Monte Carlo Schedule Risk Analysis
- a process for developing rational and realistic risk models

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Abstract

Monte Carlo schedule risk analysis has become a widely practiced technique in project management and can be very useful if conducted to high standards. However, its results can be misleading unless care has been taken to ensure that the structure of models and the input estimates produce realistic simulations of project delivery. This paper describes a process that can be used to develop realistic and useful schedule risk models. The process is also designed to avoid a number of common practices that can produce irrational models and unrealistic estimates.

Monte Carlo Schedule Risk Models

Monte Carlo Schedule risk analysis is described in a number of guides to project risk management including the Project Management Institute (PMI) Practice Guide and the Association for Project Management (APM) Project Risk Analysis and Management (PRAM) Guide. This support for the technique reflects its increasingly wide usage. There are also a number of commercial software tools that support the technique including Primavera Risk (previously marketed as Pertmaster) and @RISK for Projects. These tools support a number of common features of Monte Carlo schedule risk models as well as a number of other features that can be used as appropriate.

Figure 2 illustrates common features of Monte Carlo schedule risk models.

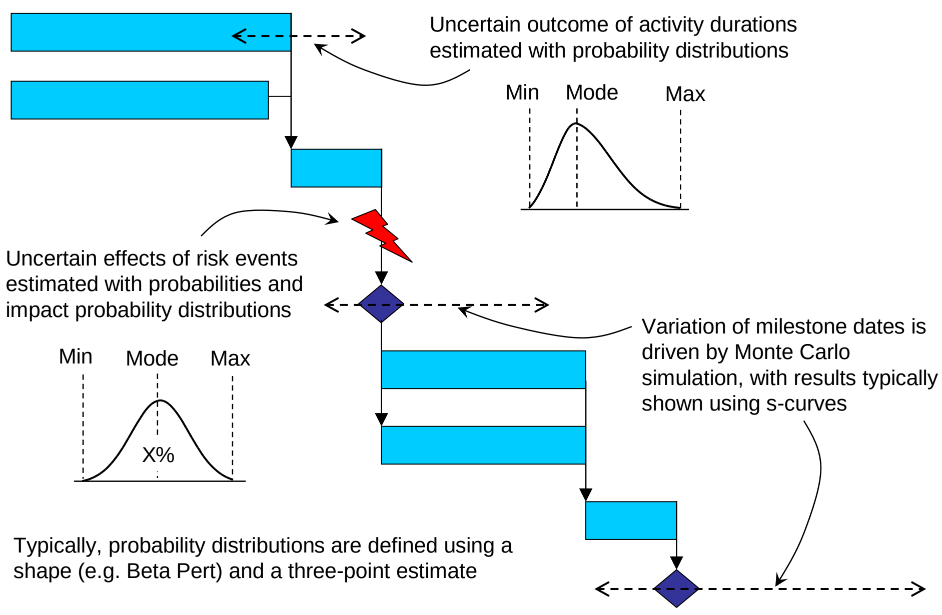

Figure 2: Common features of Monte Carlo schedule risk models

Common features of schedule risk networks include activities, risk events, milestones and network dependencies. A working-time calendar (or combination of calendars) is also required. In addition to these features, some risk models may include one or more of the following:

- Probabilistic dependencies
- Conditional dependencies
- Resource constraints and/or resource uncertainties
- Calendar risk profiles (e.g. to simulate date-dependent weather risk)

Purposes of Schedule Risk Analysis

Schedule risk analysis may have a number of purposes. The primary purpose is often to provide risk-based confidence forecasts for the achievement of key milestones, including the project's end milestone. Typically, these forecasts are presented in the form of histograms or cumulative probability (S-curve) graphs. Figure 2 is an example of the latter, identifying 80th percentile confidence (P80) dates for the completion of two milestones.

