector. Rio Tinto is undertaking a Proof of Concept for Battery Electric Locomotives as part of the company's strategy to reduce its carbon emissions. The project entails the purchase and trial of battery-electric trains for use in the Pilbara region of Western Australia in order to test battery performance in the existing operational environment. Many technologies required to achieve net-zero, including the battery electric locomotives, are in early Research and Development (R&D) stages. Implementing R&D projects requires innovative ways to manage schedule uncertainty and risk. In this context, the SRA increased confidence in the schedule and delivered enhanced project risk management maturity. This paper will discuss how the SRA was implemented, highlighting the planning governance process and the level of collaboration with internal and external partners. Finally, lessons learnt that may be leveraged and applied across other industry sectors will be presented.

Authors Bio:

Author: Ricardo Alves is a Lead Planner with two decades of expertise in rail, mining, infrastructure, and energy projects. He holds a degree in Industrial Engineering and a Masters in Project Management. Ricardo serves as the Lead Planner for the Battery Electric Locomotive project and specializes in Schedule Risk Analysis, effectively applying it to various large and complex projects throughout his career.

Co-Author: Beau Tickner is a Career project leader, with a history in mining and metals, Oil & Gas, manufacturing technology and Cyber Security. He holds degrees in civil and mechanical engineering and industry qualifications in Occupational safety, quality assurance, Project management and cyber security. Beau serves as the Project Manager for the Battery Electric Locomotive program and is accountable for the safe and successful delivery of this initiative.

1. Introduction

Schedule overruns in large and complex projects is a well-documented problem worldwide. Associated complexities and risks add uncertainty to the achievement of project objectives.

Further complexity is faced by companies pursing emission reduction targets in line with the United Nations Sustainable Development Goals (UNSDG). Adoption of emerging technologies and delivery of R&D projects are required to achieve such targets.

Rio Tinto is undertaking a Proof of Concept for Battery Electric Locomotives as part of the company's strategy to reduce its carbon emissions. The project entails the purchase and trial of battery-electric trains for use in the Pilbara region of Western Australia in order to test battery performance in the existing operational environment. The Battery Electric Locomotives project encompasses four key workstreams: Locomotives, Charging Infrastructure, Rail Systems Integration, and Operational Trials.

Schedule overrun is a high risk to projects in general and even more so for R&D projects. To support projects meeting targets, improved scheduling practices are required.

By applying Schedule Risk Analysis (SRA) principles in such projects, companies can establish confidence in schedules and identify major risks. Rio Tinto recognises the value of SRA to manage schedule-related risks and it is one of the tools employed by Rio Tinto in their risk management approach.

2. Schedule Risk analysis concepts

Project schedules based on the Critical Path method (CPM) assume exact and definitive sequence and durations for activities. Such a deterministic approach disregards underlying risks and uncertainties inherent to projects.

In contrast, SRA is a probabilistic approach that investigates uncertainties that occur in a project by modelling and simulating possible schedule scenarios. It accounts for inherent uncertainties, estimating errors, and possible biases in activity duration estimates.

An important reason to perform SRA is the merge bias. Because a schedule's structure has many points where parallel paths merge that can cause the schedule to lengthen, the timing of these merge points is determined by the latest merging path [1], with several paths leading to a merge point, a single path delay can affect the overall schedule.

Uncertainties and risks are inputs for the Monte Carlo Simulations (as part of the SRA), which are assessed through risk interviews with individuals, small groups or larger workshop settings [2]. It is imperative to gather Subject Matter Experts (SMEs) that cover the entire project scope. It is also important to gather the various organisations that may be involved in the project.

Through experts' opinion and records from previous projects, the most suitable distribution function is determined for each schedule activity [3]. Distribution functions are shaped by statistical parameters such as the lower limit (minimum), mode (Most likely) and upper limit (maximum), which are applicable to the project schedule domain. Triangular and BetaPert are some of the distribution functions determined by such parameters hence widely utilized in SRA.

The Beta distribution (example below) has a smooth shape compared to the linear shape of the Triangle distribution, making it desirable for representing activity durations. A computational model is then built based on the CPM schedule and such activities distribution functions.

