December 6, 2023

TABLE OF CONTENTS

December 6, 2023

1. INTRODUCTION

This recommended practice (RP) of AACE International defines a structure of the practice maturity of schedule risk analysis (SRA) for an organization. This is a topic within quantitative risk analysis, a subsection in *Section 7.6.2.2 Risk Assessment* of the *Total Cost Management Framework* (TCM). [1, p. Section 7.6.2.2] Quantitative schedule risk analysis is often paired with quantitative cost risk analysis to provide a picture of the risk to two key project controls targets, time and cost that are causally related, since longer activity durations in the schedule will cause higher time-dependent resource direct and indirect cost. One goal of these analysis approaches is to quantify the desired level of contingency of time and cost for a project. Another is to identify those risks that primarily cause the need for contingency for the purpose of mitigating them to achieve better project results. SRA addresses both of these objectives. Organizations will benefit from this practical RP by knowing how mature their current practices are, and having descriptions of more mature systems, with their capabilities required, benefits/strengths, and weaknesses described to decide whether to improve their practices. This recommended practice follows the material published in *Cost Engineering* earlier. [2]

1.1. Scope

This recommended practice defines and explains the different levels of maturity of schedule risk analysis practice being used by the profession. It is intended to be a practical document that organizations can implement. “Maturity” indicates the level of detail and professional methodology included, where more detail and more capable methodology yields more and better-quality results. As an example, Level 4 is the lowest level at which the analysis distinguishes between uncertainty and identified risks as drivers of the Monte Carlo simulation (MCS). At level 5, schedule and cost risk are integrated as described in RP 57R-09, *Integrated Cost and Schedule Risk Analysis using Risk Drivers and a Monte Carlo Simulation of a CPM Schedule*. [3]

Less mature levels of SRA practice are described in part because they are widely used, but also because some of the lower-maturity SRA methods contain elements of methodology that are used in the more mature levels. For instance, Level 2 emphasizes capturing and expressing probability and impact of risk, so a mature approach at that level will produce a higher-quality risk register. At Level 3, the project schedule is introduced as the platform for analysis, so a mature system at that level and above would produce a better-quality schedule usable at that and all more mature levels of maturity.

One distinguishing feature of SRA maturity is compliance with RP 40R-08, *Contingency Estimating – General Principles*. [4] The key principles of interest here are; “starts with identifying risk drivers”, and “links risk drivers and cost/schedule outcomes”. The practice of risk analysis generally employs empiricism, experience, and competency in data collection. This RP addresses risk analysis processes in projects with an estimate maturity level at Classes 1 to 3, where project schedules will generally be developed. Reference class forecasting and parametric models are more suitable for projects that have estimate maturity levels at Class 4 or Class 5. [5]

Organizations may decide to stay at Level 2 since, done right, that level identifies all identified risks and has a way to prioritize them for focused handling. However, Level 2 does not produce an estimate of schedule contingency and does not take advantage of the project schedule to calibrate the risks’ impacts.

This RP helps organizations understand where their SRA methods fall in maturity compared to where they might wish to be. In that way, this RP provides practical information that helps the reader self-identify and understand the problems with their current method, as well as describing more competent methods, their strengths and weaknesses, and the competencies needed to reach those.

1.2. Purpose

This RP is intended to provide practical guidelines (i.e., not a standard) to describe different levels of the practice of SRA that most practitioners would consider to be good descriptions of the maturity of that practice. With this RP organizations can assess their present SRA maturity level. The RP also has strengths and weaknesses of the practice at each level and descriptions of capabilities needed to improve their maturity of practice of SRA. This RP describes and compares the maturity of analysis along increasingly mature, and hence capable, risk analysis methods. This method is mostly used by those who practice integrated cost and schedule risk analysis using Monte Carlo simulation of a CPM model. [3]

The reader is also encouraged to read recommended practice 122R-22, *Quantitative Risk Analysis Maturity Model* for a higher-level discussion of the current and projected future of risk analysis in general. [6]

1.3. Background

Project schedules provide a picture in the time dimension of the project plan. The schedule follows a work breakdown structure (WBS) that captures and organizes all of the work required to complete the project. The schedule adds substance to this plan by laying it out on a time scale determined by estimates of how long individual activities are estimated to take to complete, and which activities are logically linked together in predecessor-successor relationships. The logic-linked activities and their durations form a network reflecting how the scope is planned to be done. With this framework, a schedule leads to major milestone dates for the project, including a finish date when the entire scope of work (SOW) is planned to be completed.

The nature of a project schedule is that the activities' durations are estimated with the information available at the time of building the schedule. This information is often approximated or estimated from little knowledge so the durations are estimated with some error. In addition, there may be some bias imparted to the durations based on showing accomplishing the project by a pre-determined finish date. Finally, looking into the future through the execution of the project plan, risks can be identified and quantified to add realism to the scheduling exercise. Schedule risk analysis is conducted because organizational managers recognize that the durations assigned to the activities are uncertain and that the impact of risks may easily delay completion unless the risks are mitigated or structural change to the plan and its schedule. In the schedule, activity durations are represented by single-value numbers, but they are best understood as estimates of work to be done in the future and are not guaranteed to be accurate.

This recommended practice is applicable to projects that have or are about to create a project schedule and want to use it as the platform for a schedule or an integrated cost-schedule risk analysis. This condition does not often occur with projects that do not have a Class 3 or more mature plan. [5] The organization following the maturity levels described here generally will be applying the Monte Carlo simulation methods described in recommended practices 57R-09 [3] and 117R-21. [7] At maturity Levels 0, 1, and 2, the project's future success does not require a schedule. At maturity Level 2, the risk register is developed that attempts to identify the most important risks to the schedule and produces a risk register. The risk register identifies risks and assesses their probability and impact on the finish date without the benefit of a schedule. The risk register does identify the most important risks for handling, but it does not use the SRA tools that are available, such as the schedule and MCS, so Level 2 SRA is viewed as a low level of maturity.

Maturity Levels 4 and 5 examine how uncertainty and identified risks affect the durations of activities and, hence, when connected together by logic, the dates of milestones, including the final milestone of the project. SRA at these levels examines uncertainty of durations and probability and impact of identified risks as they affect the duration of project activities and the contingency needed to achieve a desired target of certainty.

Two definitions in RP 10S-90, *Cost Engineering Terminology* [8], are important at maturity Levels 4 and 5.

- Uncertainty is defined as:
  "Background variability, with a probability of occurrence of 100%, that may typically result from causes such as:
  (a) inherent variability of the work,
  (b) estimating error or error of prediction, and
  (c) bias in estimation or prediction." [8]

The identity and importance of risks, including identified project specific and systemic risks, that can be characterized by their probability of occurring with some impact on the activity durations, the degree of impact on the activity durations and the activities in the schedule that they affect if they occur.

- A risk is defined as: "In total cost management, an uncertain event or condition that could affect a project objective of a business goal." [8]

The main analytical approach is to use Monte Carlo simulation (MCS).

2. RECOMMENDED PRACTICE

2.1. Purpose

This recommended practice helps an organization to evaluate the way SRA is being conducted in comparison to what otherwise could be done. An early action is to describe the SAR maturity status that exists. [20] Strengths and weaknesses of each maturity level are described, and capabilities of the organization's staff and the analytical tools required to conduct more mature risk analysis are discussed, so the financial commitment of achieving a higher level of maturity can be assessed.

The needs of maturity in SRA may differ by project. In addition to choosing which maturity level is needed at a given time, the organization might have a general desire to become more adept in executing project risk analysis over time. The SRA maturity model will help management plan and budget for the next step, including hiring and training risk staff, acquiring new software tools, and embedding "supports schedule risk analysis" into the project team's annual goals for success.

Not every organization needs to achieve Level 5, advanced integrated cost-schedule risk analysis. The RP does not make that decision. Clearly, Level 5 has more capabilities and analytical strength than other levels, but describing Level 5 should not be taken to imply an organization needs to achieve it or to plan to achieve it over time. The benefits of Level 5 SRA on large, long, and complex projects may be self-evident. Other projects may not warrant or show much benefit of a Level 5 treatment.

It is not clear that progression along the maturity ladder needs to be step-by-step over a number of years. An early version of this approach was introduced in 2008. [9] The organization decided to jump directly into Level 5 for offshore gas production platforms (summarized in the case study below), skipping Levels 3 and 4.