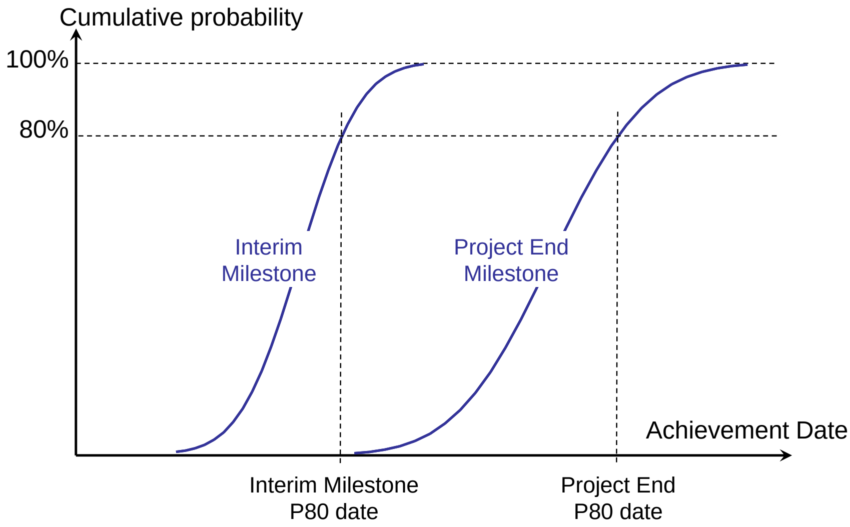

Figure 2: Illustration of risk-based schedule confidence forecasts

Forecasts such as that illustrated in Figure 2 convey useful information about overall project schedule risk to stakeholders. They can therefore be used in connection with project approval points. For example, the UK's Ministry of Defence requires P10, P50 and P90 confidence forecasts to be included in the business case for any major project at the point of Main Gate approval. This allows project sponsors and project approval boards to assess whether or not the degree of risk associated with the project is commensurate with the organisation's risk appetite.

Risk-based confidence forecasts can also help to quantify a project's schedule contingency requirements and position schedule contingencies appropriately. Moreover, schedule risk models can be varied to reflect the implications of options for project delivery in order to determine which are most likely to achieve the best results. Both of these approaches can contribute towards making plans risk-robust.

Finally, statistics from Monte Carlo simulation can be used to generate metrics such as criticality and schedule sensitivity index which identify the activities and risks that contribute most to a project's overall schedule risk. This provides a risk prioritisation approach that is superior to common, but more simplistic, techniques such as the Probability-Impact Matrix.

All of these purposes of schedule risk analysis have been proven to be useful in practice. However, they are only useful if the analysis is based on a realistic model. As with any quantitative modelling technique, the validity of the results is critically dependent upon the quality of the input data. If model inputs, are of poor quality, the results may be misleading. It is thus important to understand what constitutes a good quality schedule risk model and how to develop one.

Characteristics of a Good Quality Schedule risk model

A good quality schedule risk model is one that simulates the important implications of all significant sources of risk in a realistic and rational manner. The aim should be to use as simple a model as is possible whilst still achieving these objectives.

A key first test when validating a risk model is to consider whether or not the implications that it simulates are important and the right focus for management interest. In essence this means that the purposes of conducting the analysis should have been identified. There is no point, for example in conducting analysis on milestones that are unimportant, using assumptions that are unrealistic or in circumstances where the results will not influence decisions. It should also be remembered that the analysis can have different purposes. In his book on Quantitative Risk Analysis (3rd Ed 2008), David Vose notes that *"The biggest uncertainty in risk analysis is whether we started off analysing the right thing and in the right way".*

Second, the model should take account of all significant sources of schedule risk. There may exist sources of risk that govern whether or not events will occur that would giver rise additional activities to those planned. Such event risks are often to be found in a project risk register. They can be included in schedule risks models as activities that may or may not occur. Alternatively some event risks might be better represented using techniques such as probabilistic dependencies or calendar risks. However, not all risks are event risks. Some risks are attributable to sources of uncertainty that drive activity duration over a continuous range i.e. variability risks. The implications of such risks can be reflected in the probability distributions assigned to activities in the risk network. An important feature of good quality risk models is that all significant sources of risk have been identified, understood and appropriately simulated.

