Risk Management – Correlation and Dependencies for Planning, Design and Construction

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SUMMARY

While the basic elements of risk management, including probability, consequences, risk registers, mitigation measures, etc., are now well understood, the process to include correlation, dependencies and linkage of risks and risk scenarios is less well defined and not well understood. To perform accurate and complete risk analysis and risk management, it is necessary to include correlation, dependencies and linkage between risk events, as well as risks that may occur multiple times. In this way, owners and contractors can more accurately determine risk-based costs, risk impacts and risk mitigation strategies.

This paper will outline methods to deal with correlation, dependencies and linkage and will consider risks that may occur multiple times. Practical result comparisons – with or without these elements – will be presented.

INTRODUCTION

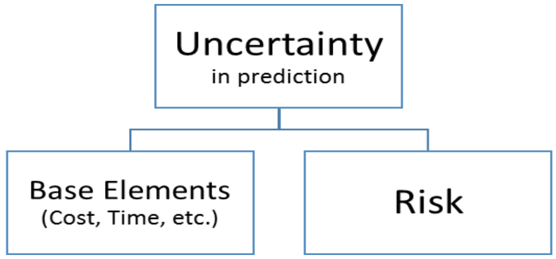
We believe the reader is familiar with basic concepts of risk, risk management and mitigation and the use of probabilistic cost-risk processes versus deterministic ones (Reilly et al. 2015; Sander et al. 2015). The probabilistic approach, compared to the simpler and more common deterministic approach (unit prices times unit costs plus a contingency), offers more useful information with respect to the range of probable cost as well as cost "drivers" and better quantifies the effects of risks, opportunities and variability – which improves understanding, leading to a better potential for profit (or loss) for contractors and added value for owners.

In this context, a valid and sufficient quantification of correlation, dependencies and linkage of risk events, plus the impact of risks that may occur multiple times, is essential.

Components of Cost Estimates – Base Cost, Risks and Other Uncertainties

The components of cost that need to be correctly addressed in an estimate include (Moergeli et al. 2015):

- Base costs – the costs that will result if "all goes according to plan" (Reilly 2004)
- Risk costs – the resulting costs of threat and opportunity events, if they should occur
- Escalation costs – costs resulting from normally expected inflation with variability
- Other uncertain costs – costs that result from other events, normally external to the project team's control, which may include unanticipated events, politically related changes and "black swan" events (Talib 2007)



→ Will always occur
→ Exact quantity and price are uncertain

→ Has an additional probability of occurrence
→ Consequences (cost, time, etc.) are also uncertain

Figure 1: Uncertainty categorized from base elements and risk (Sander 2014)

Characterization of Risk

Risk is the combination of the probability of an uncertain event and the consequences if the event should occur. The probability and consequences of a specific risk event can be complex and, as a practical matter, the estimation of probability and consequences are often simplified – normal practice is to use a standard three-point estimate (low, most likely, high) for consequences and a percentage estimate for probability of occurrence.

Inclusion of Risks - Risk Modelling

There are several ways to include risks in a cost estimate. The normal deterministic approach adds risk costs to base costs by using: (a) a contingency from guidelines (AACE 2003) or (b) “bandwith” estimates or (c) “square-root” or (d) other approximate methods which statistically or arithmetically add estimated ranges of cost for each risk event to the base cost (Moergeli et al. 2015).

There are significant drawbacks to such deterministic approaches (Reilly et al. 2015) leading to the conclusion that probalistic modeling is the best way to estimate the probable out-turn cost of a project, including appropriate characterization of risks to be included in the cost model as well as to be used for risk mitigation (Sander 2015; ITA 2004; Reilly 2008).

Probabilistic models generally structure the project as a set of hierarchical elements, each with a base cost (subject to variations in prices or quantities) and the consequences of risk events, which, if they occur, will probabilistically increase or decrease that element’s cost.

The advantages of very advanced, probabilistic risk modeling (RIAAT 2014), such as is currently used for the Koralm and Brenner Base Tunnels in Austria, include:

- Better, more complete modeling of the project and the ability to correlate risk events
- A more detailed risk assessment and useful risk management information
- More transparency and reporting of outcomes, e.g., ranking of risks, tornado diagrams
- The ability to monitor and document changes to the project
- The ability to integrate change order management

CORRELATIONS AND DEPENDENCIES

Although correlations (and dependencies) are a ubiquitous concept in modern risk management, they are also one of the most misunderstood concepts (DaCosta 2004). Correct quantification and inclusion of correlations and dependencies is essential for valid probabilistic models.

Correlations quantify how a change on one project element or characteristic is linked to a change in related project elements. For example: a change in the price of steel will cause changes in the cost of several related project elements. In risk assessments, correlations are used to determine follow-on consequences, e.g., a probability of high labor costs can lead to a high impact of time-related cost in other project elements.

Dependencies characterize risks that are related – each with specific probabilities of occurrence – and which may be dependent on predecessor risk events. One risk may trigger one or more other risks, or one risk may influence the consequence (value) of another risk (or multiple risks). Example: if a TBM is stuck in a fault zone, it might get buried and, as a further consequence, deadlocked. This may lead to other consequences (risks) which are dependent on the initial risk sequence.

