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# FORENSIC SCHEDULE ANALYSIS ON RISK-ADJUSTED SCHEDULES

**Abstract:** With increasing time and cost pressure from owners, it is likely that risk-adjusted schedules will expand beyond their current uses and become more common in buildings and infrastructure construction. Risk-adjusted Critical Path Method (CPM) schedules use computer modeling to analyze the likely fluctuation of activity durations resulting from a range of uncertainties and risks, and then analyze the effects of the variations on the float of the schedule as different chains of activities are given different durations and the amount of float changes. The result is a schedule that has a series of potential critical paths with varying degrees of likelihood, rather than a single critical path and subcritical paths. Forensic schedule analysis, however, is predicated on identifying the single contemporaneous critical path, often defined as the path with zero float. So what happens when the CPM schedule series has been risk-adjusted so that float is variable and more activities paths are critical? This paper will discuss a theoretical model for performing a delay analysis on a project where the initial baseline and all updates were adjusted for risk.

## INTRODUCTION

The critical path, the longest continuous chain of activities that establishes the minimum overall project duration for a project[1] is identified through the development of a CPM schedule. This schedule must be developed to a sufficient level of detail that includes a list of activities fully encompassing the contract scope of work, logic that accurately describes the planned order of the work, and durations that are calculated with respect to the planned level of resources to be applied to that scope of work. Using this information, a scheduler can calculate the longest continuous chain of activities through a network and determine the predicted completion date for the work. This is the critical path, and a slippage or delay in completion of any activity along that path will extend final completion correspondingly.

1. AACE International, RP 10S-90, Cost Engineering Terminology", Rev. Dec. 3, 2012, AACE International, Morgantown, W.V.

The construction industry has long understood — first through intuitive understanding of the construction process, and then through analysis and court decisions — that the critical path of a project is not static, and will likely not remain on the exact path determined by the initial CPM calculations. Knowing that the baseline CPM does not necessarily predict the final as-built critical path through the project, and that the uncertain conditions surrounding construction will likely cause the critical path to shift, the process of Quantitative Risk Analysis (QRA) has become an increasingly popular tool to try to identify all the likely delays to project completion, and to help mitigate them. In RP 10S-90, "Cost Engineering Terminology," QRA is defined as:

> *"Risk analysis used to estimate a numerical value (usually probabilistic) on risk outcomes wherein risk probabilities of occurrence and impact values are used directly rather than expressing severity narratively or by ranking as in qualitative methods."*[2]

The purpose of QRA is defined by RP 64R-11 "CPM Schedule Risk Modeling and Analysis: Special Considerations," as:

- Assessing the potential variability in project duration (in individual activities, various subnetworks, or the overall completion milestone) resulting from identified project risks;
- Assessing how risks, including threats and opportunities, in the project schedule may influence project economics
- Understanding which paths in the schedule have the highest probability of influencing the schedule completion or key milestones
- Understanding which risks have the most influence on overall schedule variability[3]

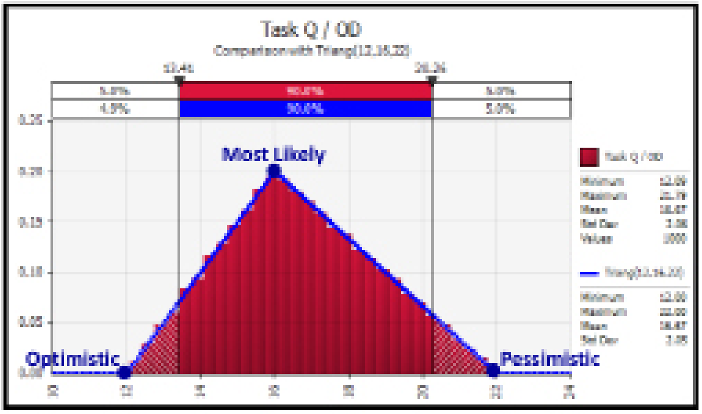
The final two bullets are particularly germane, speaking directly to the ability that at the start of a project it is possible to envision how combinations of different events, both positive and negative, could influence the final critical path. Rather than speaking of one defined critical path, risk-0adjusted schedules speak of the likelihood of events influencing predicted project completion.