Third, the input risk estimates must be realistic. This requires an unbiased and appropriately structured approach to the risk estimating process. In the absence of a structured approach, estimates will be based on intuition and thus exposed to the effects of heuristics (mental shortcuts) that tend to produce risk estimates that are both biased and too narrow. A frequent indication of unrealistic estimates is the de facto use of the project's deterministic schedule to obtain Mode estimates for variability risk and the estimation of distribution extremes using a standard +/- percentage (e.g. +/- 10%) metric. Making realistic risk estimates requires time and care. Resorting to

+/- percentage estimates is often the result of a project having too many estimates to make. The solution is to ensure that risk models are restricted to a manageable number of activities and risks. This is one reason for recommending that no risk model should include more than 200 activities and that this should be regarded as a ceiling for large and complex projects. Most schedule risk models should be much simpler.

Finally, for a risk model to be considered rational, there should be evidence that the combination of its parts should be capable of a correct simulation of overall schedule risk. Since risks often interact in complex ways, it is usually difficult to provide such evidence unless the model has been developed iteratively in a top down manner. It should also be noted that it is easy to produce irrational schedule risk models unintentionally. The modelling verification process should therefore provide assurance that known common causes of irrational models have been avoided.

Irrational risk models may be the consequence of:

1. Modelling at low levels of activity detail, using activities and dependencies that are not unlikely to evolve during the course of project delivery (thus assuming a degree of certainty about the network that is not rational in the context of simulating the implications of uncertainty). Most risk models with more than 200 activities are irrational for this reason, as are many with fewer than 200 activities.
2. Using inappropriate schedule constraints on activities (e.g. “must finish by”) that override the Monte Carlo simulation.
3. Using network dependencies inappropriately such that affected activities fail to influence the simulation results. Finish-Finish dependencies can result in this fault if used to represent partially overlapping activities.
4. Using dependencies with leads or lags that mask the significance of risk associated with missing activities.
5. Including activities in the network that do not directly drive schedule risk (e.g. project management or routine meetings).
6. Unquestioning use of information from the project’s deterministic schedule in circumstances when it is known to be immature, faulty or biased.
7. Using ambiguous activities and/or risk events that provide an inadequate basis for estimating.
8. Duplicating the implications of risks e.g. by adding event risks to the model when their implications are already simulated by dependencies.
9. Pulling across risk estimates from a risk register that have not been made in the context of the schedule risk model.

In practice, the most frequent cause of irrational risk models is electronic copying of the project’s deterministic schedule (often referred to as the plan). It should be noted that the first five points in the above list refer to techniques that may be legitimate in the context of planning but irrational if pulled through to risk analysis. Hence, even if the project’s schedule is of good quality, it is usually a mistake to simply copy it for the purpose of risk modelling.

Since good quality risk models cannot usually be produced by copying a project’s schedule, there is a need for a process for doing so.

A Process for Monte Carlo Schedule Risk Models

Figure 3 illustrates a process for developing and using a project Monte Carlo schedule risk model. The subsequent sections of this paper describe why each stage of the process is important and how it should be implemented.