2.2. The Maturity Matrix Structure

Figure 1 shows the six maturity levels of SRA risk analysis.

December 6, 2023

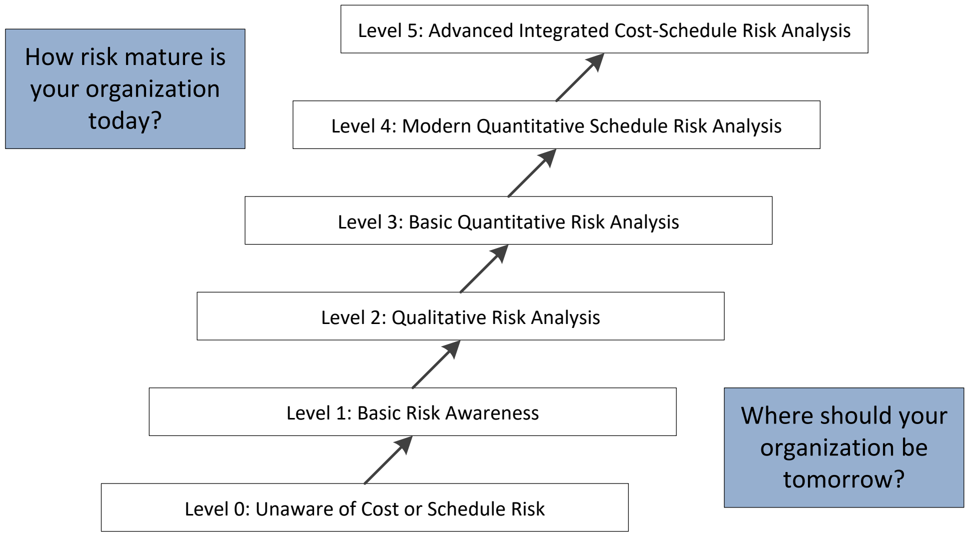


Figure 1: The SRA Maturity Model [2]

This diagram may be understood to distinguish the levels of maturity in SRA:

- Level 0 is named specifically for the lack of any awareness of risk affecting the results of the project.
- Level 1 indicates that the organization is aware of risk but is not organized to analyze it.
- Level 2 is the qualitative risk analysis that results in the risk register and the typical risk heat map that allows sorting risks into high, moderate and low importance by their apparent probability of occurring with some impact and the size of that impact on the finish date of the project.
- Level 3 introduces quantitative methods using the schedule as the analysis platform and applying MCS methods. Level 3 relies on placing range estimates that represent the variability of each activity's scheduled duration directly on the activities. It does not separately identify the impacts of uncertainty from those of identified risks. It does not reflect that some risks affect multiple activities and therefore create a correlation between those activities' duration during simulation. This level of maturity produces an estimate of the schedule contingency needed to provide a desired target of confidence. Level 3 does not satisfy the first principles of AACE risk analysis. [4]
- Level 4 is a fully functional SRA that is driven by uncertainty and identified risks placed on the activities they affect if they occur in an iteration of the MCS. The results include identifying a schedule contingency for achieving the desired level of confidence. Risk prioritization for mitigation occurs.
- Level 5 adds costs to the SRA schedule for an integrated cost-schedule risk analysis (ICSRA). One fact that this step makes clear is that schedule risk drives the cost of time-dependent direct and indirect resources. Consequently, any cost risk analysis that cannot deal with schedule risk simultaneously is in danger of underestimating the risk to cost and the cost contingency needed.

The steps of the maturity model ladder are described by their features, strengths and weaknesses, and capabilities needed in helping the organization deal with risks to schedule.

2.3. Level 0 Unaware of Cost or Schedule Risk

This level of dealing with risk does not mean that the organization is not managing the project, but that management leaves out any consideration of risk. This approach may succeed on a repetitive type of project such as constructing 100 houses of the same design at the same location.

- Project teams rely entirely on the accuracy of milestone and project finish dates that are produced by computing project scheduling software. They defend those dates to management.
- Individuals do not think or plan for any event that is a threat to achieving the finish date produced by the schedule. Risks that occur are surprises and are probably not handled well.
- When faced with contrary results from other projects risk-unaware individuals will claim “this project is different” or “it won’t happen on my project.”

2.3.1. Weaknesses at Level 0

The fact that some projects at Level 0 of the SRA succeed is not because of effective risk analysis but luck may shine on the project by chance. The organization may attempt to rely on and support the schedule software’s result long after it becomes obvious the project is not performing to those dates. Risks are not addressed, so they may happen when they could have been avoided, or their impact on the schedule may be larger than necessary. Surprises, excuses, and “firefighting” responses after the risk occurs are common at this level of maturity. Success in schedule completion is essentially a random event.

2.4. Level 1: Basic Risk Awareness

This maturity level indicates an awareness of project risk as something to consider when reviewing or reporting to management, but there is no structured methodology to help examine risk. It represents opening people’s eyes to the benefits of probabilistic thinking about projects without giving them the tools to conduct organized risk analysis or recognizing that there are processes and tools to help them. Risks are viewed as unpredictable random events because there is no framework to organize them.

2.4.1. Distinguishing Features at Level 1

This level is characterized by an awareness of the importance of risk to executing a successful project, but the lack of a systematic way to think about risks means this awareness does not lead to risk mitigation or an SRA. Risks are discussed frequently, and decisions may take account of the risk posed by alternatives, but the influence of risk is not analyzed or calibrated. Risk analysis is not embraced by the culture or required before decisions are made. Many organizations perform informal risk management in this way without benefiting from the use of systematic methodologies generally available. The success or failure to address risk depends on the intelligence and awareness level of organizational management. The organization does not learn how to analyze risks from one incident to another.

Individuals at this maturity level show awareness that activity durations are uncertain, and they exhibit a willingness to examine assumptions that underlie the schedule. These attitudes imply that the organization is questioning the deterministic scheduling results without having the tools or systems to examine the risks and uncertainty directly.

At this basic level of risk maturity is awareness that *the* schedule is only correct when: (1) the durations are known with certainty and (2) things go according to plan. The organization realizes that *“go according to plan”* occurs infrequently. They are aware that achieving the deterministic plan requires recognizing and dealing with risks to the activity durations. The risk-aware organization may realize that it does not know the finish date just by looking at the results of even the most sophisticated scheduling software tool, but it has no organized structure, data or tools to help it proceed beyond this awareness. It also has no tools to prioritize one risk over another, so its risk management is inefficient. Schedule contingency is often applied by a “standard” multiplier that may be accepted by industry, such a adding 15% of the original duration, *2.4.2. Capabilities Required at Level 1*

The main tools at Level 1 are awareness at the top of the organization that project schedule cannot be assured. Project team meetings are conducted to discuss the project's prospects of finishing on time. These discussions are conducted without an organized way of looking at the risks, so they are episodic and not well-structured. The meetings often go over old ground and come to no conclusion, repeating the same arguments from positions held earlier based upon inconsistent frames of reference. The discussions are not organized for success because the sources, parameters, and ways of analyzing the risks are not known. Learning from experience is not practice. There are no historical databases that can shed light on risk to the next project's schedule.

The ability to think and talk freely and candidly about risks that could affect the schedule durations and the view of whether the schedule is realistic may exist. But since it is not a recognized specialty, the discussions may be inconclusive and scattered.

Individuals could compare the project in light of the results of actual, recent, and similar projects to consider what to expect. Data needed for this comparison is ad hoc but not systematically maintained at Level 1. This approach has been called the "outside view" following Daniel Kahneman. [10] [11] [12]

2.4.3. Benefits / Strengths at Level 1

If a project schedule has been developed, the risk team may have a feeling that the estimates of activity durations have been biased, usually to produce an earlier finish date by forces such as management mandates, customer or competitive pressure, etc. If scheduling bias is discovered, the schedule may be re-baselined. At a higher level of maturity, this estimating bias may be corrected in the application of uncertainty before simulation, but that solution is not available at Level 1.