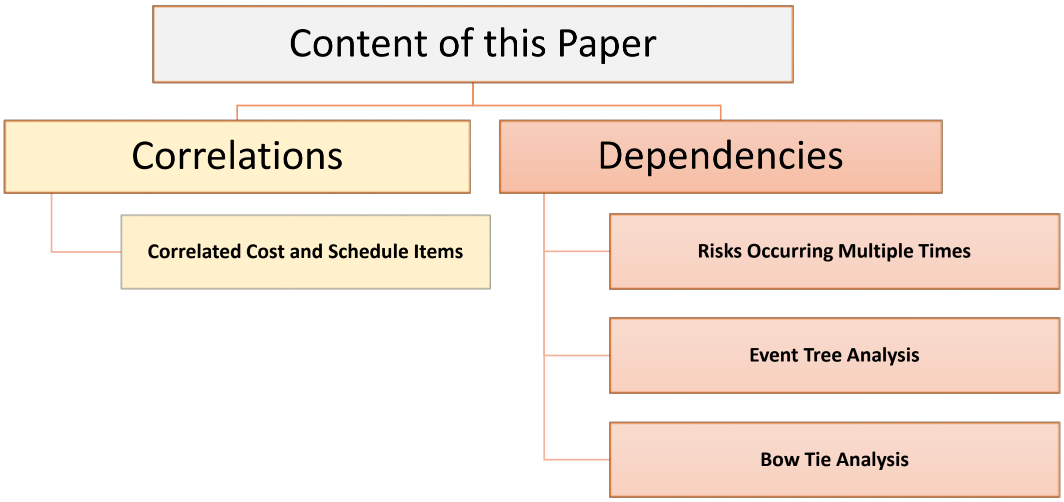


Figure 2: Correlation and Dependencies – Content of this paper

This paper describes selected examples of the above elements, taken from a large set of tunneling projects. In the following sections, we will illustrate correlations and dependencies based on projects that all have been modelled in RIAAT Risk software (http://riaat.riskcon.at).

CORRELATIONS - CORRELATED COST ITEMS

The following diagrams show how one form of correlation can be included. In this case, we are using simple three-point estimates of uncertainty for all elements.

The scenario describes a risk whose consequence will delay the project if it occurs. If the risk occurs, the cost of the consequences are calculated using the labor cost of the two items (deterministic value = $15,000 per day) and time-related cost (deterministic value = $30,000 per day).

If these elements are not correlated, two independent random numbers would be used for each cost item, which would lead to the result that labor cost and time-related cost would be (or could be) calculated using different delay values. In reality, labor cost and time-related cost must be correlated because they are based on the same delay value. In consequence, both cost items have to be perfectly correlated and are modelled as such. The full RIAAT model for this case above is shown in Figures 3 and 4 (following).

To keep it simple, the example below demonstrates the correlation effect with only two distributions. However, even using only two distributions, our example shows a VaR 95 of $708k versus a VaR 95 of $776k. The difference between the independent result and the perfect correlation will significantly increase as more distributions are used, particularly when comparing the outer edges of the ranges (VaR 5 and VaR 95).