The most common method of performing a QRA involves the use of a "Monte Carlo" simulation, which Monte Carlo simulations are defined as follows, "Methods for finding solutions to mathematical and statistical problems by simulation. Used when the analytic solution of the problem is either intractable or time-consuming."[4] Mathematically predicting with certainty the actual completion date, in the face of all the variables discussed above, is time consuming and probably indefinite. Monte Carlo simulations rely on a well-developed CPM schedule and "probability distributions" established for each of the activity durations. Probability distributions are graphs that plot the duration of an activity against the estimated frequency with which that duration will occur. There are many probability distributions, including the triangular distribution, discussed below, but also including the bell-shap normal distribution, and many others. Different distribution curves can be selected to model different situations, based on the judgment of the analyst. In other words, an analyst in a certain situation might decide that the selection of the triangular distribution curve is not appropriate and that an activity should be modeled using a normal distribution curve, because the normal distribution more correctly represents the frequency with which certain durations will occur.

However, it is most often the triangular distribution curve that is used in simulating CPM schedule models. The triangular distribution (such as the distribution shown in Figure 1) establishes the optimistic, most likely, and pessimistic durations, for a specific activity, given the analyst's understanding of the likelihood and severity of the risks identified for that activity within the risk register. In the activity identified in Figure 1, the optimistic duration is 12 days, the most likely duration is 16 days, and the pessimistic duration is 22 days. Identification of risks, their likelihood and their likely effects, within a "risk register," allows an analyst to establish this range of variability for activity durations. An activity with a number of risks — especially when those risks are of high likelihood and high severity — will necessitate a higher most likely and pessimistic duration, shifting the apex of the triangle to the right. The establishment of these points of the triangular distribution curve is a matter of judgment for the scheduler and the risk analyst, but these points have a major effect on the Monte Carlo simulation. It is essential to the quality of the risk analysis, and to subsequent forensic delay analysis, that these possible durations are provably the product of calculations accounting for the scope of work described by the activity, the number of resources planned for that activity, the estimated production rates of those resources, and an estimate of the potential effects of risks (or opportunities) specific to that activity.

2. Ibid.
3. Caddell, Christopher P., et al., Rev. May 2, 2012, RP 64R-11 CPM Schedule Risk Modeling and Analysis: Special Considerations, p. 2, AACE International, Morgantown, W.V.
4. Rubinstein, R. Y., *Simulation and the Monte Carlo Method,* Wiley, New York

### Figure 1. Three-Point Estimate




The range of durations for each activity then allows an analyst to run a Monte Carlo simulation to establish a range of likely durations for the overall project, given the assigned logic. The simulation itself is performed by a software program designed to do these analyses (in this case, we are using @RISK for Excel, Version 5.7.1 Professional Edition, Optimistic, Pessimistic, Most Likely, by Palisade Corporation). The Monte Carlo simulation runs the CPM calculations repeatedly, over thousands of individual iterations, but within each iteration it is selecting a duration for each activity based on the parameters and the distribution curve established by the analyst. The selection of these durations in this manner is modeling the likely effects of risks identified in the risk register and represented in the analysis by the three-point estimates. The software tracks the results of the CPM calculations throughout each of these iterations, and plots the results in various types of outputs, including graphs and tables. Importantly, while the CPM schedule will only determine a single critical path through the project (and possibly some near-critical paths) these outputs identify multiple possible critical paths; with a percentage of likelihood that each of the paths will eventually drive the project completion date.

Use of Monte Carlo simulation therefore provides the project scheduler with an additional tool to gain a predictive advantage over uncertainties and risk. Therefore, such simulations are a useful supplement to the CPM scheduling technique, and as such will continue to grow in usage. This article, however, is not a primer on the performance of risk analysis. We recommend the following documents to any who seek guidance on the practical means of performing such an analysis:

- *Practical Schedule Risk Analysis, by David T. Hulett, Gower Publishing Ltd, Farnham, Surrey, England (2009)*
- "GAO Schedule Assessment Guide," U.S. Government Accountability Office, May 2012 (GAO-12-120G), Section 8 "Conducting a Schedule Risk Analysis"
- "RP 57R-09 Integrated Cost and Schedule Risk Analysis Using Monte Carlo Simulation of a CPM Model," AACE International, 2011
- "RP 64R-11 CPM Schedule Risk Modeling and Analysis: Special Considerations," AACE International, May 2, 2012

## PROBLEM

The construction industry also knows that on occasion, despite the best efforts of the parties involved, a construction project may end in a dispute that often involves disagreement over the cause and quantum of delays to project completion. When this happens, many contractors and owners rely on forensic schedule analysts to aid in the process of quantifying and apportioning responsibility for delays to the project's critical path. Because risk-adjusted schedules speak about the likelihood of a particular logical path driving the final predicted completion date, projects having such schedules are far less specific about the location of the critical path. This is probably a more realistic view of the project; however, for the forensic analyst, this creates several problems.