2.4.4. Weaknesses at Level 1

To achieve this level of SRA maturity, individuals need to adopt a way of thinking probabilistically about finish dates that may differ from the way they were taught to use the scheduling software. This awareness of risks affecting schedule milestone dates requires practice, but at Level 1, there is no one person or group designated to analyze project risk. Reinforcing the nascent risk attitude will be harder for management because every project needs to start from a beginning.

Since the risks are not addressed in an organized way, some important risks will be overlooked with noticeable results. Even with the risks that have been identified, they may not be the root causes of schedule variability because the structure of a risk statement and a risk breakdown structure (RBS) does not exist at Level 1. This level lacks an organized way of calculating how individual risks can be prioritized by their probability and possible impact on the finish date. While a risk may seem to be important, it may not be on the critical path that could delay the project. At Level 1, there is no mechanism to prioritize the risks to determine which to address first. At level 1, addressing risks is *ad hoc* and, therefore, may be inefficient.

2.5. Level 2: Qualitative Risk Analysis

This level of maturity represents examining project risk to schedule (and to other objectives such as cost, quality and scope) using qualitative methods that lead to developing a project risk register. [11] [12]

2.5.1. Distinguishing Features at Level 2

Qualitative risk analysis is often viewed as a low-cost and easily-understood method of addressing project risks. Level 2 includes organized ways to gather information on the identity of risks to the schedule. The outputs at Level 2 include a risk register that sorts the risks by their probability and impact into high, moderate and low (red, yellow and green) categories. This classification can lead to risk mitigation actions focusing on the highest priority risks first, a significant benefit to the organization. Maturity at level 2 may be sufficient for some projects or some organizations.

Risk analysis at Level 2 embodies an organized and consistent methodology for naming risks and for focusing on their two primary characteristics; (1) probability of occurring with some impact on the project schedule, and (2) impact on the project finish date if it happens. It relies on a widely recognized definition of a risk as: "…an uncertain event or condition that could affect a project objective or business goal." Risks can be classified as project-specific and systemic. [8]

2.5.2. Capabilities Required at Level 2

Included in this group of capabilities to be reinforced are:

- Ability to identify and name project risks by the sentence structure of "cause (a fact) leads to something that may happen (the risk) that has consequences (the impact)." This structure helps the organization focus on the uncertainty that may happen rather than confuse it with the cause, that is, a fact or the effect that is the result or symptom of the risk projected on the project.
- Ability to represent a risk's probability as the concept that a risk will happen to the extent of affecting the project finish date to a greater or lesser degree; in other words, "uncertainty that matters."
- Ability to estimate within a range the effects of a risk occurring on the project finish date (and other objective such as cost, quality and scope) based on criteria that are tailored to the project.
- Ability to participate in or lead a risk workshop to help identify risks and estimate the probability and impact parameters.
- A related ability is to gather data on risks that are difficult to talk about in a workshop because their consequence could lead to the project's failure. Other such risks would be those that contradict official statements to the customers, funding agencies, the public, or joint-venture partners. Success in gaining the project team's candid opinions might require conducting confidential interviews instead of workshops.
- Ability to create and maintain a project risk register. Done well, the risk register helps management identify and handle individual risks effectively.
- There are some software tools that support risk register development, but standard spreadsheet tools are often used effectively.

A capability to help gather data on the risk to a project is the risk breakdown structure, a generalized example [11] [12] to be tailored to the specific project before being used in risk identification. A standard RBS is shown in Figure 2. The RBS should help the organization realize that the causes of risks arise from many directions and encourage the project team members to think outside of their "stove pipes" or their work assignment areas. Risk identification should address technical risk but also risk arising from external, organizational and even project management sources.

The RBS is to be tailored to specific projects. For instance, an oil drilling project might emphasize sub-surface conditions while a pharmaceutical plant construction project might require more details on regulatory requirements or regulations in other countries. These areas can be added to the typical RBS, which is used as a starting point.

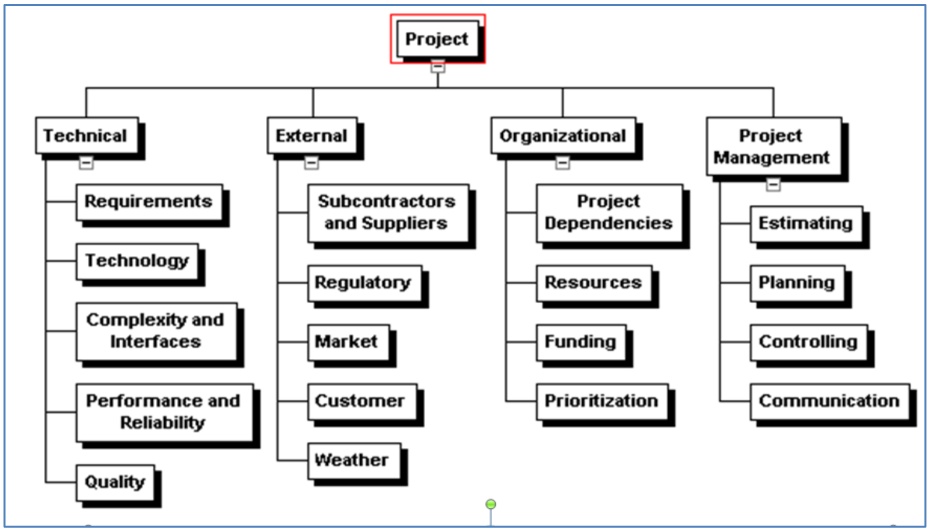


Figure 2: Typical Risk Breakdown Structure, to be Tailored to the Project [2]

The impact of risks on the total project objective selected must be defined for the qualitative risk exercise by project management. This provides the assessment of risks' impact to be applied consistently so that risks can be compared. An example of the definitions of impact at five levels from very low to very high and for schedule and cost different objectives is shown in Figure 3. These definitions need to be scaled appropriately for the project at hand with the participation of the project manager who will be using the results to influence decisions.

Definition of Probability and Impact Scales for Threats at Level 2 (example values to be tailored)					
Objective	**Very Low**	**Low**	**Moderate**	**High**	**Very High**
Probability of Occurring with Some Impact	< 5%	6% - 20%	21% - 50%	51% - 80%	> 80%
Impact on Finish Date (Schedule)	Insignificant Schedule Increase	< 2 weeks	2 to 5 weeks	5 - 10 weeks	> 10 Weeks
Impact on Total Project Cost	Insignificant Cost Increase	< $ 0.5 million	$0.5 to $5 million	$5 to 20 million	> $ 20 million

Figure 3: Example Definitions for Probability and Impact of Schedule and Cost that are used at Level 2

After approving the impact scales, the project manager needs to identify which combinations of probability and impact warrant attention. Risks are classified as "red," yellow," or "green" for the risks based on their probability and impact, as shown in Figure 4. The zones of the probability and impact matrix are designated as very low, low, moderate high or very high risk according to the decision of the project manager about which combination of probability and impact warrant the most, moderate, and the least attention.

A simple probability and impact (PxI) matrix for both threat and opportunity is shown in Figure 4. The combinations of probability and impact that show as red in the red-yellow-green scheme are viewed as the most important and serve as the *arrow of attention*, a phrase coined by David Hillson. [13]

Qualitative Risk Rating by Probability and Impact for Schedule at Level 2										
Probability Ranking	**Threats**					**Opportunities**				
Very High										
High										
Moderate										
Low										
Very Low										
	Very Low	Low	Moderate	High	Very High	Very High	High	Moderate	Low	Very Low
	Threat Impact Ranking					**Opportunity Impact Ranking**				

Figure 4: Classifying Risks by their Probability and Impact at Level 2

2.5.3. Benefits / Strengths at Level 2

Handling schedule risk at maturity Level 2 may be effective enough for many projects that do not need more detail or an estimate of schedule contingency. The smaller, shorter-duration, lower-cost projects might be handled with the development and maintenance of a risk register.

The risk register can also record the mitigation of risks and their post-mitigation assessed probability and impact scores. Attention needs to be paid to the quality of the risk mitigations that are assumed to improve scores and hence may be counted on to move risks from red to yellow or yellow to green. Mitigation actions are new actions, not just a continuation of existing processes. The mitigations also need to be agreed to by the participants before conferring to improve the risk scores.

More elaborate risk register approaches will display the timing of the mitigation and a waterfall of planned improvement in the outlook associated with that risk.