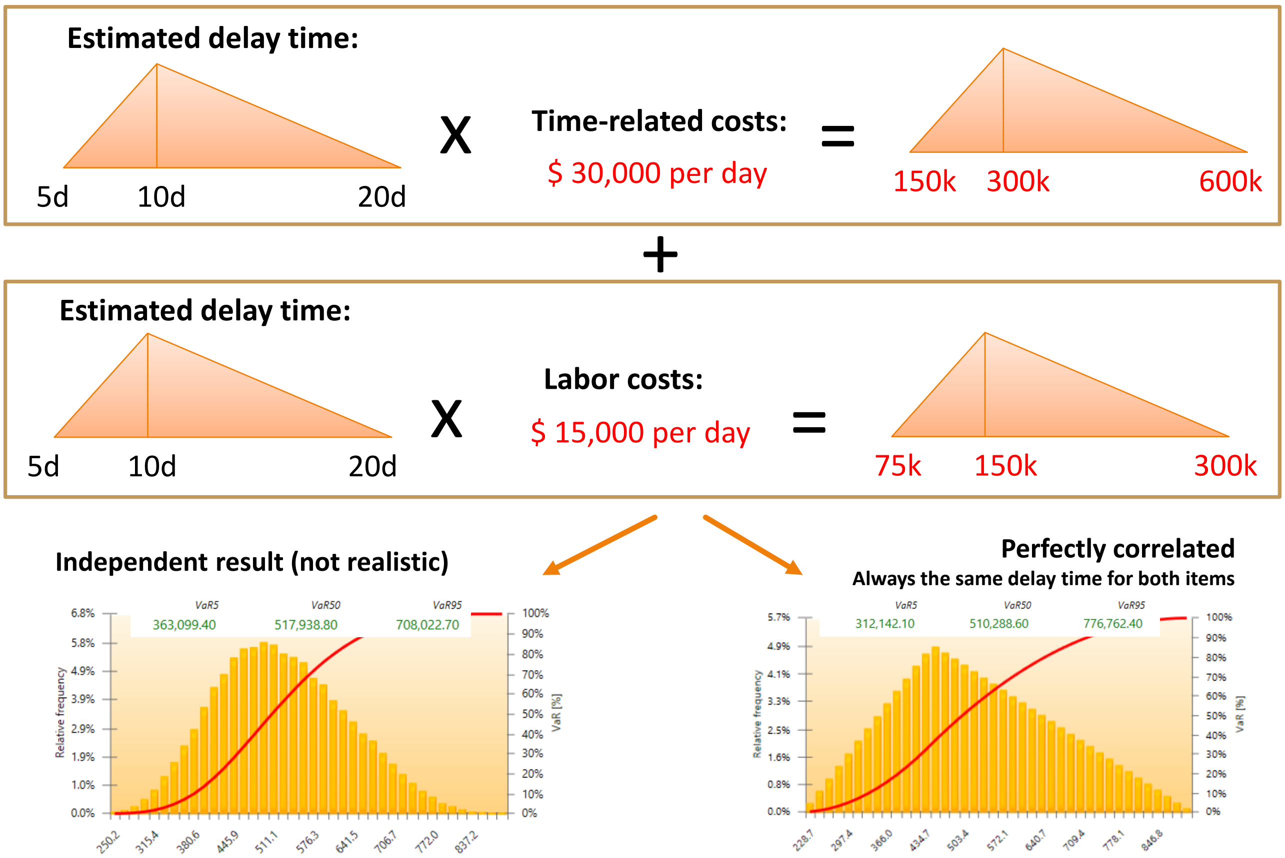


Figure 3: Evaluating the financial impact of a time delay on two related / correlated cost elements

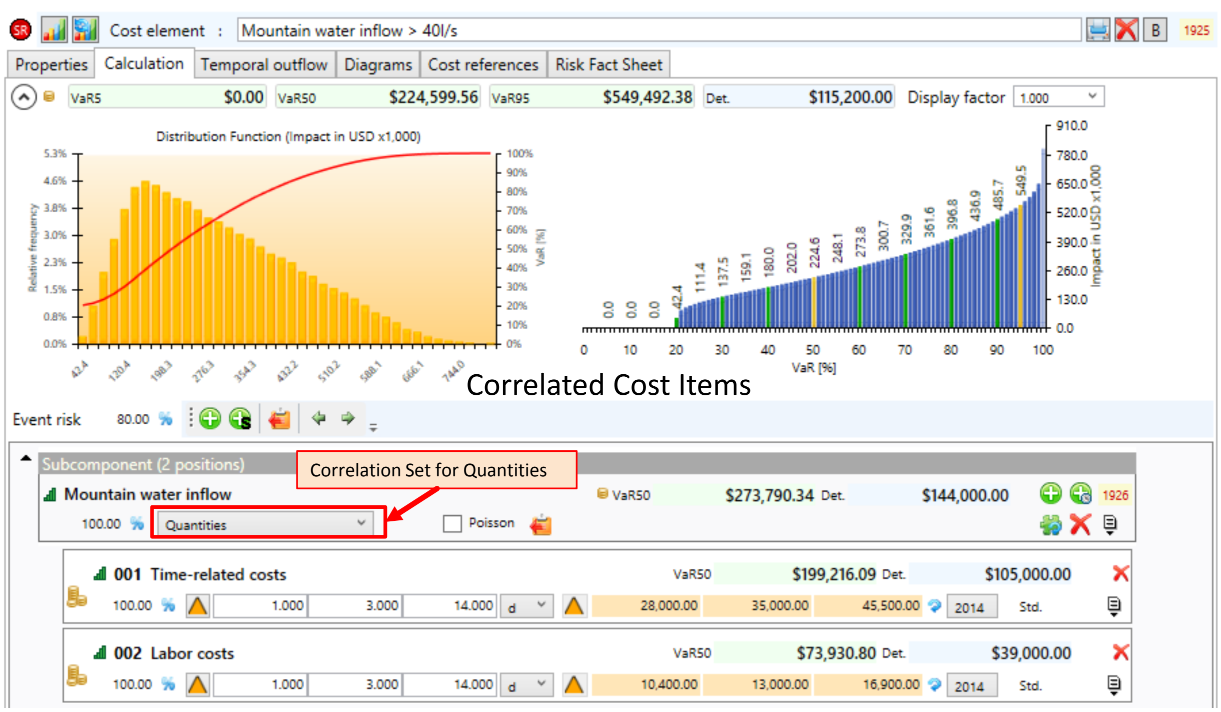


Figure 4: RIAAT Model - Evaluating the financial impact of a risk in two items

DEPENDENCIES

Risks Occurring Multiple Times. A common mistake, normally due to limited risk modelling capabilities or lack of appreciation of this possibility, is not to include risks that might occur more than once. Especially in tunneling (which can have long drives through similar or different geotechnical conditions), we must consider risks that can occur multiple times (e.g., fault zones, cave-ins, water ingress, unstable conditions, etc.).