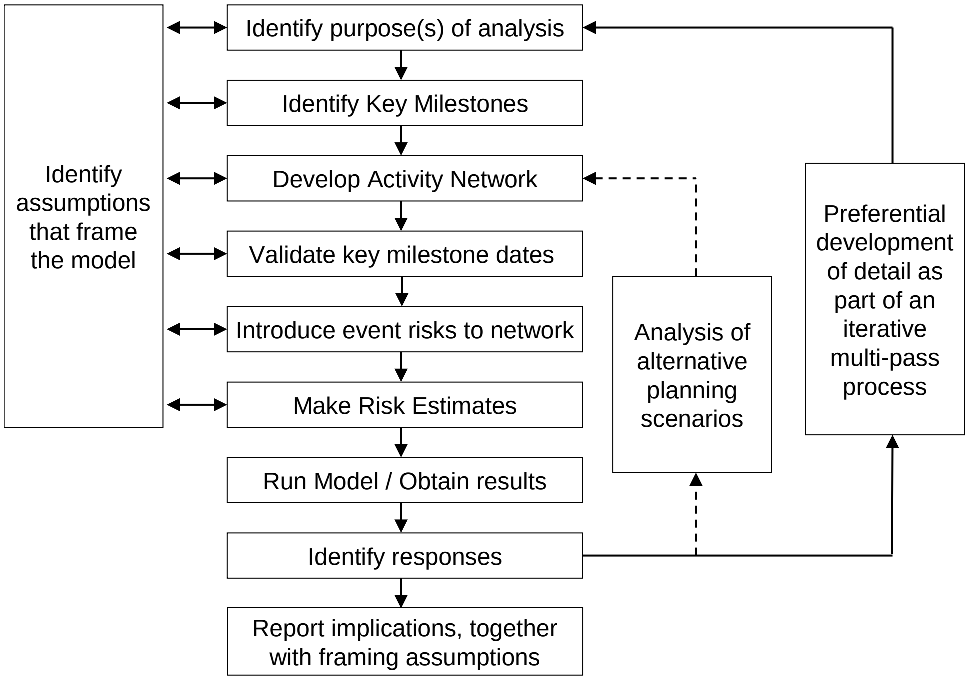

Figure 3: Process for developing and using a Monte Carlo schedule risk model

Identify purpose(s) of analysis

The function of any risk model is to support decisions that might be taken in response to the insights that it produces. Since schedule risk analysis may have one or more purposes, it important to identify what those purposes are and who will use the analysis results. This will help scope the analysis appropriately and identify the key milestones around which the model structure should be built. Clarifying these points with decision makers will also help to convey assurance that their requirements have been understood thus making it more likely that they will act on the analysis results.

Identify Key Milestones

Identifying the purpose of the analysis should help identify the milestones that are the subject of the analysis results, as depicted, for example in Figure 2. It may also help to identify other key milestones in order to structure and validate the model as it is developed. Typically, there might be 4 and 10 key milestones, with the number reflecting the project's size and complexity. Key milestones might be selected on the basis that they:

- can be associated with well-defined products or events;
- represent points at which activity paths in the schedule converge;
- are known e.g. from previous experience, to be exposed to schedule risk;

- are relatively evenly spread over time, and
- are of significant interest to decision makers and project stakeholders;

Develop Activity Network

The product of this step of the process is an activity network that models how key milestones are driven. It is good practice to use simple Finish-Start logic unless there are good reasons for doing otherwise. It is also good practice to start with the simplest possible network, working with the minimum number of high level activities commensurate with this aim. Further detail using lower level activities can be added in later passes of the model's development. The reasons for this are that:

- Working with a complex network often makes it easier to overlook the fact that fundamental assumptions are being made to frame the model.
- Starting with a simple network can help to clarify which dependencies override others. In practice, there are usually only a limited number of dependencies are unalterable. Differentiating between these and other dependencies can be a useful way of identifying where the merits of different plans could be compared using risk analysis and where the use of lower level activities might be irrational.
- Key areas of risk and ways in which they interact are sometimes easier to identify when working with a high level schedule. One of the arts of good risk modelling is to preferentially develop detail in areas of the model that matter most from a risk perspective.

As the model is developed, insights gained from the each stage of its development can be responded to with either further development of detail or the production of alternative versions that allow different planning scenarios to be compared.

Validate Key Milestone Dates

It should be possible to compare the deterministic version of the risk model activity network with the project's schedule. The dates for key milestones provide a convenient check that they are aligned. A lack of alignment can indicate the presence of issues with either the risk model or the schedule. Errors in either can be corrected during this step of the process. Decision makers who use the analysis results are more likely to be persuaded on the risk model's validity if it aligned with dates that they recognise from the project schedule. Equally, however, it should be appreciated that an advantage of developing a separate schedule risk model is that provides a health check on the project plan.

