RISK.10

The Benefits of Monte-Carlo Schedule Analysis

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A major benefit of Monte-Carlo schedule analysis is to expose underlying risks to a specific project execution plan that may not be obvious. There are additional benefits that can be realized through applying Monte-Carlo schedule analysis that can be a great value to owners, engineers and construction contractors.

This paper outlines the additional rewards of using Monte-Carlo schedule analysis on Engineering, Procurement and Construction (EPC) projects and is based on practical experience gathered in the field using Primavera and risk analysis software. It explains the general principles of Monte-Carlo schedule analysis and the various advantages of using it.

A major benefit of Monte-Carlo schedule analysis is to determine the level of risk in a project schedule. By using Monte-Carlo analysis to quantify the probability of achieving an end date, it can identify the risk associated with achieving the schedule based on the schedule logic. An end date with a 5% probability of being achieved is more risky than the 95% probability end date. The benefit of identifying the risk on the schedule is through risk identification and quantification, one has the ability to influence factors to reduce risk to improve the likelihood of succeeding.

Monte-Carlo analysis is a powerful tool that can give project controls professionals and project managers additional benefits to project execution by:

- Changing the expectations of a single project end date with an unknown probability to a range of end dates with quantified probability
- Identifying the most important activities within a schedule that may not be on the critical path
- Developing a realistic execution plan
- Aligning the stakeholders involved in a project
- Avoiding claims and potential liquidated damages.

MONTE-CARLO ANALYSIS - WHAT IS IT?

Monte-Carlo analysis utilizes random sampling that selects numbers within a range for variables to a problem. The analysis then uses the variations of random numbers to generate simulations. The results of the simulations are summarized, which yields statistics on achieving the end result to the problem. Table 1 illustrates how to apply Monte-Carlo analysis to a simple schedule of commuting to work.

What this simple example indicates is even though the most time it could take to commute to work could be 50 minutes and the best could be 24 minutes, you stand a good chance of being at work on time if you count on it taking between 32 and 40 minutes. This example only looks at three simulations, but with the aid of computers and software, more complex models and problems can be quickly analyzed through hundreds of iterations giving a range of results with more accuracy. This can be a very powerful tool, allowing an analysis of data throughout a range rather than just a single result.

MONTE-CARLO SCHEDULE ANALYSIS

Monte-Carlo analysis has been used for some time for cost engineering and estimating. It has been used less often with scheduling, but that is changing with the advancement of software. User friendly software interfaces seamlessly to both Primavera and Microsoft Project, making Monte-Carlo schedule analysis easy to apply.

The application of Monte-Carlo analysis to scheduling changes the traditional approach of having one end date and one critical path in a schedule (deterministic approach) to a range of end dates and potential critical paths with associated probabilities (probabilistic approach). The project schedule will still be driven by a single critical path (the longest uninterrupted path through the network) but the Monte-Carlo approach analyzes more than just a single critical path. Refer to Figure 1 to see the differences between the 2 approaches.

Through Monte-Carlo schedule analysis, dynamic date ranges can be introduced modeling potential changes in task durations and simulating multiple variations of a schedule in a probabilistic way versus a deterministic single duration schedule. Hundreds of variations of the schedule and critical paths can be simulated quickly. Through the results of all these simulations, data can be analyzed to understand what activities have the most likelihood of impacting the end date versus just the activities on the current critical path. It can also give the ability to identify a realistic end date that can be agreed upon by owners and contractors.