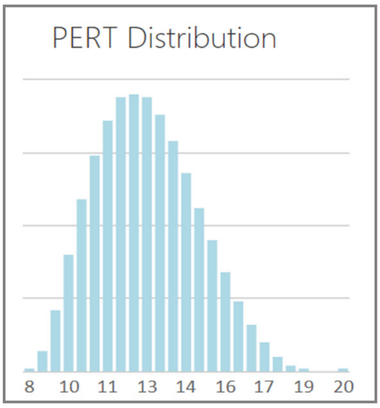

Figure 1 – BetaPert distribution (parameters Minimum=8, Most Likely=12 and Maximum = 20)

Activity correlation reflects the tendency of activities to systematically over-run or under-run together, a common characteristic in project management [2]. Failing to assign correlation to risks and activities can lead to an understatement of schedule variability and the completion date or key milestone dates. Assigning correlations is crucial for developing an accurate schedule model that represents the project schedule's variability [4].

Monte Carlo Simulation runs thousands of iterations using the Monte Carlo statistical method. In each iteration, the software's random number generator assigns a duration within the boundaries of Minimum and Maximum values. The frequency of each duration value is determined by the assigned distribution function [3].

Based on the allocated durations for all schedule activities in each iteration, the CPM schedule recalculates and records the resulting schedule scenario. The aggregated results from the iterations provide valuable data on risk exposure, schedule confidence, contingency levels, and risk drivers, which support executive-level decision making.

3. Approach

To perform a SRA, minimum conditions of satisfaction include; having a quality schedule, team-approved schedule, and a risk register [4]. A detailed schedule developed in collaboration with team members integrates the Supplier schedules with self-delivered scopes to create the Integrated Project Schedule in Primavera P6.

A comprehensive exercise was conducted to enhance the quality of Supplier Baseline Schedules, involving strong collaboration between internal and external partners. This quality uplift was also applied to the Integrated Project Schedule.

Quality assurance reports are run for all schedules in support of the schedules uplift. The expected outcome is a quality schedule that has logic links that appropriately reflect the sequence of work and the dependences between activities and realistic critical and near-critical paths [4].

Fuse® Analyst Report									
Missing Logic	Logic Density™	Critical	Hard Constraints	Negative Float	Insufficient Detail™	Number of Lags	Number of Leads	Merge Hotspot	Score
9	3.56	65	4	0	22	36	0	86	79
1%		13%	1%	0%	4%	6%	0%	14%	

Figure 2 – Battery Electric Locomotives Integrated Schedule Quality Assurance Report

This report contains quality metrics with the number of activities that fail the metric test and its percentage of the total number of schedule activities. Issues identified through the quality metrics are reviewed and addressed until it achieves a satisfactory level.

The Battery Electric Locomotives project consists of interdependent workstreams with multiple predecessors to activities, affecting the Merge Hotspot and Logic Density metrics. Extensive equipment procurement and associated long lead times contribute to the insufficient detail metric. In this context, lower scores in these metrics are deemed acceptable.

Special attention in Quality Assurance was dedicated to the Equipment Manufacturer schedule. The Locomotives workstream drives the critical path of the overall schedule, thus requiring a more detailed and mature schedule than usually produced by an Equipment Manufacturer.

The supplier schedule baselines were formally approved, and the Integrated Schedule was revised based on the supplier schedule baselines, that was accepted by the project team and end user.

Two approaches are used in formulating a CPM schedule model for risk analysis. One uses the detailed project schedule in its entirety, which may involve thousands of activities. The other uses a summary CPM model to represent the detailed project schedule, typically with only a few hundred activities or less [4].

For the Battery Electric Locomotives project, the summary schedule was deemed the most suitable due to its lower level of detail to better utilize the time of the large audience required for the Risk Assessment workshop. Also, the summary schedule allows an assessment of holistic or captured risks for the summarised schedules to be made and increases the benefits of the risk spread as per the convergence theorem.

A Summary schedule is prepared for critical and near-critical path activities and is reviewed against the risk register to ensure that summary activities are captured for all risks with schedule impact. Activities with less than 4 months of float as a ratio of 20% of the overall schedule duration were deemed near critical. The Summary Schedule is reviewed with the Project team and Suppliers to verify it accurately captures the critical works, interdependencies across workstreams and the activities with higher risk delivery risk exposure.

Qualitative risk assessment sessions were undertaken to review existent risk register, ensuring its comprehensiveness and currency. Risks with schedule impacts are classified and pre-selected to support Risk Assessment workshops.