Introduce risk events to the network

The activity network developed by previous steps should be augmented so that it is able to simulate the implications of event risks. Event risks are potential step changes to the underlying plan that may or may not occur. Many event risks can be simulated as activities that may or may not exist – risk probability is effectively the probability of task existence. Such risks are connected into the network using dependencies in the same way as activities which can be assumed to exist. However, there may be circumstances in which certain event risks can only be simulated using other means such as probabilistic dependencies, calendar-related risk or resource availability variance.

In practice, a project's risk register is often a good starting point for the identification of event risks. However, it should be noted that some risks in the risk register might already be inherent to the risk model's activity network e.g. the risk that "manufacturing might be delayed by late issue of drawings". Care thus needs to be taken when selecting risks to be modelled as events.

Make Risk Estimates

Having developed a complete risk network, estimates are required to drive the Monte Carlo simulation. As a minimum estimates will be required for:

- Probability distributions associated with the duration of activities, often defined using a probability distribution shape and three-point estimate.
- Probability and impact estimates for risk events simulated as activities that may or may not occur, with impact estimates usually estimated in the form of a probability distribution rather than single value.

These estimates are crucial to the simulation results; care is required to ensure that they are realistic and unbiased. The issues involved in achieving this aim are complex and discussed in a number of works. The notes below provide a brief summary of how some of the most important factors can be addressed.

1. Estimates should be made by subject matter experts (SMEs) with the aid of a risk management specialist who can guide them in the use of an appropriately structured approach. For example, SMEs should understand the implications of the probability distribution shapes that being used.
2. Risks should be understood clearly before estimates are made. For example, in order to estimate an event risk probability there should be clarity about the sources of uncertainty that influence whether or not the risk would occur.
3. Sources of uncertainty that affect activity or risk impact variance may combine in complex or compound ways. One cause of unrealistically narrow three-point estimates is that the relevant sources of uncertainty are not identified explicitly or that insights from this information are not used appropriately.
4. When making three-point estimates, it is good practice to estimate the High estimate first, then the low estimate and finally the mode (most likely), in each case taking care to understand the circumstances in which these could arise. This approach avoids the anchoring bias inherent to the oft used assumption that planned deterministic durations are the same as the mode.
5. It may be possible to use quantitative historical data from previous projects to help validate the estimates. However, care needs to be taken to ensure that such projects are genuinely representative of the new project for which estimates are being made. It should also be remembered that the number of projects may not provide a statistically valid sample. The realistic range of uncertainty is thus usually wider than would be indicated by the outcomes of any of the previous projects.

6. Estimators must be committed to the principle of making unbiased estimates. It is likely to help if estimators are accountable for outcomes. If the nature of the project environment is one that could foster bias, estimates should be subject to independent scrutiny.

Dependent upon the structure and development stage of the model, estimates may also be required to:

- Simulating the effects of covariance between associated activities and risks (usually using correlation inputs).
- Specify relative probabilities for probabilistic dependencies.

Identify assumptions that frame the model

As any risk model is developed, assumptions have to be made in order to structure the model and simplify the ways in which the implications of uncertainty are simulated. Some assumptions may be explicitly built into the model, for example an assumed start date or dependencies representative of contractual obligations. Other assumptions, such as the project's purpose, objectives and contracting strategy, may be implicit to the risk network and estimates.

Key assumptions should be recorded as the model is developed. They include assumptions that are fundamental to the project or the context in which the analysis results should be interpreted. Other key assumptions may imply the exclusion of risks from the model that cannot rationally be modelled e.g. potential "showstoppers".

If the people who act upon the analysis results are not made aware of key assumptions, they might misinterpret the results and take inappropriate action. The primary reason for recording assumptions is thus to ensure that they are disclosed in conjunction with the reporting of results. However, it should also be noted that records of assumptions that imply constraints may lead to the identification of opportunities for schedule improvement.

Run model and obtain results

With modern computer software and processing power, running a Monte Carlo simulation now takes little more than seconds. As a result, the question of how many iterations of the simulation are required to in order to produce reliable results has become a less important issue than it used to be. For the purposes of project schedule risk analysis, 3000 iterations are usually more than sufficient, although there is little time penalty for using a higher number. The more important issue is how the results are used and whether or not they can be used to identify appropriate responses.