It is common practice in risk assessment to use a simple percentage between 0 and 100 for the probability of occurrence of a risk event. However, this considers only one possible event. Multiple occurrences are not always considered and, even if they are considered, they may not be modelled correctly and the consequences may be estimated too low. If a simple percentage between 0 and 100 is used for evaluation and the risk has already occurred once, the model is not valid anymore. The risk is possibly underestimated because potential additional events are not considered. This problem can be solved by using a Poisson Distribution (Sander 2012) so that:

- There is a rate of occurrence instead of a simple probability of occurrence
- The rate reflects the expected number of events (which is much easier to estimate in comparison to a percentage)
- A possible number of events above and below the estimated rate of the Poisson Distribution can be considered
- The model allows consideration, in every iteration, of a different number of events that might occur

Why choose a Poisson Distribution? The Poisson Distribution is often mistakenly considered to be only a distribution of rare events. It is certainly used in this sense to approximate a binominal distribution, but it has far more importance than that. For example, one could stand on a street corner during rush hour, looking for red cars to pass by. For the duration of the rush hour, we consider that the frequency of cars going by is quite constant, and if the red cars in the traffic are randomly distributed among the city's traffic, then the number of red cars passing by will be distributed according to a Poisson distribution (Vose 2009). For a project application, the risk manager must decide which distribution best fits the project-specific case. For example, where there is a continuum of exposure to an event (i.e., multiple potential occurrences) for a linear project such as a tunnel, if the project is split up into many small divisions, the probability of an event occurring in each division can become very small. The risk manager must decide, for a specific project, how to assign the potential multiple occurrences in terms of overall number for the full drive, or a number of occurrences within a division of the drive, such as a particular geological condition within or for that division.

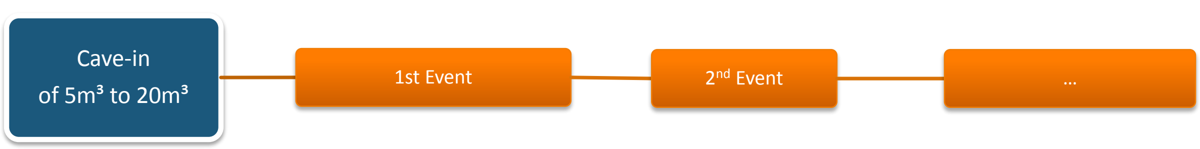


Figure 5: Risk – Illustration of a risk potentially occurring multiple times

The following sample scenario models cave-in events with a frequency of three expected cave-ins for a particular tunnel section. For simplicity, one cave-in is estimated to cost $100,000 (a deterministic value is used here; however, realistically it should be modeled as a distribution).

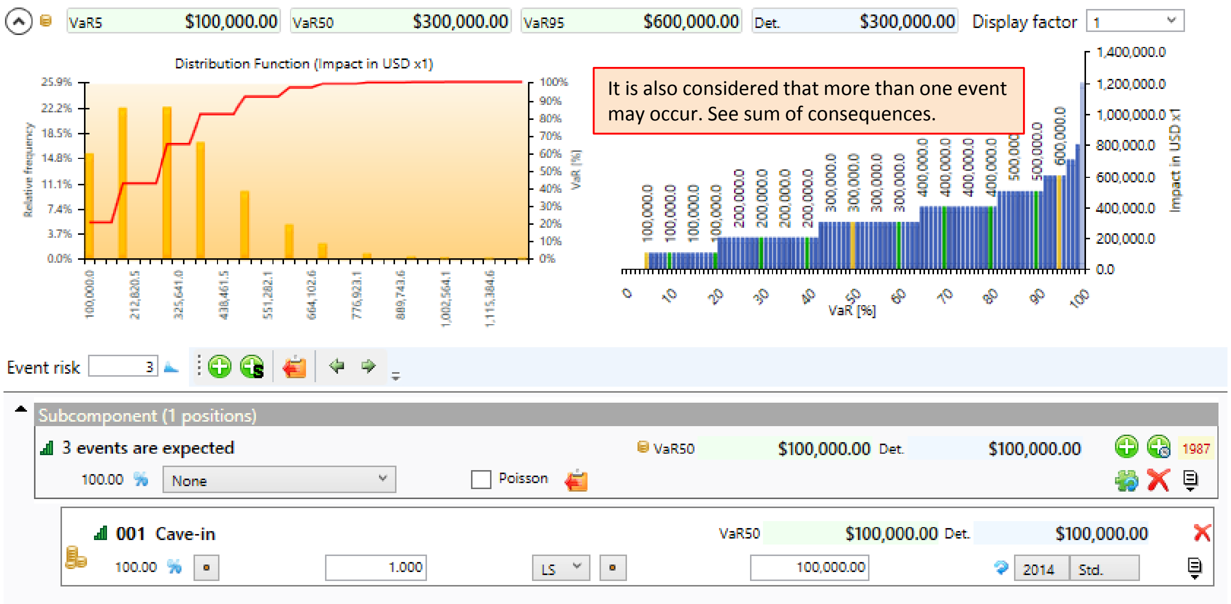


Figure 6: Poisson Distribution for three expected events with an estimated cost of $100,000