Item Description	Range of Time	Simulation 1	Simulation 2	Simulation 3	Worst Case	Best Case
Get out of House	10 to 15 Minutes	12	11	15	15	10
Drive to Train	5 to 10 Minutes	6	7	9	10	5
Wait for Train	1 to 15 Minutes	5	10	6	15	1
Train Ride	8 to 10 Minutes	9	8	10	10	8
Total		**32**	**35**	**40**	**50**	**24**

Table 1— COmmuting Schedule

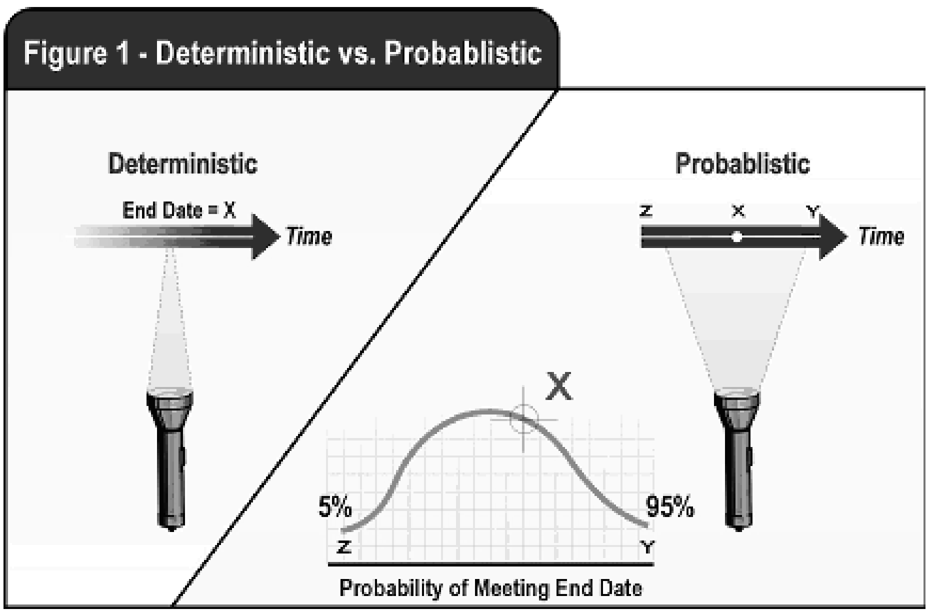

Figure 1 — Deterministic vs. Probalistic

How to Apply It—The starting point of a Monte-Carlo schedule analysis is taking a schedule that has the appropriate level of detail activities and correct logic [1]. How many activities to use in a schedule is a question that does not have an exact answer, but if a 10,000 or 1,000 activity schedule network is used, it will be difficult to get much value out of the analysis. Based on practical experience using Monte-Carlo schedule analysis, somewhere in the range of 50 to 200 activities is a reasonable number of activities to analyze. For example, if a complicated year long project was broken down into thousands of activities down to the hour, the ranges would be in minutes. The significance of each activity is lost within the amount of detail in the schedule.

Once an adequate schedule is developed, a duration range is applied to each of the schedule's activities. The duration range involves three data points comprised of the pessimistic (longest), most likely and optimistic (shortest).

To assess the range of durations for each activity, experience is required and it often helps to have more than one opinion on durations of activities to make an accurate assessment. Usually a scheduler/planner can make an initial assessment, but the best results occur when a small team of people involved in the project collaboratively assess the duration ranges. By involving multiple people, it adds validity to the date range and the team approach can also help to align team members on realistic durations, logic and an execution plan for the schedule. To further improve the accuracy of date ranges, the ranges should be compared against historical benchmark data to take some of the subjectivity out of the assessment process.

Most software can automatically assess ranges for the durations based on default percentages, but the validity of using these defaults other than a starting point is questionable. When using default ranges, any in-depth knowledge of the project and any benchmark information for specific activities are lost. In most projects, all activities do not have the same pessimism or optimism that is applied as a default. Also if you apply the same defaults to different projects, you will end up with similar results if you use the same defaults and this would rarely be the case because each project is unique.

PROBABILISTIC & CONDITIONAL BRANCHING

It is important to understand that in reality, schedules are only dynamic project models and the logic necessary to achieve a schedule can change significantly. It is difficult to model this real life variable mathematically. Probabilistic branching and conditional branching are two additional methods that can be added to simple Monte-Carlo analysis to try and simulate the potential quantum changes to the schedule when uncertain events occur.