Schedule risk analysis results are generally of two types:

1. Risk-based forecasts, e.g. as illustrated in Figure 2.
2. Statistical analysis of the relative importance of the model's constituent activities and event risks e.g. as illustrated in Figure 4.

Results of both types can be used to identify risk responses and report the implications of schedule risk to stakeholders and project decision makers.

Identify responses

In cases where there are relationships between the project's risk register and its schedule risk model, some schedule risk responses may already be identified in the risk register. However, schedule risk analysis results can provide a sharper focus on the importance of certain activities or risks, thus leading to further consideration as to how associated risks responses could be made more effective. Typically, this focus is provided through Tornado charts based on metrics such as criticality, cruciality or schedule sensitivity index (SSI). Figure 4 illustrates the Tornado chart format. The activities and event risks with the longest bars are those that have the greatest influence on overall schedule risk.

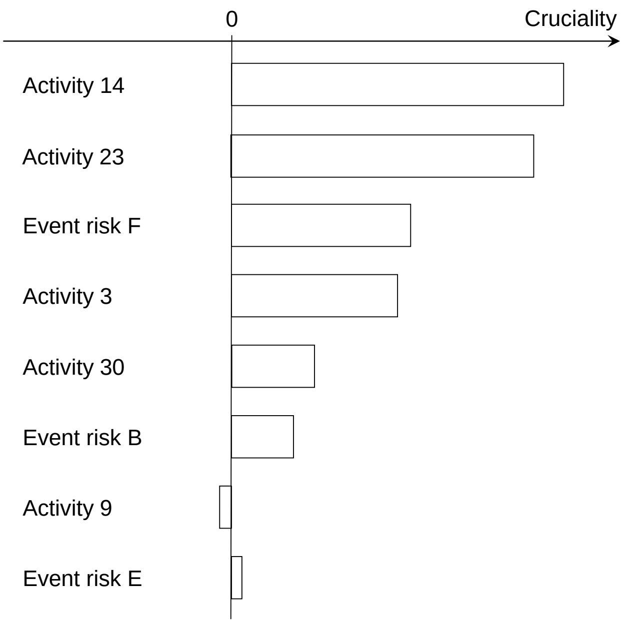

Figure 4: Illustration of a Schedule Risk Analysis Tornado Chart

Schedule risk analysis can also lead to the identification of risk responses that might not be identified or assessed using a risk register. Such responses include:

1. Making provisions for schedule contingency in the project plan, in response to the risk-based forecasts obtained for key milestones;
2. identification of further modelling actions that may be required to obtain a more detailed analysis of risk (preferential development of detail as part of an iterative multi-pass process), and
3. Using variants to the schedule risk model to assess the effect of potential risk mitigation activities or other options that would alter delivery plans.

The second and third of these types of response require further cycles of modelling represented by feedback loops in the process illustrated in Figure 3.

Preferential development of detail as part of an iterative multi-pass process

A number of the most respected academic works in the field of project risk management recommend the use of an iterative top-down process. For example Chapman and Ward (2002) uses ten case studies to show how key insights and rational risk models can be developed iteratively from a constructively simple initial model. This principle of using top-down iterative process is also inherent to the APM's guides to project risk.

It is tempting to develop modelling detail preferentially in areas of the schedule that are best understood and that can be estimated with the most precision. Indeed, this makes good sense in the context of project planning. However, in the field of risk management it makes more sense to focus preferentially on areas of the schedule that have the greatest degrees of risk exposure. One approach to identifying these areas is to run a high-level schedule risk model in order to identify the activities that have the most influence on overall risk e.g. using Tornado diagram results as illustrated in Figure 4. These activities can then be addressed as being composite risks that might be better understood if broken down into a more detailed risk network for modelling purposes.

The other key reason for using a top-down approach to schedule risk model development is that (for reasons detailed earlier in this paper) it provides assurance that the model is rational. In contrast, the common-practice single pass approach in which a detailed risk register is merged with a detailed project schedule frequently produces an irrational risk model.