2.5.4. Weaknesses at Level 2

There are limitations to the qualitative method of handling project risks at Level 2:

- It does not provide an estimate of the probability that the scheduled finish date will be overrun or the amount of contingency that should be added to the schedule to provide a desired level of certainty. This is because (a) each risk is assessed independently of the others, and (b) the risks are not analyzed within the framework of the project schedule.
- Risks are often identified and calibrated in risk workshops. Risk workshops often omit or avoid some of the most important risks that are known but not talked about, called the "unknown knowns." Hence, some of the main dangers lie in the "unknown knowns"—the disavowed beliefs, suppositions and … practices we pretend not to know about, even though they form the background of our public values. [14]
- Some people put numbers 1-to-5 to the probability and impact ranges and then treat these numbers as if they were cardinal values to be multiplied together to determine the red-yellow-green shading of the cells in the PxI matrix. Handling these probability or impact levels as cardinal numbers that can be added, multiplied, or otherwise numerically compared is a fallacy. In fact, the impact ranges are ordinal so that

high impact (4) is higher than low impact (2), but not necessarily twice as negative to the organization as low impact. These numbers cannot be added, multiplied, divided, or otherwise mathematically manipulated.

2.6. Level 3: Basic Quantitative Schedule Risk Analysis Maturity

2.6.1. Distinguishing Features at Level 3

Maturity Level 3 recognizes that project schedule success is affected by the uncertainty of the estimated durations of the activities in the project schedule and can be analyzed statistically by applying Monte Carlo simulation (MCS) with specialized but available software to the critical path method (CPM) schedule. An earlier method of applying uncertainty to activity durations was originally described in RP 41R-08, *Risk Analysis and Contingency Determination Using Range Estimating*," originally published in October 2008. That RP was retired in February 2022 by a revised 41R-08 entitled *Understanding Estimate Ranging*.[1] [15] Range estimating is now limited to representing uncertainty caused by estimating error and bias and by the inherent variability of the work, not sources from identified risks. Many organizations are still practicing SRA at Level 3, and risk ranging is featured in books, articles, guidelines, and courses.

At maturity Level 3, possible fluctuations of activity durations from planned are represented by applying probability distributions directly to the activity durations individually. Typically, these distributions are described with a 3-point estimate of possible days representing minimum (low, optimistic), most likely, and maximum (high, pessimistic) days. [16] The 3-point impact is assessed for the activity durations, often using workshops or interviews of the activity leaders. The 3-point estimate represents the influence of all identified project-specific and systemic risks plus uncertainty that would cause the activities' durations to fluctuate. Probability distributions of added days, such as those shown in Figure 5, are used depending on the activity.

[1] Range estimating method, embodied in 41R-08, no longer serves the needs of its members. This decision was made because range estimating does not follow the first principles established in 40R-08 *Contingency Estimating – General Principles* [1] that the analysis "starts with identifying risk drivers" and "links risk drivers and cost/schedule outcomes." A revision of 41R-08, published in February 2022, explains the reasonings and describes areas representing background uncertainty where range estimating is still an approved practice.

December 6, 2023

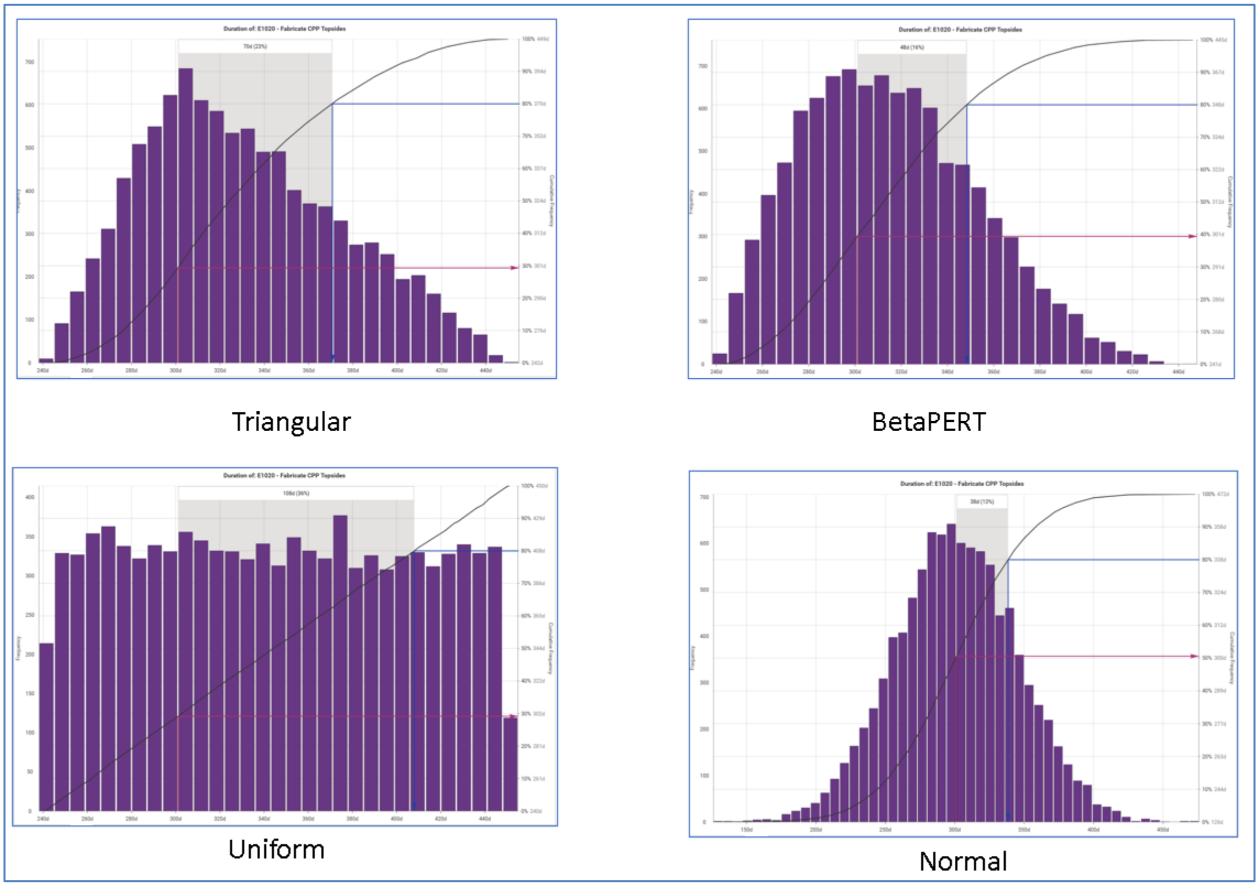


Figure 5: Probability Distributions Typically Applied to Activity Durations at Level 3

The schedule model is computed or "iterated" many times using specialized Monte Carlo software that imports a critical path method (CPM) schedule from scheduling software. Each iteration that the schedule produces uses durations selected randomly from the distributions assigned to the variable activities and produces a finish date for the project as a probability distribution.

The results are shown by a histogram and cumulative distribution of possible finish dates consistent with the assumptions applied as shown in Figure 6. The figure shows a project histogram by vertical bars indicating the number of times in simulation the finish date occurred in the week indicated. It also shows the cumulative distribution, that is, the accumulation of dates from moving from left to right, summing the number of "hits" in the vertical bars. The cumulative distribution shows the probability that the project finishes on a chosen date or earlier. In Figure 6, assuming the schedule and risks attached, there is an 80 percent chance that this project will finish on or before June 17, 2025. Figure 6 also shows that the scheduled finish for this project is October 27, 2023, and that date has only a 5% likelihood of being achieved.