As will be discussed, it is clear in RP 29R-03, "Forensic Schedule Analysis"[5] that the contemporaneous understanding of criticality must be considered when identifying what was delaying a project at a given point in time. So, understanding the importance of what the project team thought at the time, the following three questions arise:

- If the project team was using a risk-adjusted schedule series, with its identification of the likelihood of various logic paths as possibly driving the longest path through the project rather than the simpler calculation of a single zero-float path through the static network, then what did the project team think was critical at the time?
- What implications does the QRA process have for identification of delays and apportionment of responsibility?
- How should analysts use the information generated in the QRA, with regards to methodology selection and execution?

5. Hoshino, K. P., RP 29R-03, "Forensic Schedule Analysis," AACE International, Morgantown, W.V.

## CONTEMPORANEOUS UNDERSTANDING OF CRITICALITY VS. THE VARIABILITY OF THE CRITICAL PATH IN RISK-ADJUSTED SCHEDULES

The seminal text, *Construction Scheduling: Preparation, Liability, and Claims,* by Jon M. Wickwire, et al., states the primacy of understanding the contemporaneous understanding of criticality within a forensic delay analysis: "**Delays are best evaluated on a chronological and cumulative basis, taking into account the status (and critical path[s]) of the project at the time of the delay in question. With this methodology and protocol, all parties on the project live with the events, actions, and 'sins' of the past**"[6] From the perspective of the project management team, properly using their prospective schedules for planning and executing the next period of work, their knowledge of what was critical to project completion (and therefore the explanation of their actions at the time) is related to the status of the critical path at the time in question. Even in the case where future events shift the final as-built critical path away from an activity that was considered critical at the time, the understanding of the project management team's actions is possible only by understanding what they thought was critical at the time. Furthermore, in "Bruner & O'Connor on Construction Law," the authors state:

*Proof of what activities were "critical" to timely completion at any point in time is no easy task because the critical path is dynamic and accommodates and adjusts to ever-changing job conditions.... The problem of locating the critical path under dynamic project conditions was articulated by the United States Claims Court in Sterling Millwrights, Inc. v. United States:*

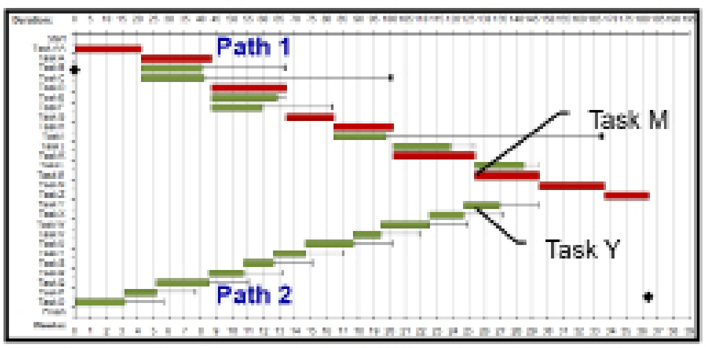
*"There very well may be more than one critical path on a project, and the critical path may change during the life of a project, i.e., activities that were not on the original critical path subsequently may be added. It is also true that delay of a critical path item may not result in a per se delay in completion because the critical path is only an educated estimate of the impact of delay; lost time in one phase may be made up in later phases. Theoretically, if an activity on the critical path is delayed by one day, and no compensating change is made by rescheduling or some form of acceleration, the entire project will be delayed by one day. Running parallel to the construction events on the critical path, there will probably be other activities, which should easily keep pace with the critical construction events. Because these events have more time available to them on the schedule than is actually necessary to complete these events, they are said to have "float time," i.e., an amount of time in excess of the minimum reasonable amount of time required to complete that item of work.* **While every construction event can eventually become "critical" by having its cushion or float time used up, this is not anticipated in the initial scheduling.**"[7]

6. Wickwire, J., Driscoll, T., Hurlbut, R., and Hillman, R., 2010, §9.05, p. 268, *Construction Scheduling: Preparation, Liability, and Claims*, 3rd edition, Aspen Publishers.
7. Bruner, P. and O'Connor, J., 2007, Section 15:120, p. 321, "Bruner & O'Connor on Construction Law", Vol. 2, West Thomson Reuters, New York.

QRA using Monte Carlo simulation is designed to address exactly this last point — it is attempting to quantify, using the initial schedule, what events are most likely to have their cushion of total float time consumed. This is the primary piece of information that the project management team would have at the outset when risk-adjusted schedules are employed, as compared to other projects, and it is this information therefore that forensic analysts should seek to understand.