In reality, the consequences will be evaluated in a range using a triangle distribution:

- The RIAAT model for three expected cave-in events is shown below
- Cost of one cave-in is evaluated using a three-point estimate
- Min: $50,000 – Most-likely: $100,000 – Max: $200,000 (triangle distribution)

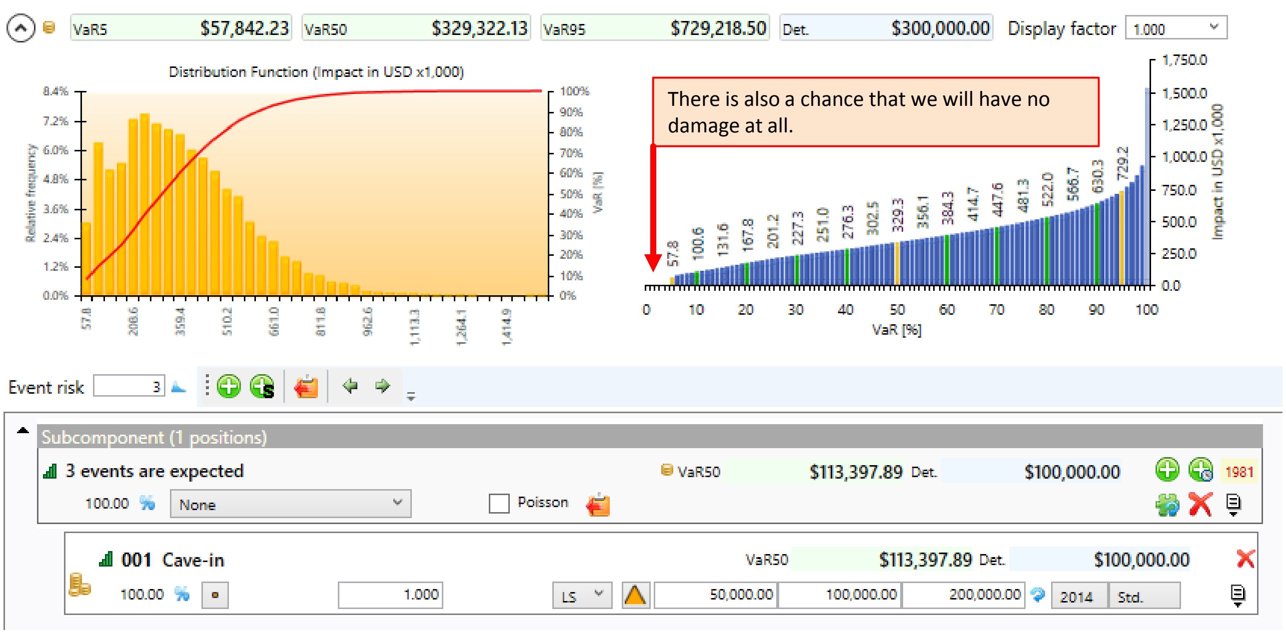


Figure 7: Poisson Distribution for three expected events with estimated costs of $50k, $100k and $150k

Event Tree Analysis. In this analysis, one risk may trigger a different risk and several sequential risks. An example is a tunnel in a dense urban environment, where one risk event (e.g., subsidence) may trigger several sequential risks – such as building settlement, consequent building damage, utility damage, project delay, etc.

Event Tree analysis is a "bottom up" method that identifies the possible outcomes when the probability of occurrence of the initiating event is determined. The approach has proven to be a useful tool for performing analysis of facilities in terms of identifying the sequence of events that follow the initiating event and for generating other possible sequences. Usually, it is assumed that each sequence event is either a success (no consequence) or a failure (with consequences) (Dhillon 2010).

This model can be used if one risk triggers another and only one of the successors can be triggered. Of course there are also models that allow modelling risks that trigger multiple risks. We have demonstrated this before; however, this is beyond the scope of this current paper.

The sample scenario below defines the risks associated with a TBM advancing through a fault zone. For this case, the Event Tree model is developed in three levels:

- TBM buried
- TBM deadlocked
- Bypass tunnel

In the worst case, all scenarios are triggered.

The more uncertain scenarios might be, the more important it is to model them by distributions.
In the following example, 12.5% is used because it is estimated that there will be one event for every 8th fault zone (based on the team's experience). Generally a qualitative model is first used for an initial, visualized approach to help the team to understand complex scenarios.