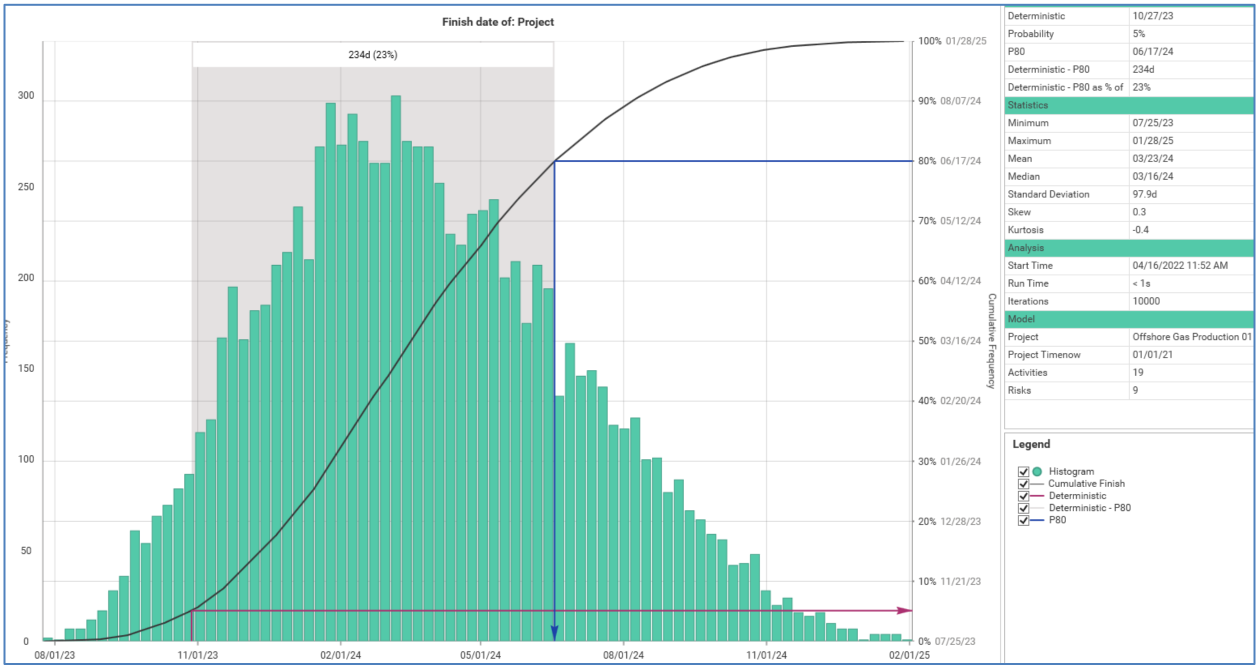


Figure 6: Results of a Simulation at Level 3 Showing the Possible Finish Dates of a Project

2.6.2. Capabilities Required at Level 3

Skills required at this level of maturity include an ability to understand and assess the quality of the project schedule used in the analysis. Many mature SRA practitioners have become competent in project scheduling, as well as learning the scheduling software available, of necessity since many schedules do not comply with best practices. This means becoming familiar with scheduling best practices. [17]

Practitioners at Level 3 also collect activity duration ranges from activity managers and create probability distributions for each activity that has uncertain durations. Activity managers provide 3-point estimates (or 2-point if representing a uniform distribution) from their own experience on past projects. Level 3 is the point at which there is a general understanding of stochastic representations of activity durations that are represented by single-point deterministic values in the schedule.

At Level 3, the analyst needs to understand and use the specialized Monte Carlo simulation software that can use the uncertain distributions to calculate the schedule thousands of times by selecting durations at random from the distributions on activity durations. This software can be used at Levels 4 and 5 as well.

2.6.3. Benefits/Strengths at Level 3

While AACE International no longer recognizes range estimating as a recommended practice, range estimating's continuing use recognizes that there are some benefits to this approach compared to Level 2. Applying probability distributions to the activity durations directly has the benefit that it facilitates Monte Carlo simulations using the schedule's logic. It can compute a probability distribution of finish dates and identify a date that provides management's desired protection from further schedule overrun. Other outputs include the risk criticality of activities by the percentage of iterations an activity appeared on the critical path. Sensitivity analysis is usually calculated for each activity by measuring its correlation during simulation.

Level 3 uses the project schedule and Monte Carlo simulation software for the calibration of the impact of duration uncertainty on the project completion date. This method recognizes the important contribution to schedule risk of the “merge bias” that may occur when an activity or milestone has two or more predecessors, and the schedule impact of risk exceeds the free float of at least two of the merging paths.

2.6.4. Weaknesses at Level 3

Notice that the risk register is not listed in the description of maturity Level 3. That is because risk analysis at maturity Level 3 does not use risks as drivers of the simulation, opting to use probability distributions applied directly to the activities to represent both uncertainty and all risks. As stated above, this approach does not comply with best practices in the risk analysis profession or with the first principles of AACE. [4]

At Level 3, the ranges applied directly to activity durations contain the influence of all sources of uncertainty and identifiable risks for the activities affected.

- These probability distributions, placed directly on the activity durations, do not incorporate the notion that the risks have a probability of occurring in addition to an impact on durations.
- While the analyst responsible for any activity may list one or more risks as being considered when specifying the probability distribution for that activity, the distribution consolidates all such risks, as well as uncertainty, as applied to that activity’s duration. Since some activities are impacted by multiple risks, the impact of an individual risk cannot be distinguished because they are all combined into one distribution.
- Risks can impact several or many activities in the project schedule. Placing impact distributions on each activity individually masks the fact that some risks affect many activities, so the method cannot represent the total impact of those risks.
- The risks cannot be prioritized since they are not individually identifiable and used as drivers of the simulation.
- Risk prioritization using tornado charts is based on activities rather than risks. Hence, at Level 3, activities can be prioritized, but the risks themselves cannot be prioritized for mitigation.
- Sometimes, the analyst specifies a correlation between activity durations. However, individuals are particularly ill-equipped to specify these correlations directly, having little information or experience on which to base the size of these coefficients. Yet, handling the effect of correlation can impact important results, such as the projected finish date and the probability of overrunning the schedule. At Level 3, the correlation used is largely a guess.

2.7. Level 4: Modern Quantitative Schedule Risk Analysis Maturity

2.7.1. Distinguishing Features at Level 4

The main capabilities available at SRA Maturity Level 4 are described in RP 57R-09, *Integrated Cost and Schedule Risk Analysis using Risk Drivers and Monte Carlo Simulation of a CPM Schedule*. [3] [12] [20] The benefits are gained because the Monte Carlo simulation is driven by; (1) identified <u>risks</u> specified by their probability and impact and assigned to all activities they affect and, separately, by (2) <u>uncertainty</u> that is 100% likely, can be assigned to all activities or as reference ranges by groupings of activities.

Identified risks include both project-specific and systemic risks. Some systemic risks are: [18] [19]

- Completeness of scope definition
- Quality of project control
- Quality of project scheduling

December 6, 2023

- Quality of team development
- Extent of new technology in the project
- Extent of complexity

In addition, it is always a good idea to review the results of the risk analyses described in this maturity presentation against relevant and recent historical data. This analysis of historical data brings the perspective of an "outside view". [20]

The case study illustrating Level 4 capabilities uses a summary schedule of building an offshore gas production platform. It is shown in Figure 7.

Activity ID	Description	Duration	Early Start	Early Finish	Cost
Gas Platform-4	Offshore Gas Production Platform	1030	01/01/23	10/26/25	1,721,200
Gas Platform-4.1	Milestones and Hammocks	1030	01/01/23	10/26/25	240,000
A1000	Project Start	0	01/01/23	01/01/23	0
A1010	Final Investment Decision (FID)	0	12/16/23	12/16/23	0
A1020	First Gas	0	10/26/25	10/26/25	0
A1030	Project Management (Hammock)	1030	01/01/23	10/26/25	240,000
Gas Platform-4.2	Decision Making	100	09/08/23	12/16/23	48,000
B1000	Approval Process	100	09/08/23	12/16/23	48,000
Gas Platform-4.3	Engineering	550	01/01/23	07/03/24	120,000
C1000	FEED	250	01/01/23	09/07/23	40,000
C1010	Detailed Engineering	300	09/08/23	07/03/24	80,000
Gas Platform-4.4	Procurement	500	12/17/23	04/29/25	450,000
D1000	Procurement of LLE	500	12/17/23	04/29/25	250,000
D1010	Procurement of Other Equipment	250	07/04/24	03/10/25	200,000
Gas Platform-4.5	Fabrication	300	07/04/24	04/29/25	656,000
E1000	Fabricate Drilling Topsides	250	08/23/24	04/29/25	200,000
E1010	Fabricate Drilling Jacket	200	08/23/24	03/10/25	120,000
E1020	Fabricate CPP Topsides	300	07/04/24	04/29/25	240,000
E1030	Fabricate CPP Jacket	250	07/04/24	03/10/25	96,000
Gas Platform-4.6	Drilling	140	05/25/25	10/11/25	96,000
F1000	Drilling for First Gas Only	140	05/25/25	10/11/25	96,000
Gas Platform-4.7	Installation	110	03/11/25	06/28/25	47,200
G1000	Install Drilling Platform Jacket	20	03/11/25	03/30/25	8,000
G1010	Install Drilling Topsides	25	04/30/25	05/24/25	13,600
G1020	Install CPP Jacket	20	03/11/25	03/30/25	9,600
G1030	Install CPP Topsides	60	04/30/25	06/28/25	16,000
Gas Platform-4.8	HUC	120	06/29/25	10/26/25	64,000
H1000	Hook UP and Commissioning for First Gas	120	06/29/25	10/26/25	64,000