To demonstrate this, consider the simplified network in Figure 2, consisting of two primary logical paths through the network. Path 1, consisting of Tasks AA through M (and proceeding from the top left of the figure and cascading downward) terminates with a finish-to-start relationship with Task N. Path 2, consisting of Tasks O through Y (and proceeding from the bottom left and rising) also terminates with a finish-to-start relationship with Task N. From Task N, the network proceeds through Task Z to the final completion milestone.

### Figure 2. Critical Path for a Simple Network, Using CPM Calculations Only




Using a simple CPM algorithm[8] the network calculates a predicted completion date of 182 days, with the critical path running through several of the Path 1 activities. The total float value for Task Y (and by extension all of Path 2) is 12 days (6.5 percent of project duration). Using the @RISK software package, which provides additional analysis tools to Microsoft Excel, the authors created triangular distributions for each of the activities in the network and ran Monte Carlo simulations.

### Figure 3. Critical Path for a Simple Network, Using CPM Calculations Only

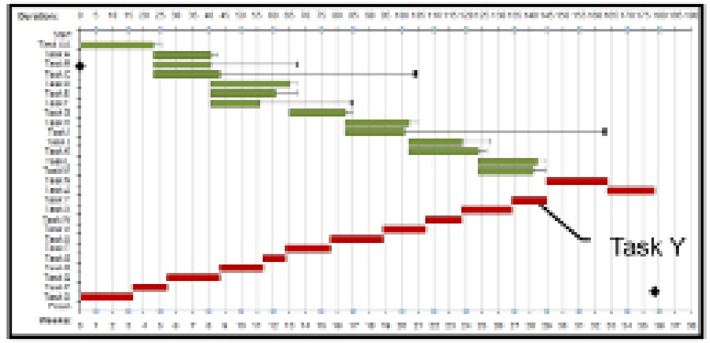
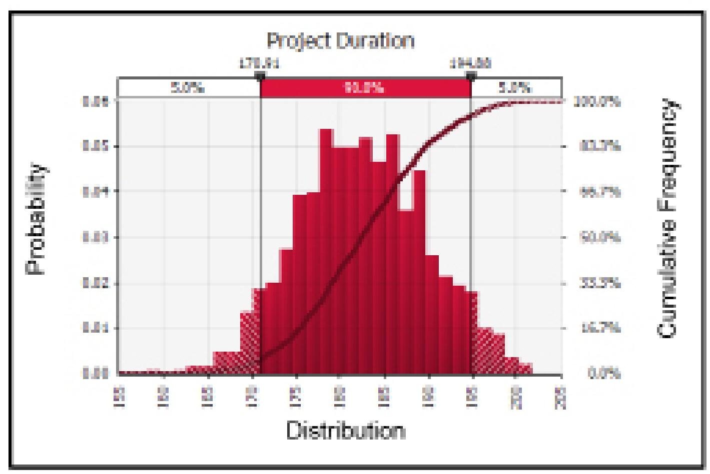



Figure 3 shows one of those iterations — in this case, one that resulted in the critical path flowing through Path 2 rather than Path 1. Task Y has zero float, of course, but Task M has four days of total float. The network's predicted duration for this particular iteration was 179 days. The simulation consisted of 5,000 such iterations, the results of which were captured and charted by the @RISK software. Note that although Figure 3 shows a single iteration that captures Path 2 in a state of criticality, the simulation ultimately shows that Path 2 is not the most likely critical path. Figure 4 shows the distribution of probable durations for the entire network (i.e., the predicted project duration).

### Figure 4. Probability Distribution of Project Duration



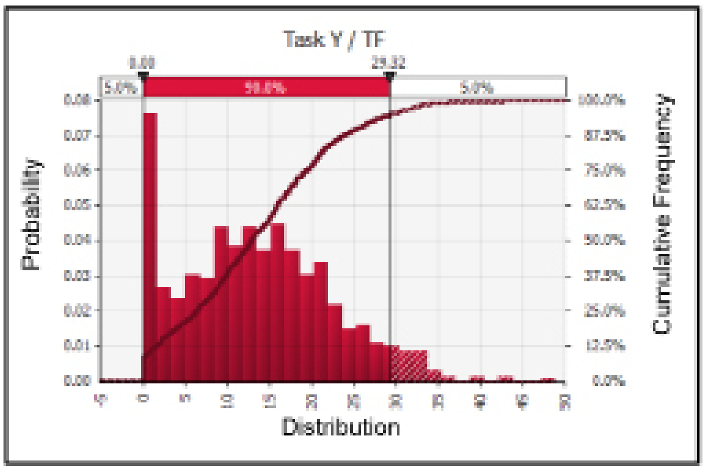

As shown in Figure 4, given the triangular distributions assigned to the individual activities in the network — which is presumed to accurately represent realistic estimates based on planned resources and possible risk-related impacts — the @RISK

8. This network was created in a Microsoft Excel spreadsheet, rather than a traditional scheduling software package, to facilitate integration of the features provided by Palisade's @ RISK software add-on features.

software calculated a 90 percent likelihood that the project will finish within 195 days. This is compared to the CPM calculated finish date of 182 days, as shown in Figure 2. This calculation shows that the likelihood of finishing in 182 days is only roughly 50 percent.