Probabilistic branching is used to model the probability of additional activities being added to the schedule. An example of probabilistic branching can be used in turnaround planning for an activity of taking catalyst out of a vessel. Normally, the duration could take between 15 and 20 days, with a most likely of 17. There is a 10% chance, that upon inspection of the vessel, the internals may need to be reworked which could add two weeks to the duration. This event can be modeled quite easily in most Monte-Carlo schedule software. If it is found that this is the driving factor in an overall turnaround duration a mitigation plan can be developed.

Conditional branching is used to model "If then Else" type of real life conditions. For example it could be used to model the Canadian winter freeze up of the St. Lawrence River. After freeze up of the major shipping way, materials cannot be shipped. This can be modeled by using conditional branching which essentially says if key equipment has not arrived before December freeze up, then it must arrive in the spring time, and a backup plan must be used.

While probabilistic and conditional branching can model some of the variations to schedule logic, it is impossible to simulate all of the combinations of different execution plans that can be used such as the ability to alter the work shift, work on parallel fronts, or change the entire execution.

SCHEDULE ANALYSIS - PRACTICAL ADVICE & CAUTIONS

While Monte-Carlo schedule analysis can be a very valuable tool, it is important to realize what shortcomings it has. Awareness of the potential difficulties makes it easier to achieve an objective analysis of all of the information given by both the traditional means of scheduling analysis and Monte-Carlo analysis.

Some pitfalls exist when applying Monte-Carlo analysis to certain types of schedule logic that could generate results that may not make sense. A schedule with Finish to Start relationships provides results that are easy to analyze and understand. Finish to Finish and Start to Start logic within a schedule network can skew results and give answers that may not seem valid. [1]

Take for example pipe spool fabrication from engineering drawings which is illustrated graphically using a Gantt chart in Figure 2. Typical logic for this task is finish to finish with a lag. For this example, eight weeks after finish of all the drawings, the last spool is completed. Spool fabrication can start before the last drawing is issued. This works well when scheduling in the deterministic way as the start of spool fabrication can be controlled through the relationship between the lag and the fabrication duration.

During random simulation in Monte-Carlo analysis, the drawing activity may be simulated at the shorter (optimistic) end of the range, and the fabrication activity is simulated taking longer (pessimistic), this can cause the fabrication to start before the 1st Drawing has been issued.

Normally, the problems with finish to finish and start to start logic are camouflaged by only looking at the results of the project end date. If a schedule network has a lot of start to start and finish to finish logic, the overall simulation result may not make sense. Often, a schedule network may need to be summarized, logic simplified, and constraints removed to yield valid results.

Unlike cost analysis, a complexity is added when applying Monte-Carlo analysis to schedules as logic is added to the equation. In cost analysis, the results are additive for each component as the sum of all the cost components is linear. In schedules, the logic for most projects involves multiple branches and parallel paths. Logic paths that may not be on the original critical path may drive the project completion during the simulation, and they may drive it more often. The addition of logic is also why Monte-Carlo schedule analysis can be so valuable. In real life there is variation between the logic paths which drive the end date. A basic understanding of the schedule logic is required to validate, analyze and comprehend the results of Monte-Carlo schedule analysis

Even though Monte-Carlo analysis yields probabilities that seem very accurate, it is important to analyze what the numbers are really indicating. When comparing the percentages, look qualitatively at what the numbers are indicating versus quantitatively. There is not a major difference between a 10% probability and a 25% probability; they are both less likely to achieve than a 50% or 75%, the hard percentages are not as important as generally what the data is demonstrating.

Monte-Carlo analysis will never replace good judgment and the human ability to make decisions based on experience. Never take the results of Monte-Carlo schedule analysis and use them without first taking a critical look and ensuring that the results are understood.