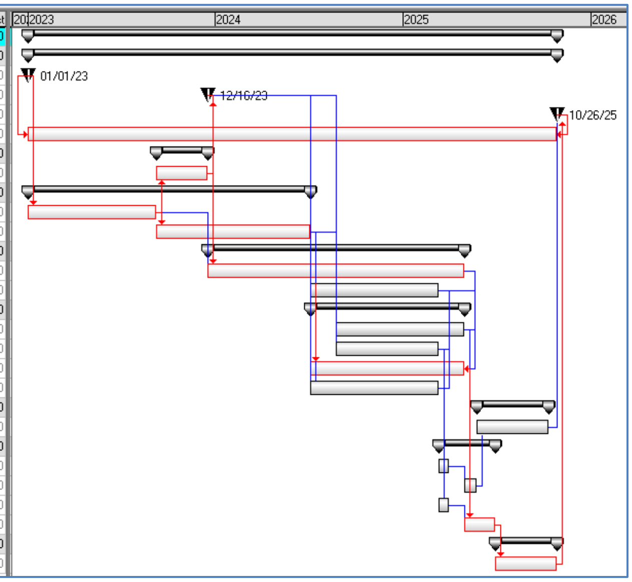


Figure 7: Summary Schedule of the Construction of an Offshore Gas Production Platform

Uncertainty and identified risks are separated at Level 4.

- Uncertainty is caused by estimating error, estimating bias and inherent variability of the work. [8] The first two of these causes have already happened and are embedded in the durations of the schedule, so uncertainty must correct for them. Inherent variability of the work is a condition but caused by many factors that are not individually identified and, therefore, cannot be mitigated.
- Identified risks include both known project-specific risks and systemic risks. [8] in Figure 8 Risk-1 is schedule uncertainty, Risks 103 – 109 are project specific risks and Risk 110 is representative of a systemic risk.

Id	Description	Risk Type	Probability	Color
Risk-1	Schedule Uncertainty	Standard	100%	
Risk-103	Organiation may not make timely decisions	Standard	80%	
Risk-104	Engineering may be more or less difficult than planned	Standard	65%	
Risk-105	Fabrication productivity may not be as high as planned	Standard	70%	
Risk-106	Installation may experience coordination issues	Standard	65%	
Risk-107	Equipment suppliers may be busy	Standard	40%	
Risk-108	Subsea structures may not be well documented	Standard	35%	
Risk-109	HUC may reveal design and fabrication problems	Standard	80%	
Risk-110	The project team may not be adequate for the complex tasks	Standard	20%	

Figure 8: Schedule Uncertainty (100%) and Eight Identified Risks

The impacts of the identified risks can be represented by “Risk-105, Fabrication productivity may not be as high as planned,” as shown using a triangular distribution Figure 9.

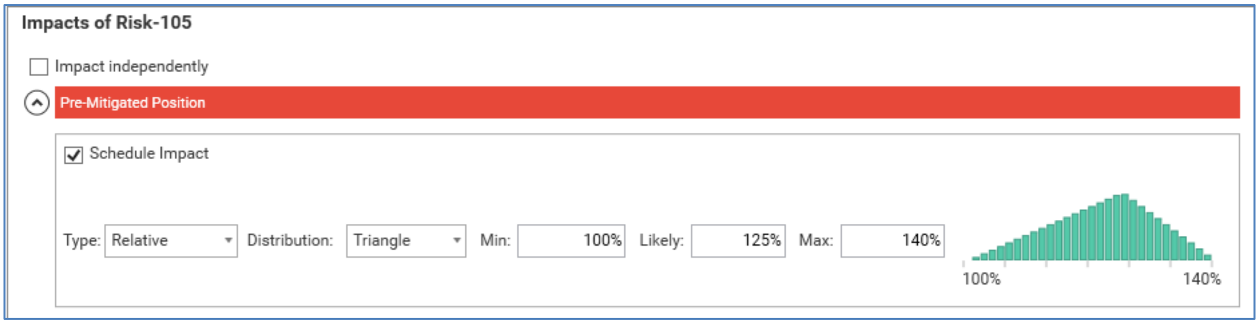
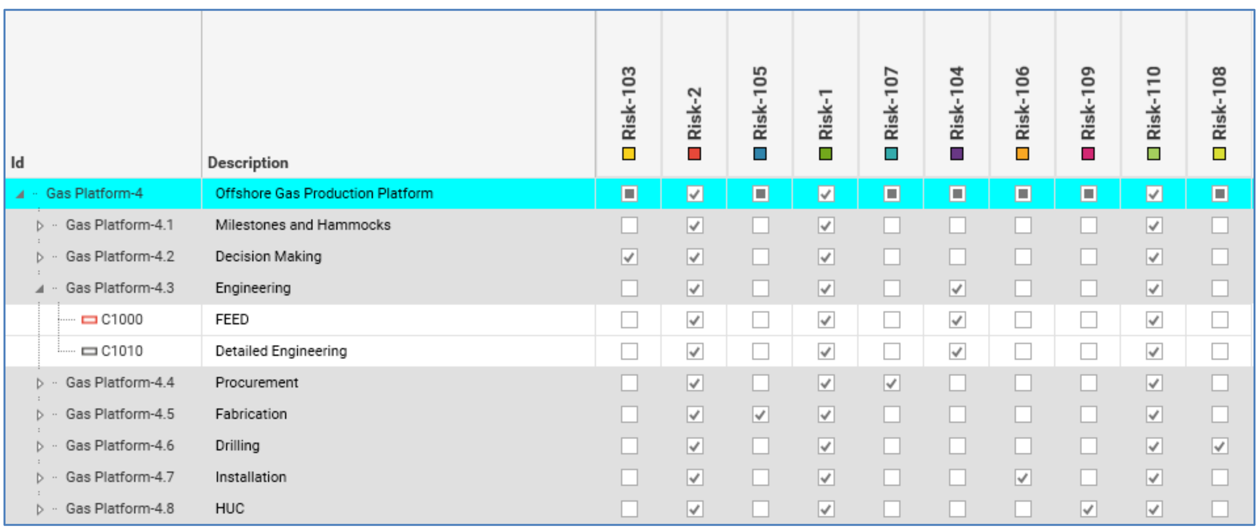


Figure 9: Example of Impact Probability Distribution using a Triangular distribution with 3-point Estimates

The use of identified risks allows those risks to be assigned to many activities if applicable for the project. This also implies that some, perhaps many, activities are affected by more than one risk. These characteristics more closely model reality, particularly in complex projects and produce benefits discussed below.

When combined with the logical structure of the schedule, with parallel paths, merge points, and critical paths, placing the influence of risks onto the right detailed tasks gives the result accuracy and transparency.

The risks are assigned to the activities they affect. Some, such as the systemic risks, are assigned to many activities, while others are assigned to specific types of activity. Figure 10 illustrates assigning risks to the case study schedule. Notice that Risks 1 and 2 are schedule uncertainty and cost uncertainty, expressed for convenience as risk drivers. Also, Risk 110 is the systemic risk that the project team may not be adequate for the complex task and was deemed to affect any and all project components.