In the simulation for the simple network in Figures 2 and 3, the @RISK software was set to track the Total Float value of Task Y, selected due to its position on the secondary float path. The results were tracked, and are shown in Figure 5. The cumulative graph overlaid atop the distribution chart shows roughly a 10 percent likelihood of Path 2 driving the critical path, and a 50 percent probability that Path 2 will have total float of 15 days.

### Figure 5. Distribution of Total Float Values for Task Y




If this simplified network had been developed by the owner prior to the contractor beginning work on the project, and the 182-day duration had been written into the contract, this difference of 13 days (7 percent of the original predicted duration) could be identified to the various follow-on contractors or end-users as a contingency. This is a common use of risk analysis that likely has little, to no, effect on the forensic schedule analyst. The one theoretical exception to this is if this risk contingency is somehow used as "owned float." If the contingency exists within the contract (e.g., the contract was written for 195 days but the final completion milestone — enforceable by liquidated damages — was still at 182 days) then the contingency generated from a risk analysis becomes subject to the same disputes as any owner schedule contingency within a contract.

However, if the project team examines, discusses, and documents in its risk mitigation plan the various likely critical paths (such as, in this example, the likelihood that Path 2 will ultimately drive the critical path), this information does become relevant to the forensic schedule analyst. Note the following discussion of identification of the near-critical paths provided in RP 29R-03:

*The purpose of quantifying the near-critical path is to reduce the effort of identifying and analyzing potential concurrent delays. A rational system of identifying all activities and delays that are near-critical is the first step in objectively streamlining the process of evaluating the schedule for concurrent delays. Thus, if the analyst chooses to analyze all delays and activities on a network, the quantification of near-critical is unnecessary. But in most cases, analyzing all activities, especially on large complex schedules, is excessively time consuming and unnecessary.*

*Near-critical delays have the greatest potential of becoming concurrent delays. This is because a near-critical delay, upon consumption of relative float against the critical path delay, will become critical. Therefore the near-critical delays are the most likely suspects of concurrency, and must be analyzed for partial concurrency to the extent that the net effect of that delay may exceed such relative float.*[9]

9. Hoshino, K.P., RP 29R-03, "Forensic Schedule Analysis", p. 114, AACE International, Morgantown, W.V.

For a prospective scheduler, conducting a risk analysis through a Monte Carlo simulation is a more robust alternative to the identification of near-critical paths, in that not only does it help identify the various float paths through a network, it also provides a likelihood that a particular path will drive the critical path. Furthermore, the forensic schedule analyst must consider the following:

> *Proof of causation and duration of time impacting events requires establishing, at the relevant times, the project's critical path. Without some reasonable critical path analysis, a court cannot exclude the possibility that the contractor may have caused concurrent delay on the project.*[10]

If the QRA process is used during construction, it is providing information to the project management team about the primary, CPM-calculated critical path, as well as various near-critical paths and their likelihood of becoming the driving factor (singularly or concurrently) to predicted completion. Again, because risk-adjusted schedules better model the reality of construction projects — that the baseline CPM does not necessarily predict the final as-built critical path through the project, and that the uncertain conditions surrounding construction will likely cause the critical path to shift — it is essential to know whether those models influenced the project management team's actions during the project. If the QRA did, then the forensic analyst has an excellent source of information to explain what happened on the project and assist in the apportionment of delay. However, if a QRA was performed, but no one on the project management team paid attention to it, the information generated by the QRA may still have analytical value to the forensic analyst. Therefore, on projects where a risk-adjusted schedule series was used, the forensic analyst must seek to understand how that schedule was risk-adjusted, how well the QRA was performed, and whether or not the risk-adjusted schedule influenced the contemporaneous understanding of criticality. The analyst can then use this information (along with the other selection factors[11]) in order to choose an appropriate delay analysis methodology.