4. Risk Assessment and Simulations

Risk Assessment workshops are held bi-annually and attended by the Project Team, End users and Suppliers – Engineering Consultant, Locomotives Manufacturer, and Rail Systems Integrator. Separate workshops for Locomotives, Infrastructure, and Rail Systems Integration workstreams involve approximately 20 people each.

The workshops aim to review risks events with schedule impacts and assess duration ranges for schedule activities. To minimize biases and subjectivity, several actions are implemented, including:

- Appointing an external advisor to facilitate the workshops
- Involving a comprehensive list of SMEs from Rio Tinto and Suppliers
- Providing a comprehensive workshop brief on SRA concepts, approach, and estimating biases
- Establishing a psychologically safe and collaborative environment

Minimum, Most Likely, and Maximum duration values are extensively discussed and agreed upon for activities in the Summary schedule. Minimum and maximum values were assessed as being 1 out of 100 cases. Risks events with schedule impacts are reviewed and accounted for in the duration ranges.

Events such as natural disasters, industry collapses, and world events should generally be excluded and documented, from uncertainty modelling [5], and such events were beyond the scope of this SRA.

Assumptions underlying the agreed-upon ranges are captured in a detailed register for future reference or what-if analyses.

A Monte Carlo model is developed utilising the Summary Schedule and workshop inputs. Activities exposed to the same risks are assigned correlation coefficients, reflecting they are not independent variables. For example, design activities performed by the same Supplier and prone to design non-compliance risks are correlated.

Monte Carlo Simulation runs 5,000 iterations, ensuring statistical convergence parameters are met. The simulation results are presented in the following section.

5. Results

The Mean date for the project completion stands as P55 and the applicable contingency against the Mean date stands as 8% of the project duration.

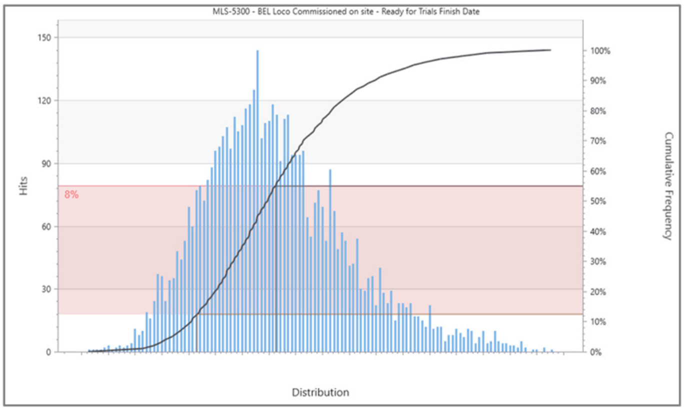

Figure 3 – Risk Exposure Histogram (P55 and contingency)

The merge hotspot metric identified in Section 3 and the number of critical paths significantly contributes to a lower confidence in achieving the deterministic date. The Critical Schedule Driver chart below displays the large number of critical paths in the simulation results:

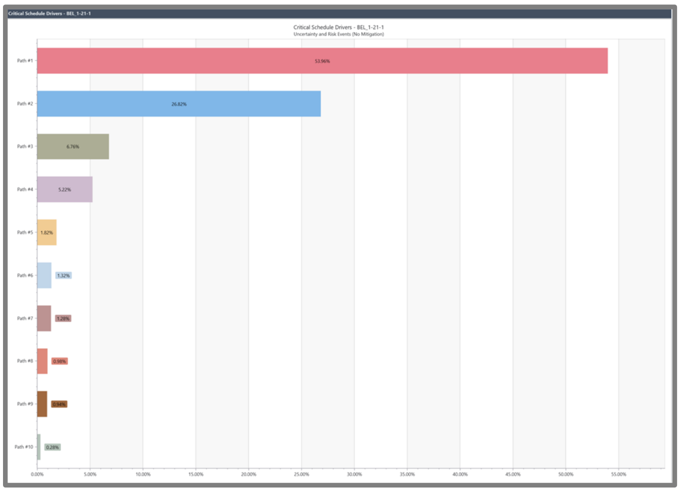

Figure 4 – Critical Schedule Drivers

The chart bars represent the percentage of times a specific path is critical during simulations. It reveals that 10 paths alternately emerge as critical, with the top 4 paths occurring frequently or considerably.