Id	Description	Risk-103	Risk-2	Risk-105	Risk-1	Risk-107	Risk-104	Risk-106	Risk-109	Risk-110	Risk-108
Gas Platform-4	Offshore Gas Production Platform	■	✓	■	✓	■	■	■	■	✓	■
Gas Platform-4.1	Milestones and Hammocks	☐	✓	☐	✓	☐	☐	☐	☐	✓	☐
Gas Platform-4.2	Decision Making	✓	✓	☐	✓	☐	☐	☐	☐	✓	☐
Gas Platform-4.3	Engineering	☐	✓	☐	✓	☐	✓	☐	☐	✓	☐
C1000	FEED	☐	✓	☐	✓	☐	✓	☐	☐	✓	☐
C1010	Detailed Engineering	☐	✓	☐	✓	☐	✓	☐	☐	✓	☐
Gas Platform-4.4	Procurement	☐	✓	☐	✓	✓	☐	☐	☐	✓	☐
Gas Platform-4.5	Fabrication	☐	✓	✓	✓	☐	☐	☐	☐	✓	☐
Gas Platform-4.6	Drilling	☐	✓	☐	✓	☐	☐	☐	☐	✓	✓
Gas Platform-4.7	Installation	☐	✓	☐	✓	☐	☐	✓	☐	✓	☐
Gas Platform-4.8	HUC	☐	✓	☐	✓	☐	☐	☐	✓	✓	☐

Figure 10: Assigning Risks to Specific Activities

2.7.2. Capabilities Required at Level 4

December 6, 2023

The risks have to be identified to be calibrated and to be modeled in the Monte Carlo simulation at Level 4. Besides calibrating risks, risk analysts will calibrate expert judgments to reduce bias and improve the realism of inputs related to schedule probability of occurring (with some impact) and impact on the activities affected if it occurs. Risk identification is required and discussed at Level 2 where the risk register is first developed. Experience finds that the risk register is usually incomplete and new risks are identified during the confidential interviews, also described at Level 2. Often there are risks that cannot be discussed in risk workshops because of cultural or hierarchical pressures, so the risk analyst will need to conduct probing confidential interviews to unearth the important risks that need to be added to the risk list used for the quantitative SRA at Levels 4 and 5.

.

The risk analyst will often decide to develop a summary schedule for the risk analysis at Level 4 if that has not been done in Level 3. Common Class 3 to Class 1 contractor-developed schedules are not always compliant with scheduling best practices, and, in any case, they contain more detail than is needed in a strategic risk analysis. A summary schedule needs to include a representation of all the work in the project and should represent in summary form the key critical paths and appropriate total float values as the detailed schedule. Notice that the critical path in the baseline schedule may not be the path most likely to delay the project, as revealed by the simulation.

2.7.3. Benefits / Strengths at Level 4

Using the project-specific risks to drive the simulation allows the analysis model to follow reality more closely than at Level 3. In particular, one method used at this level of maturity, where the identifiable risks are modeled as risk drivers affecting more than one activity, causes activity durations to become correlated during simulation. Allowing a risk driver to affect two – or, in some instances, many – activities produces a correlation between activity durations during simulation, thus removing the need for the analyst to estimate correlation coefficients. Modeling correlations in this way produces a correlation coefficient matrix that is nonnegative definite, i.e., has no negative eigenvalues.[4] Generating a correlation coefficient between activity durations is shown in Figure 11 below:

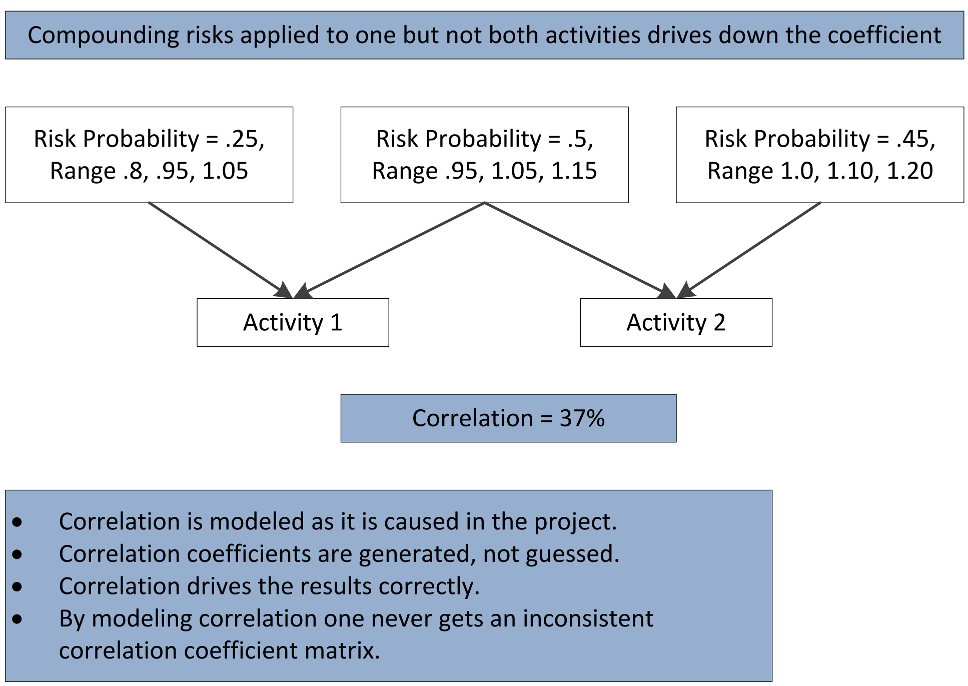


Figure 11: Modeling how Risk Drivers Modeling Causes Correlation Between Activity Durations [2] [23]

The simulation of this case study provides the standard results for schedule risk analysis in Levels 4 and 5. The histogram and cumulative distribution are shown in Figure 12. Notice the second mode at about October-November 2026, representing the impact of the systemic risk.

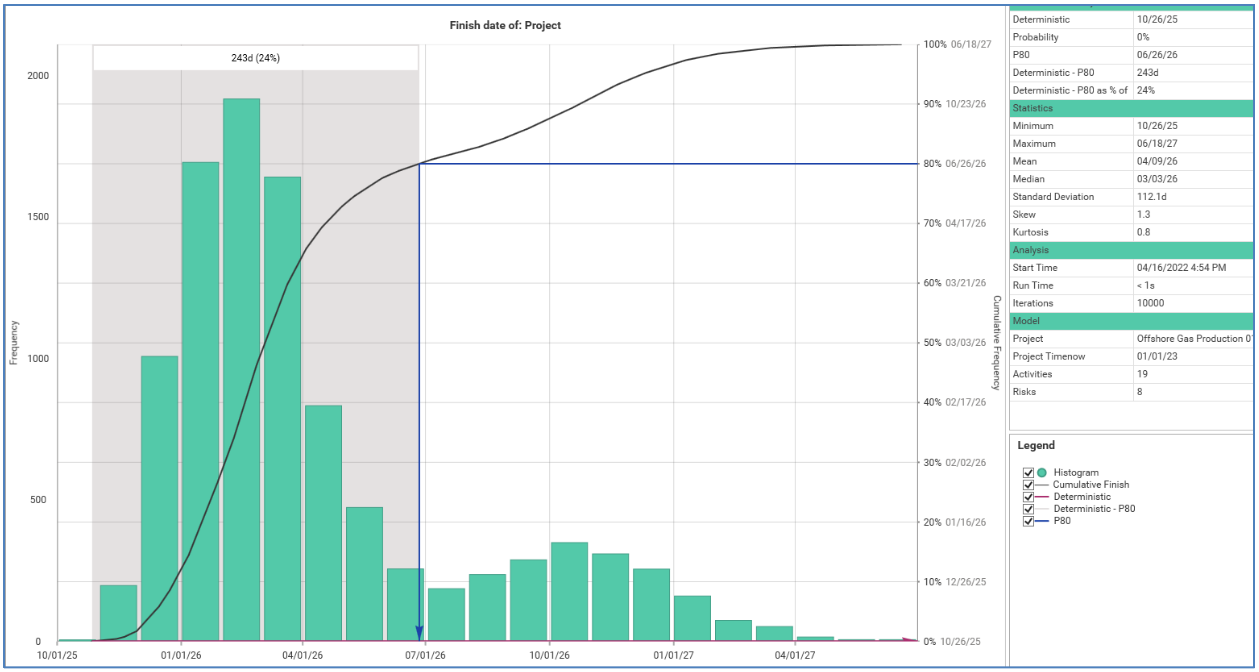


Figure 12: Histogram and Cumulative Distribution using Uncertainty and Risk Drivers

The cumulative distribution in Figure 12 allows the calculation of project schedule contingency up to a desired level of confidence for the organization. In Figure 12, that level is shown as the P80 level, which occurs on June 26, 2026, indicates providing eight months of contingency beyond the scheduled finish date of October 26, 2025. Put another way, 80 percent of the results with this schedule and these uncertainties and risks are provided for if June 26, 2026, is adopted as the finish date of this project.