## FIRST QUESTION: HOW WAS THE SCHEDULE RISK-ADJUSTED?

There are different methods of risk-adjusting a schedule, and those methods are applied for different reasons. One of the primary divergences amongst practitioners of QRA is whether to use a detailed, fully developed construction schedule (Level 3 or greater[12]) or instead use a summarized schedule (likely Level 2 or 3[13]). RP 64R-11 "CPM Schedule Risk Modeling and Analysis: Special Considerations" describes the two approaches in this way:

> *Two basic 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. There are proponents to each approach. Risk analysis benefits from team input. Also, conducting a schedule risk analysis with a summary model is likely to be more understandable to the team while making better use of their time (and to take less time overall) than with a detailed project schedule. Summarized schedules are also useful for addressing more strategic risks and considerations. Use of a detailed project schedule may be more appropriate if it is expected to be incorporated into ongoing schedule management (i.e., a definitive diagnostic, tactical or control approach) for the project.*
>
> *While impact event risks may be evaluated easily and effectively with risk analysis performed on a summary schedule, the full impacts to activities in the detailed schedule will not be fully assessed from a duration uncertainty and logic network risk standpoint. The risk assessment of these schedule components will only be fully evaluated with use of a detailed CPM schedule.*[14]

10. Bruner, P. and O'Connor, J., 2007, Section 15:121, p. 326, Bruner & O'Connor Construction Law," Vol. 2, West Thomson Reuters, New York.
11. Hoshino, K. P., RP 29R-03, "Forensic Schedule Analysis", Chapter 5, AACE International, Morgantown, W.V.
12. Douglas, E. E., et al., 2010, RP 37R-06 ‚S"chedule Levels of Detail—As Applied in Engineering, Procurement, and Construction", p. 3, AACE International, Morgantown, W.V.
13. Ibid., p. 3-4.

Under first approach, it is not uncommon that the QRA was performed solely for the use of the owner and the contractor does not know of its existence as the work starts. Therefore, if the forensic analyst encounters a risk -djusted schedule that was created at the beginning of a project solely for the establishment of a time (or cost) contingency, and that schedule was not used by the contractor in the execution of the project, it is unlikely that such a schedule will be relevant to the selection or results of a delay methodology. That is not to say, however, that there can be no information gleaned from the performance of a QRA using such a summarized schedule.

Under the second approach, the QRA performed on detailed construction schedules is more likely to impact the performance of a forensic analysis, regardless of whether the contractor knew of risk study. It is within these schedules that the level of detail is examined that would shed light on, the contractor's means and methods, or whether prophylactic measures that had been anticipated as necessary in the risk register. This then leads to the next two questions for the forensic analyst: the quality of the analysis and the influence it had upon the contemporaneous understanding of criticality.

## SECOND QUESTION: WHAT WAS THE QUALITY OF THE RISK ADJUSTMENT?

Like the quality of scheduling in general, it is important to understand how well the underlying QRA was performed, prior to examining its impacts. There are many books and papers that discuss the best practices for QRA, some of which we have listed above. Notably, however, is the list of "Minimum Conditions of Satisfaction" for the performance of a risk analysis listed in RP 64R-11:

*To properly conduct a schedule risk analysis and provide quality results, the project team needs to have developed the following items consistent with the current stage of project development:*

- A development of scope of work, execution plan, cost estimate, and schedule that are consistent with each other.
- A quality schedule that includes activities for all project scope; has realistic durations for activities; has logic links that appropriately reflect the sequence of work and the dependences between activities; properly developed with full allowance for available, especially limited, resources and space for those resources to work; and realistic critical and near-critical paths.
- A team-approved schedule (where schedule readiness is acknowledged only after project team buy-in around such factors that include, but are not limited to, the validity of precedence logic, extent of broken logic, missing logic or open-ends, logic density or logic-to-activity ratio, and the number or type of constraints).
- A risk register with a comprehensive list of all identified project-specific risks, an understanding of the likely impact of each of those risks, and risk response actions for each risk.
- An understanding of the systemic risks, if not captured in the risk register, which may impact the project's performance, including schedule completion.

14. Caddell, C. P., et al., Rev. May 2, 2012, RP 64R-11, "CPM Schedule Risk Modeling and Analysis: Special Considerations," p. 3, AACE International, Morgantown, W.V.

*If these items do not exist at the start of a schedule risk analysis, the team will need to address those issues and either resolve them as a part of the analysis, determine how the gaps should be reflected in the analysis, or defer the analysis until the items are satisfactorily modeled in the schedule.*[15]

Obviously, this Recommended Practice was written in terms of ensuring the quality of a prospective QRA; however, the points are relevant to the evaluation of a QRA and could become the basis of a new Source Validation Protocol for inclusion in RP 29R-03 in the future. There are a number of questions that can arise from these minimum standards of quality, including but not limited to:

- What was the basis of estimation for the three-point estimates? Did they come from some identifiable source or quantifiable means? Were the line-by-line estimates performed in light of accurate estimates of quantity/resource levels/production rates?
- What was the basis of choice of a distribution curve, if not a triangular distribution?
- Were issues related to merge bias[16] taken into account?
- Were risks properly correlated?[17]

All this, of course, also assumes that the quality of the schedule series was sufficient, and that those schedules would pass the Source Validation Protocols that already exist in RP 29R-03.