MONTE-CARLO ANALYSIS - BENEFITS TO PROJECT EXECUTION

Sensitivity Analysis—Not only can probabilities of achieving an end date be generated, the sensitivity of the activities involved can be analyzed through Monte-Carlo analysis. By understanding what a schedule is sensitive to, it can allow changes to execution to improve the end date. Most Monte-Carlo analysis software can provide a sensitivity analysis in the form of a "tornado graph" which focuses on the top activities that are closely correlated to the statistics of the end date. A typical tornado graph is shown in Figure 3

What the tornado graph shows is the relative sensitivity of the end date to each activity in the schedule. The exact numbers shown on the tornado graph are not as important as the relative ranking of the activities. From Figure 3, the top three activities have significantly higher correlation (at least three times higher) than the other activities. There is a much higher degree of correlation with the length of these activities to the end date and by focusing on these activities, there is a higher chance of impacting

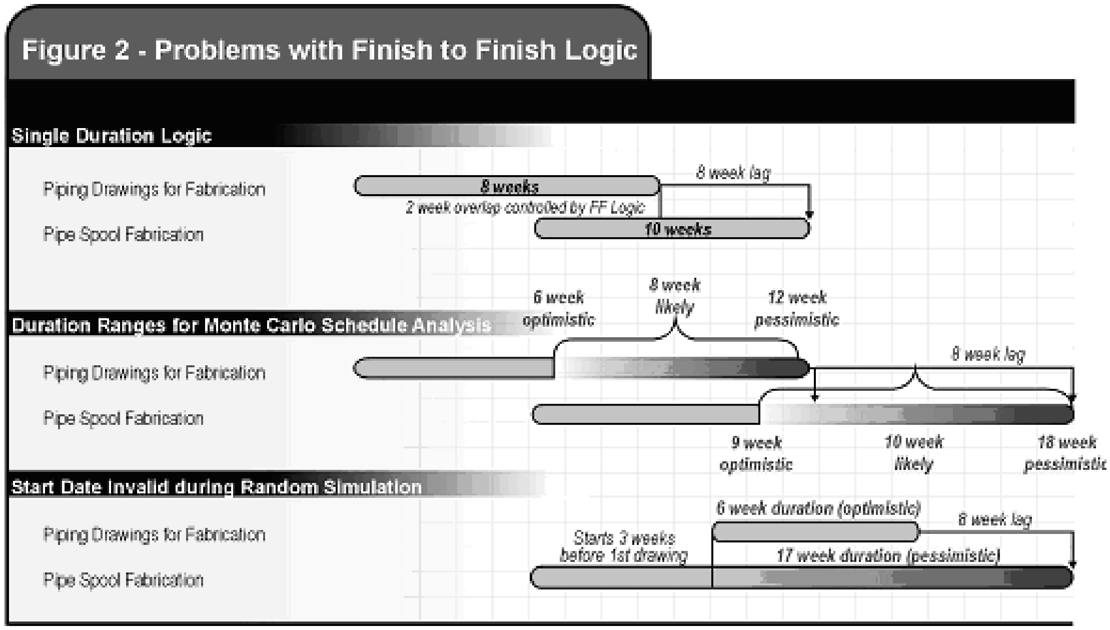

Figure 2—Problems with Finish to Logic

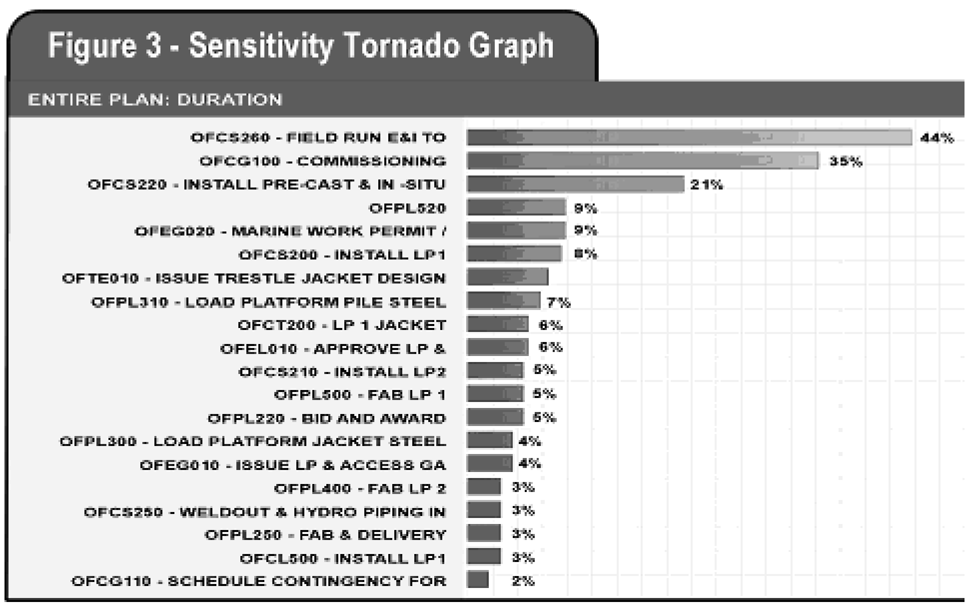

Figure 3— Sensitivity Tonado Graph

the end date. This allows the project to focus limited resources where it makes the most impact.

For simple schedules with single path logic in series, it is very easy to understand what activities drive the end date and what the most important activities are. However, for most projects the logic involves multiple parallel paths of activities and one dominant critical path. By applying ranges to all the activity durations through Monte-Carlo analysis, hundreds of variations of a schedule through multiple alternative critical paths are generated, making it difficult to understand what drives the overall schedule duration. Although there is still one critical path in any give iteration of the analysis, Monte-Carlo analysis helps to identify other paths that may have a higher probability of impacting the end date. Getting the most of this information requires understanding the sensitivity analysis and the tornado graph, which identifies the most important activities in all the various combinations. The results of this analysis can be surprising and are not always evident.