The importance of using an iterative process for risk model development is reflected in the solid feedback line in the process diagram in Figure 3. This indicates that an iterative process should be used in all cases, whereas the other feedback loop (analysis of alternative planning scenarios), represented with a dashed line, is sometimes not required, although it is often very useful.

Analysis of alternative planning scenarios

One of the advantages of developing a schedule risk model is that it becomes possible to run the analysis with different planning scenarios. This allows "what if?" planning issues to be assessed from a risk perspective.

Techniques for analysing different planning scenarios include:

- Substituting one part of the schedule with an alternative combination of activities that would achieve the same ends.
- Investigating the opportunity for schedule enhancement by using management interventions e.g. committing more resources to the project.
- Quantifying the benefits of implementing risk mitigation actions that reduce the probability and/or schedule impact of event risks (pre and post mitigation analysis).

The implications of alternative planning scenarios are reflected in different versions of the risk model that can be run so as to compare results with a view to choosing the optimal solution. Figure 5 illustrates a comparison of the results produced by two scenarios.

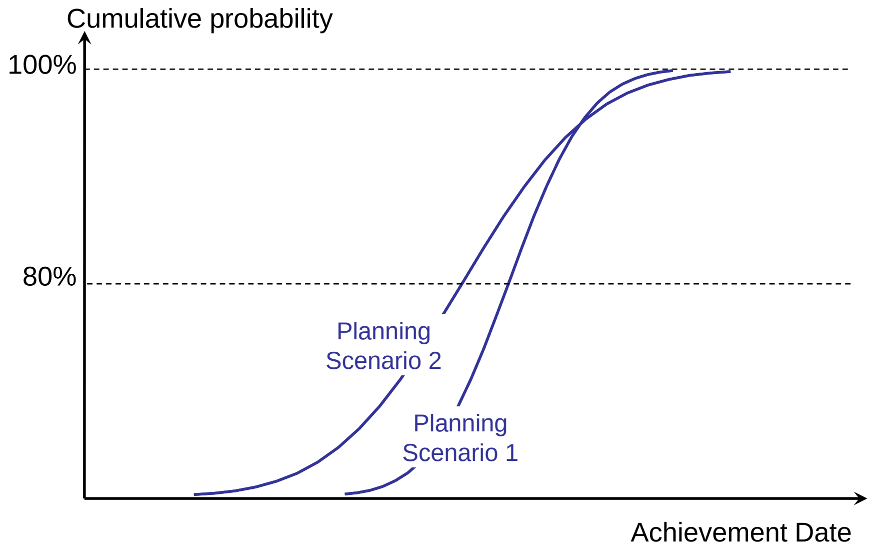

Figure 5: Example of the comparison of alternative planning scenarios

In the case of Figure 5, Scenario 2 would probably be preferred to Scenario 1 since, on average, it is likely to achieve an earlier project completion date. However, if the organisation was risk averse, Scenario 1 might be preferred since it there is less uncertainty about the date by which the project would be complete and because there is at least a possibility that Scenario 2 would achieve a later completion date. The example in Figure 5 illustrates how schedule risk analysis forecasts can be used to clarify the implications of project design decisions.

Report implications, together with framing assumptions

The last step in process described by this paper is to report results, insights and recommendations to the relevant interested parties. Depending upon the purpose of the analysis these parties might include the members of the project management team, the project sponsor, other people project governance roles or external stakeholders such as the project customer.

Each report should provide data relevant to the relevant purposes of risk analysis established during the first step of the process. Analysis reports are likely to include graphical outputs such as those shown in Figures 2 and 4. However, for the purposes of clarity, it is important that the key assumptions used for risk modelling purposes are also disclosed. It is also good practice to summarise the actions taken to verify that an appropriate process has been used for risk model development and to validate the model(s) in terms of their fitness for purpose.

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A link to download free copies of this paper and other useful project risk management resources found at www.rmcapability.com.

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