Additional questions regarding the risk register may arise. The risk register formally documents problems identified at the outset of a project, identifies likely effects of that risk, and assigns a party to be responsible for mitigating the risk. This assigned party is sometimes the party who is in the most advantageous position to control and mitigate the risk, but may not be the party who would be contractually responsible for the risk's effects. So, when reviewing the risk register, the analyst must understand the process that created the risk register. Was the risk register filled out as a communal effort? Were the parties identified who were responsible for the risk, as compared to the parties who are most able to mitigate the risk? Successful pursuit of a mitigation strategy, or failure to do so, could be a reason to assign responsibility for a delay or disruption to a specific party.

Hopefully, a high-quality QRA would have provided the project management team with good information that reflected the reality of the project at the time the analysis was performed. However, performing QRA at this level of detail is not without criticism in the industry. For instance, John Hollmann has contended that a flaw with this type of QRA: "[A] possibly more serious shortcoming of the line-by-line Monte Carlo method is that it is inherently inconsistent with basic risk management principles."[18] Hollmann identifies three primary flaws with QRA as commonly practiced: that analysts are not addressing dependencies between model variables; that they are not modeling the relationship of risk drivers to cost outcomes; and they fail to differentiate between systemic and project-specific risks. If this is the case, then the quality of the QRA can never be sufficient; however, for a forensic analyst, this question is similar to asking whether or not a baseline schedule could have been developed in better ways, or if update schedules should have been tracking progress more assiduously: these are questions that are largely relevant to the project controls industry, but not necessarily to the forensic analyst. The source data is either of a sufficient quality to be included in the analysis, or it is not. It is usually irrelevant might have been a "better" way to schedule a project. However, if the schedules and the results of a risk analysis influenced the project management team's contemporaneous understanding of criticality, the analyst must account for the results of that influence.

## THIRD QUESTION: DID THE RISK-ADJUSTED SCHEDULE INFLUENCE THE CONTEMPORANEOUS UNDERSTANDING OF CRITICALITY?

The answer to this question will likely only be found through review of the project documents, most notably project meeting minutes and/or interviews with the knowledgeable project staff. If the simulation conducted on the baseline schedule was used to identify multiple likely critical paths, and those critical paths were monitored independently and were discussed in periodic progress meetings, then the project management team was using the results of the QRA to aid in project execution. Furthermore, if the update schedules were used to continue to monitor the critical path and other likely critical paths, either through repeated simulation or via some other means (perhaps by assignment of

15. Ibid., p. 3.
16. Merge bias is the impact of having two or more parallel paths of activities, each with its own variability, merge at one milestone. Ibid., p. 12.
17. Correlation establishes how a risk's impact is sampled during the simulation process, once risk dependencies have been established.Ibid., p. 11.
18. Hollman, John, 2007, RISK.03 The Monte Carlo Challenge: A Better Approach, 2007 AACE International Transactions, p. 2,AACE International, Morgantown, WV.

an activity code, or some other method) then it is evidence that the project team was acting upon information provided by the QRA, and that therefore the contemporaneous understanding of criticality was influenced by that QRA. (Note that the authors believe that the practice of running repeated simulations on each update schedule throughout a project is unlikely, due to the cost and time associated with performing QRAs. We have not encountered such use of QRA in practice, though we feel it is theoretically possible. We have, however, seen QRA used to aid in the creation of recovery schedules using simulation, the practice of which is discussed in a paper entitled "Risk Review of Recovery Schedules," by John Ciccarelli and Matthew Murch[19]) Again, how the QRA information is specifically used will depend on the interplay of all the other facts of the case, as well as the selected methodology; however, as discussed, the analyst cannot ignore the contemporaneous understanding of criticality.

## CONCLUSION: AN ADDITIONAL BASIS FOR SELECTING A METHODOLOGY

In RP 29R-03, Section 5 lists key factors for selection of a delay analysis methodology. Factor 3, "Source Data Availability and Reliability," speaks to many of the points raised regarding the presence of a QRA, and relies heavily upon the Source Validation Protocols of Section 2, "The choice of a particular forensic scheduling methodology is substantially influenced by the availability of source data that can be validated and determined reliable for the purpose of the analysis."[20] Given that there is no active Source Validation Protocol for a QRA within RP 29R-03, analysts will have to rely on the guidelines for establishing quality discussed above.