A recent example of an offshore project schedule illustrates the importance of the sensitivity analysis. A schedule was developed showing the critical path flowing through the structural steel to build the offshore structure. The project focused on speeding up the structural steel component of the project. After a Monte-Carlo analysis was performed and the sensitivity analysis was completed, it was clear that even though the critical path was driven by the structural steel, there was not a lot of variation within the structural steel itself. More impact could be made to the end date, by changing the execution once the structure was built. There was far more variability in the end activities and by optimizing that portion of the schedule, the end date could be improved significantly. This was not evident to the project until identified through Monte-Carlo analysis.

DEVELOPING A SCHEDULE WITH A REALISTIC EXECUTION PLAN

Developing a schedule with a realistic execution plan is sometimes difficult to accomplish. Projects often have end dates that are imposed due to commercial or other requirements. Factors such as delays to contract awards or scope change decisions may delay project start dates while end dates typically do not move. The execution plan envisioned at the beginning of the project may become unrealistic due to delay factors, and Monte-Carlo analysis can identify if a schedule execution plan is becoming unrealistic.

When a schedule is becoming unrealistic, it is often described as "very aggressive" or "fast-track". Terms such as these are qualitative ways of describing unrealistic schedules. By quantifying the probability of achieving an end date, it gives evidence to how aggressive or difficult it will be to achieve. Monte-Carlo Analysis provides a means to quantify what is meant by aggressive and what can be agreed to be realistic. A less than 5% chance can be agreed to be aggressive or even not likely, a 50% or 70% chance of meeting an end date can also be agreed to be achievable or realistic. By identifying if a schedule is becoming unrealistic, it provides the opportunity to change the execution plan or schedule logic to make the execution plan more realistic and to increase the chance of project success.

The cost implications of attempting to accomplish an unrealistic schedule can be significant. If a schedule has a low probability of being met, it should be a trigger to add additional costs in the estimate for costs of attempting a low probability schedule. These extra costs do not necessarily guarantee that the end date will be met.

By quantifying the likelihood of meeting the schedule, it can highlight the risk that costs spent on the schedule may not ensure the end date. Also, a Monte-Carlo generated sensitivity analysis can identify the activities that are the best activities to spend additional cost on.