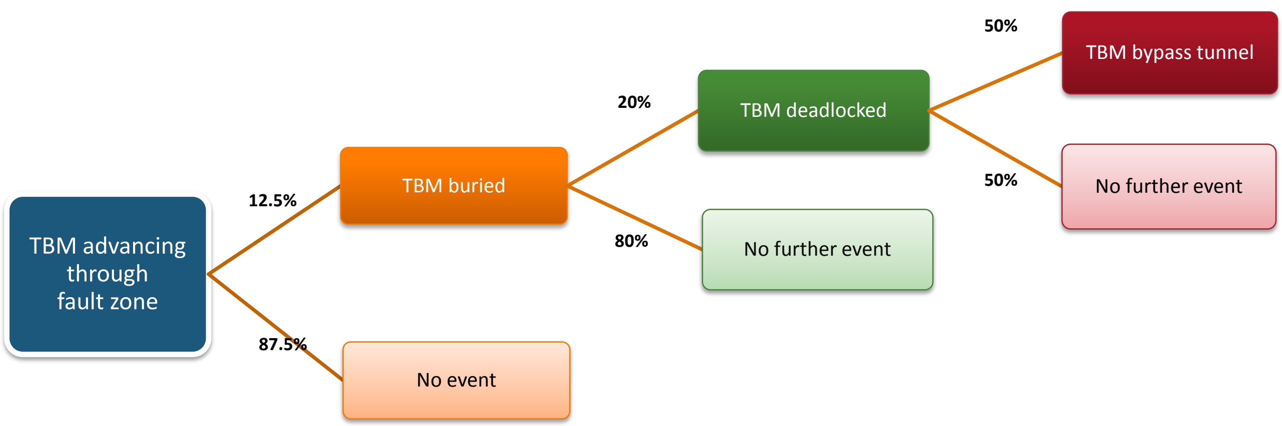
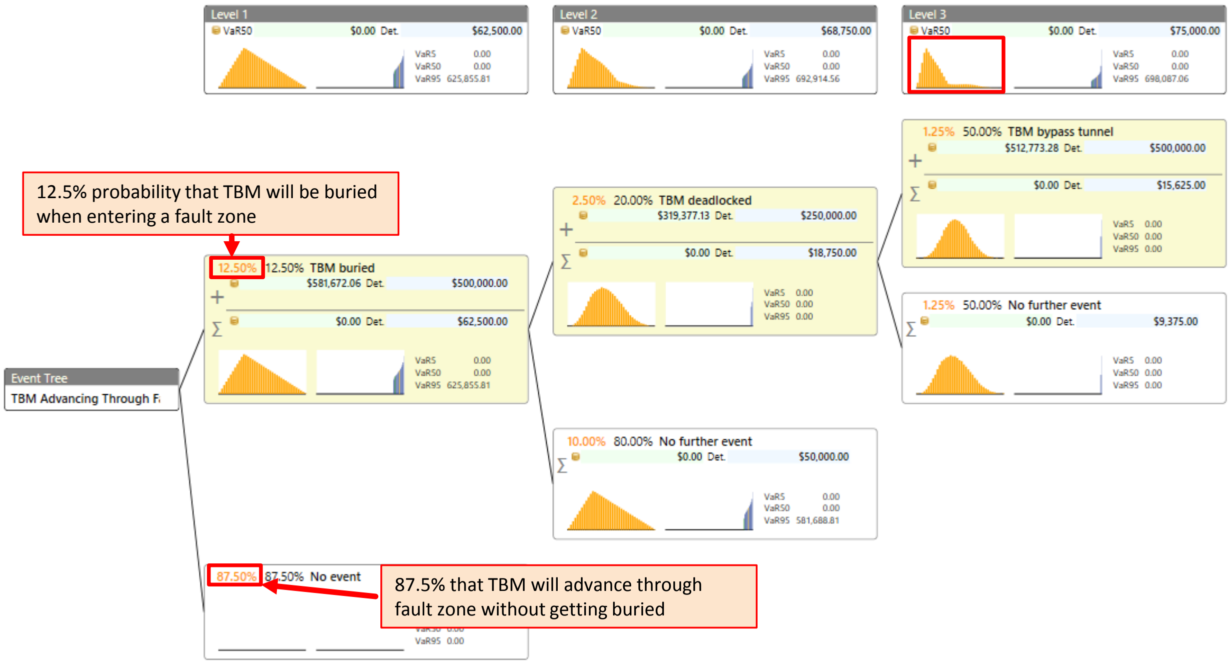


Figure 8: Scenario – TBM advancing through fault zone

All scenarios are evaluated probabilistically using the associated cost (and time) elements for each event. These scenarios and consequences can be correlated as described previously.