The sensitivity analysis on the contingency period exposed the risk drivers associated with the supply chain. This finding is further supported by the critical path in the deterministic schedule and the severity of supply chain-related risks identified during the qualitative risk assessment.

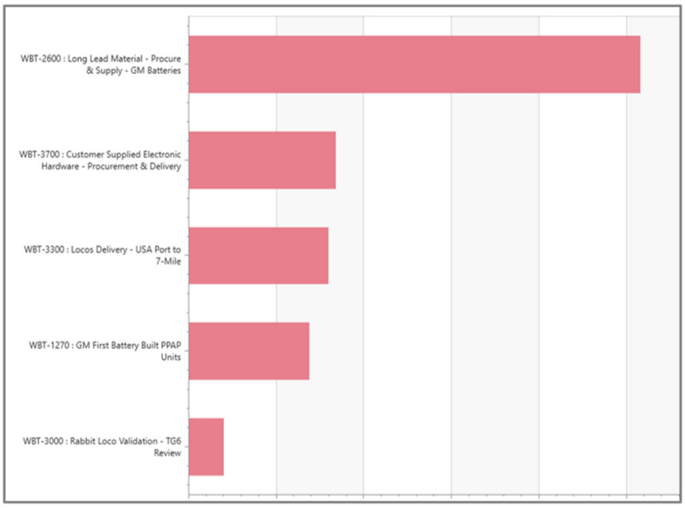

Figure 5 – Risk Drivers

To validate the SRA, the project team verified the P10, Mean and P90 dates, contingency levels, and risk drivers for various milestones. This step was crucial to ensure coherent results by leveraging the team's expertise and knowledge.

The contingency and Mean date results for intermediate and completion milestone were added to the Integrated Schedule by creating contingency specific activities in the critical path at the end of each workstream.

These SRA results flows into the Reporting function by utilising Integrated Schedule data in the Project Status Reports. Similarly, the SRA results also contribute to the cost function by relying on the Integrated Schedule to review cash flow forecasts.

The identification of risk drivers plays a pivotal role in the Project Status Report, highlighting risks that necessitate prioritisation and mitigation efforts. Moreover, the P-dates, contingency results, and risk drivers were integral components of the project submission and status updates to the executive level. This enabled the establishment of realistic target dates and data-driven decision making.

6. Conclusion

The preparation of the Supplier's Baseline Schedules facilitated frequent and ongoing schedule review forums, with benefits extending beyond the SRA. This approach supported effective management of schedule performance, issues, trends, and changes.

A strong collaboration between project team and external partners proved instrumental in the preparing and delivering the SRA. The existence of openness and trust-based relationships among all parties created a favourable environment for the process. Risk Assessment workshops with a broad and comprehensive audience were crucial in considering various perspectives.

Underestimation of minimum and maximum durations during risk assessment workshops is recognized as a challenge, especially among participants without experience in quantitative risk assessment. Ability to conceive extreme risk and opportunity scenarios when establishing minimum and maximum duration values also presented difficulties.

Therefore, it is essential to implement appropriate strategies to prevent underestimating or overestimating risks, such as involving a comprehensive list of SMEs and establishing a collaborative environment during Risk Assessment workshops.

The support provided by suppliers throughout the entire process proved time-consuming, indicating the need to consider relevant provisions in the contract for future applications.

Efficiencies and improvements to schedule sequence identified during the workshops translated into a project schedule with greater accuracy, maturity, and stakeholder buy-in.

The substantial number of common critical paths observed in this project underscores the need to address merge bias in complex projects through SRA.

The widespread application of simulation results across various project management functions, including reporting, risk, and cost, amplified the benefits derived from its implementation.

Aligning the understanding of project risks, scope, and responsibilities among project participants yielded significant benefits in this study case.

Overall, the SRA emerged as a governance process that significantly increased confidence levels in project schedules and ultimately enhanced project management maturity.

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Acronyms

CPM – Critical Path Method
R&D – Research and Development
SME – Subject Matter Expert
SRA – Schedule Risk Analysis

Authors

Author: Ricardo Alves
Company: Rio Tinto
Country: Australia
Contact: ricardo.alves@riotinto.com

Co-Author: Beau Tickner
Company: Rio Tinto
Country: Australia
Contact: beau.tickner@riotinto.com