Monte-Carlo schedule analysis can also be used to develop realistic or achievable payment milestones within a schedule. A recent example of this occurred on a major petrochemical project. Due to certain factors in the project, the incentive milestones envisioned at the beginning of the project were perceived to be not achievable, but this was just a perception. A Monte-Carlo analysis was performed and it was identified that indeed the milestones stood a low chance of being met. From the analysis, aggressive yet achievable incentive targets were agreed upon by both the owner and contractor. The identification of realistic schedule milestones could have a direct benefit to both the owner in credibility to shareholders and the contractor in profit incentives.

ALIGNMENT BETWEEN PARTIES

Monte-Carlo schedule analysis can also help align two parties such as the owner and the EPC contractor to agree on what is a realistic target by presenting a scientific and statistical approach versus picking an arbitrary end date.

Often an owner's desire to meet a given end date may not be possible without significant costs or changes to the execution plan. An owner is pressured not to change the end date usually related to commercial or business case reasons. A contractor is pressured to agree to an end date due to competitive market pressures. These pressures lead to misalignment between the owner's business objectives and the contractor's ability to meet the end date.

The end result of the misalignment is potential cost overruns passed on through claims or change orders. In addition to cost overruns, misalignment on schedule objectives can lead to missing the schedule, which may have other implications such as the validity of the business case or other commercial implications.

Monte-Carlo analysis can identify a schedule that both parties can either agree or disagree upon, based on how much risk there is involved in meeting the end date. Once the degree of risk is identified for a project schedule, there is an opportunity to include the costs associated with attempting the schedule either in owner risk contingency or contractor project contingency.

The process of collaboratively assessing the durations with clients and contractors can be used as an alignment process. Through the application of Monte-Carlo analysis, it can help align the two parties or at least identify the risks associated to the given schedule so that both parties can go forward, knowing the risks of proceeding.

CLAIMS AND LIQUIDATED DAMAGES AVOIDANCE

Identifying risks to a schedule through the early application of Monte-Carlo analysis can help avoid claims and potential liquidated damages. The identification of potential problems to a schedule, gives all parties options on how to proceed. All the options may not be benefits to both parties, but at a minimum, Monte-Carlo analysis can provide information to make informed decisions on both sides to avoid potential claims or liquidated damages.

The following table illustrates an example where a Monte-Carlo analysis showed there was less than 5% chance of meeting a project end date, potential actions and the benefits of knowing this information

Monte-Carlo analysis is an extremely valuable tool for improving project execution and managing risks associated with the schedule. With the software available today, it has become easier to apply this tool to scheduling, and the benefits of Monte-Carlo schedule analysis can be gained with relative ease.

Monte-Carlo analysis is a powerful tool that can give project controls professionals and project managers valuable information that can be used to improve project execution by identifying risks and the most important activities within a schedule that may not be on the critical path, ensuring a realistic execution plan, aligning the stakeholders involved in a project, and avoiding claims and potential liquidated damages.

REFERENCES

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Party	**Action**	**Benefit to Owner**	**Benefit to Contractor**
Owner	Change the end date	Avoids potential claims or cost overruns	Avoids the negative results of claims and cost overruns
	Keep end date the same	Upfront knowledge that the schedule may not be met	None
	Keep the end date the same and increase risk contingency	Resources are reserved or allocated for potential cost overruns	Potential cost overruns related to the schedule may be paid for
Contractor	Not Bid	Avoids any negative implications of attempting the schedule and not making it	Avoids potential liquidated damages, claims or cost overruns.
	Increase contingency to attempt the schedule Change the execution plan to meet the schedule	Potential higher cost, but greater confidence in schedule Increases likelihood of meeting the schedule. Achieve schedule related business case results	Less likelihood of overrunning, potential preserved profit Increases the chance of successful completion of the project

Table 2 —Potential Benefits and actions from Knowing a schedule is not likely to be achieved (Less than 5% likelihood)