Result after simulation:

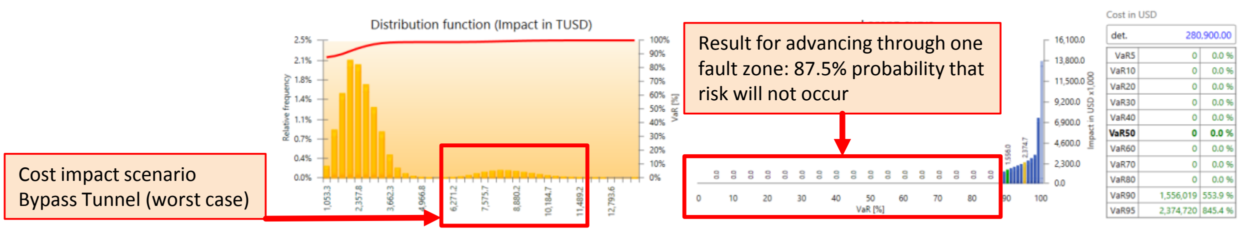


Figure 9: RIAAT Model - Result after simulation for one fault zone

An additional advantage of this model is that it can address the case that more than one fault zone might be expected ahead (say, 20 more expected fault zones). The above model, which includes risks occurring multiple times (using a Poisson Distribution), can be extended to cover this case as shown below.

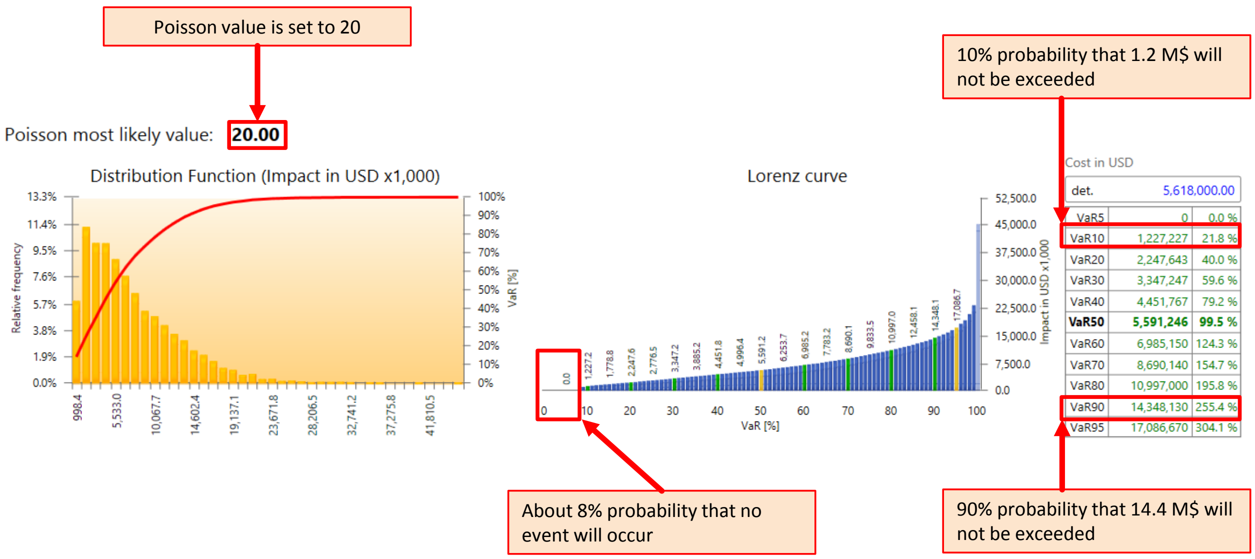


Figure 10: RIAAT Model - Result after simulation for 20 fault zones

Bow Tie Analysis. Bow Tie Analysis is a simple diagrammatic way of describing and analyzing the sequential path of elements through Fault Tree Analysis (FTA) – including triggers, conditions, circumstances, etc. leading to a risk event. The consequences from the risk event are evaluated by an Event Tree Analysis (ETA).

This process can be considered a combination of a fault tree analyzing the causes of a risk event (represented by the knot of a bow tie) and an event tree analyzing the subsequent consequences. The value of this approach is its focus on potential barriers (between the causes and the risk event) that would stop the risk event from occurring and mitigating actions that would reduce the consequences of the risk event should it occur.

Bow tie diagrams can be constructed starting from fault and event trees but are more often drawn directly from a brainstorming session (IEC/ISO 31010: 2009; Reason 1990, 1997).