The following describes the major families of analysis techniques, with reference given to the categories in terms of the functional taxonomy, and a discussion of the effects on methodology selection for each in light of a QRA.

### AS-PLANNED VS. AS-BUILT (MIP 3.1 AND 3.2)

As-Planned vs. As-Built analyses compare a baseline schedule plan, consisting of one set of network logic, to the as-built state of the same network. In its simplest implementation, the As-Planned vs. As-Built does not consider contemporaneous understanding of criticality; however, more sophisticated implementations attempt to identify the as-built critical path via one method or another. Per RP 29R-03, "[T]he closest the analyst can come to determining the as-built critical path is to cumulatively collect from successive schedule updates the activities that reside on the critical path between the data date and the data date of the subsequent updates."[21] In cases where a risk-adjusted schedule series was created, but cannot be used in the analysis (for whatever reason), the information provided by the QRA could be invaluable to the process of identifying the as-built critical path.

### CONTEMPORANEOUS PERIOD ANALYSIS (MIP 3.3, 3.4, AND 3.5)

Contemporaneous Period Analysis techniques use contemporaneously generated update schedules to reconstruct the changing nature of the critical path, as shown in each of the successive updates, as project events such as progress and unforeseen conditions conspire to delay the project beyond the originally predicted completion date. If the baseline schedule was properly adjusted for risk via a competent risk analysis, the baseline schedule can show where the likely critical paths were throughout the project. Presumably, this information would have been used by the construction team to plan and execute the project. If the update schedules were also risk-adjusted — something the authors have not observed and think unlikely — then these schedules are also apt to provide information regarding critical path activities in the current period, as well as likely critical activities in future periods.

19. Ciccarelli, J. PE CCE PSP, and Murch M., 2008, CDR.04 Risk Review of Recovery Schedules, 2008 AACE International Transactions, AACE International, Morgantown, W.V.
20. Ibid., pp. 51-70.
21. Ibid., pp. 44-51

### IMPACTED AS-PLANNED (MIP 3.6)

This technique does not inherently rely upon the contemporaneous understanding of criticality, and therefore if this methodology is selected by an analyst, we do not see any negative consequences to the existence of a QRA.

On the other hand, it is possible that there could be positive benefits, though not necessarily in line with what has been discussed thus far. Although the MIP 3.6 is not as widely accepted (by courts and practitioners) as some of the other techniques, it is possible that the existence of a QRA could help justify the choice of this methodology. The RP indicates that the MIP 3.6 works best on projects where the critical path is well-defined at the start of the project and is not likely to shift throughout the project. If a QRA had been performed at the outset of the project, and it showed a very high likelihood that the critical path would only run through one particular logic path, and then subsequent analysis showed that the critical path did indeed follow that path, these facts may help justify the selection of this methodology. Note however that the existence of the QRA does not mitigate many of the other criticisms of this particular methodology.

### RETROSPECTIVE TIA (MIP 3.7)

Because this technique is modeling actual events retrospectively, it does not rely upon the contemporaneous understanding of criticality, and therefore if this methodology is selected by an analyst, we do not see any positive or negative consequences to the existence of a QRA.

### COLLAPSED AS-BUILT (MIP 3.8 AND 3.9)

Because this technique is creating a CPM model that is derived from as-built schedules, it does not rely upon the contemporaneous understanding of criticality, and therefore if this methodology is selected by an analyst, we do not see any positive or negative consequences to the existence of a QRA.

Of the methodologies listed in RP29R-03, the authors consider MIP 3.3/4/5, (the observational Contemporaneous Period Analysis[22]), which uses schedules created coincidentally with project execution, or MIP 3.1/2 (As-Planned vs. As-Built analysis[23]), in which the definition of the As-Built Critical Path must take into account (at least in part) the understanding of criticality that existed at the time, as most likely to benefit from the existence of a QRA. In both cases, a critical element of competent forensic schedule analysis is an understanding of the critical path that the project management team saw at the time they were actually building the project, and upon which the team built their plans for project execution in the next period.[24] In all these cases, however, we do feel that the performance of the QRA will likely have generated important documentation (perhaps in terms of intentions, means, and methods, etc.) that should be nonetheless considered by analysts.

22. This assumes that the contemporaneous understanding of criticality was established through legitimate project scheduling practices. The situation is greatly complicated when the contemporaneous schedule series contains software manipulations that create "critical paths to order." Such schedule series are of limited usefulness in post-completion schedule analysis.

23. Hoshino, K. P., RP 29R-03, "Forensic Schedule Analysis", p. 128, AACE International, Morgantown, W.V.

24. Ibid., p. 116.

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