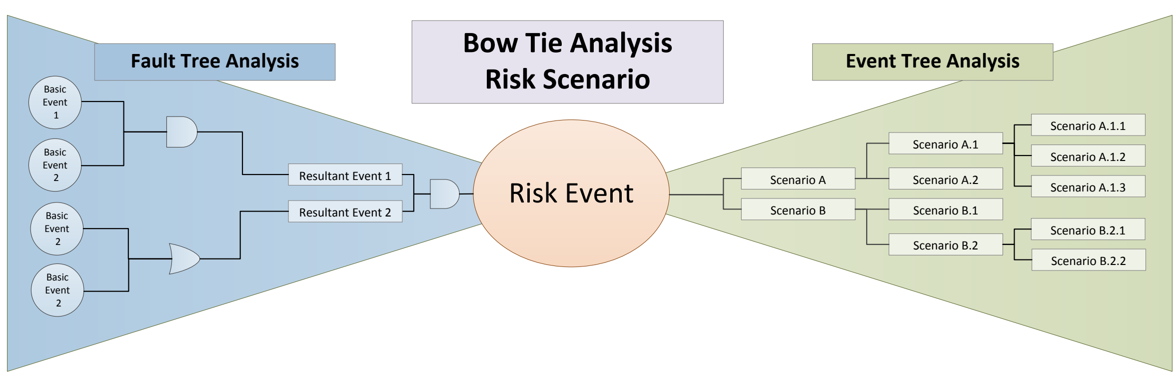


Figure 11: Bow Tie Analysis – Basic concept

Fault Tree Analysis starts by identifying a major undesirable risk event, known as a top event, associated with the system under study. Fault events (risk triggers) that can cause, or contribute to, the occurrence of the top fault event are generated and connected by logic operators such as AND, OR and others. The AND gate provides a "True" output (fault event) if all its inputs are "True," and the OR gate provides a "True" output (fault event) if one or more of its inputs are "True." The construction of a fault tree proceeds by generating fault events successively until the fault events need not be developed any further. These fault events are called basic or primary events. A fault tree is a logic structure that relates the top fault event to the primary fault events. During the construction process of a fault tree, one question successively asked is “How could this fault event occur?” (Dhillon 2010).

Key FTA benefits:

- Can model complex scenarios leading to better risk event scenarios
- Can better model consequences from these risk event scenarios
- Scenarios treated probabilistically are consistent with improved modeling
- Can evaluate system **R**eliability, **A**vailability and **M**aintainability (**RAM**)
- Can confirm the ability of the system to satisfy its specified **S**afety requirements (RAM**S**)
- Can identify critical risk areas and cost-effective improvements
- Can help to understand the functional relationship of system failures/risk triggers (minimal cut sets – all ways from a primary to the top event, the system failure)

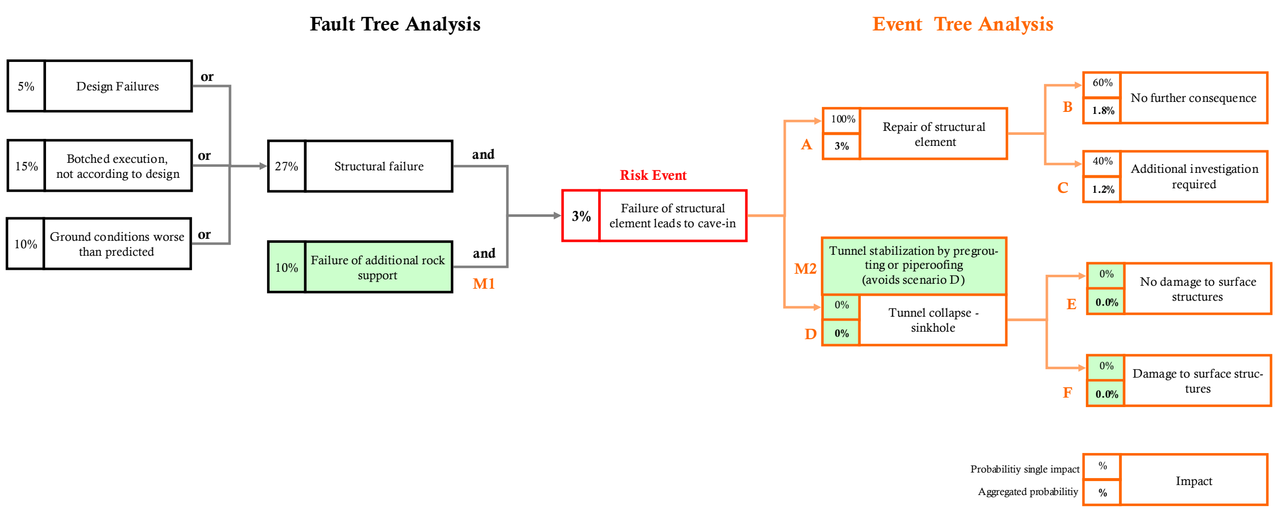


Figure 12: Bow Tie Analysis – Application (controls in green)

A CAUTION

The analysis methods presented here can be computed in great detail and are able to deal with multiple scenarios including the treatment of correlations, dependencies and multiple risk occurrences. As for any analysis, the outcome is dependent on three elements:

1. The analysis methodology
2. The validity, accuracy and relevance of the input data and assumptions
3. The selected relevant identified risks, which need be analyzed in detail and mitigated.

Item 1 is dependent on the available analysis methods and their suitability for the project under consideration. Item 2 is dependent on the capability and experience of the project team and the risk manager. Item 3 is dependent on the project risk profile. Not every risk, but major risk, need to be analyzed in detail to understand the full scenario and all possible consequences. A strong visualization for this approach is necessary.

It is the author's hope that the more advanced analysis methods described in this paper will assist project teams, who are responsible for the input data and assumptions, to better model and manage their project's risks.

CONCLUSIONS

In reality, most risks are part of complicated risk scenarios. In order to model such risk scenarios in a way that potential cost and time impacts are realistic, correlations and/or dependencies need to be defined and applied appropriately. This paper explains the basics of correlations and dependencies. All explanations are illustrated by current real-world (but anonymous) tunneling projects from all over the world, modelled and visualized in the risk software application RIAAT.

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