Since specific risks are used to drive the simulation at Level 4, those risks can be prioritized by calculating their marginal impact on the PRA results at a target level of confidence, such as the P80. The marginal impact is calibrated by days saved if the risks were fully mitigated. [21] This information is useful for project management to determine whether to implement mitigation so that its benefits in days saved are worth the cost of the mitigation actions. This prioritization measure is better than traditional “tornado diagrams” that use the correlation of activities with the finish date instead of days saved. The results of risk prioritization using this method are shown in Figure 13.

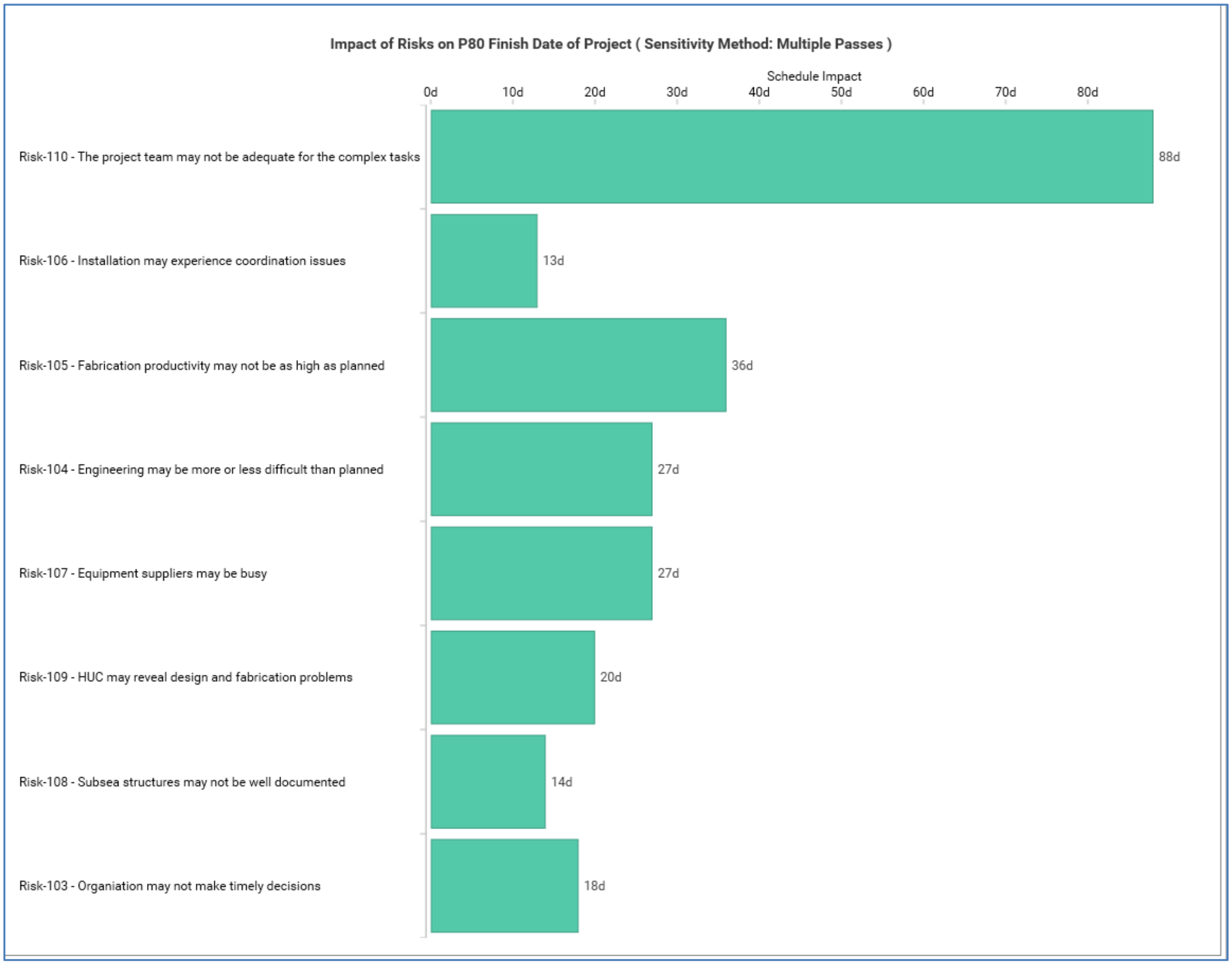


Figure 13: Prioritizing Project Risks for Mitigation

Since, at Level 4, the SRA is driven by identified risk drivers, project risk management is enhanced by the risk prioritization shown above. Risk mitigation actions should be developed focusing on the most important risk based on the days that could be saved if the risk were fully mitigated. (Uncertainty is not mitigated since the risks have already happened in risk estimating error and bias or is characterized by multiple unidentified risks that are sources of inherent variability.) A mitigation workshop can be convened to plan and assign mitigation activities that the owner and contractor, plus key stakeholders, can agree on. Once the mitigation activities are agreed to, and their cost is estimated, the simulation software lets the analyst specify post-mitigation probability and impact parameters from implementing the mitigation actions. A post-mitigation result is a new target, and the mitigation actions need to be implemented and monitored periodically to be sure they were carried out as anticipated by the mitigation workshop and are effective.

2.7.4. Weaknesses at Level 4

As at Levels 3, 4, and 5 there will be some work to do to review the schedule against good scheduling practices. The analyst may need to create a summary schedule that complies with good practices from the outset and is easier to manage and use in communicating the issues associated with risk. Also, as described under Level 2 above, the risk data collection starts with the existing risk register but needs to be augmented, probably using individual confidential interviews of project team members, management and other subject matter experts (SMEs).

Implementing a risk analysis at Level 4 is more burdensome than at Level 3. There is often a risk register available to start the SRA risk data interviews, but as at level 3, additional interviews will be needed to (1) uncover the risks not in the risk register and (2) estimate the probability and impact for the durations of the activities affected if the risk occurs. Working with identified risks at Level 4, rather than risk ranges at Level 3, requires more data collection and consolidation.

Individuals are known to exhibit biases when discussing uncertainty concepts which are, of course, about future events. Since "there are no facts about the future,"[22] one needs to recognize their inherent biases and try to offset them. [10] This is why confidential interviews are often used, to put the interviewees in a safe environment where they can say what they really mean without fear of contradiction or personal repercussions. An expert interviewer can usually identify the biases in the interviewee's responses and overcome or correct for them.

2.8. Level 5: Advanced Integrated Cost-Schedule Risk Analysis (ICSRA) Maturity

This level of maturity recognizes the important fact that activity durations and costs of time-dependent resources are related. If an activity is performed by labor-type resources including rented equipment, the costs will be higher if the task takes longer. Assuming no change in the resources applied on a daily basis, this cost will be higher in proportion to the extension of duration. Indirect costs can be placed on hammock activities, and their costs will increase in proportion to that of the detailed activities supported. The project cost budget should include a cost contingency related to accommodate the possibility that the schedule takes longer than planned. [3] [23]

In addition to the knock-on effect of schedule risk on the cost of time-dependent resources, there are risks that can affect the burn rate of these resources and the total cost of time-independent resources, such as material and equipment to be installed.

2.8.1. Distinguishing Features at Level 5

Level 5 builds on all of the capabilities of Level 4, including basing the analysis on the project schedule platform and using uncertainty and identified risks to drive the Monte Carlo simulation.

The distinguishing characteristic at Level 5 is that the schedule activities are loaded with resources, or at least costs are assigned to activities distinguished by being time-dependent (labor) or time-independent (material) of the project. The costs are expressed without adding any contingency, either in the activities or "below the line," as in a traditional cost estimate. While resource-loaded schedules may have many labor categories to support integrated cost and schedule risk analysis (ICSRA), the resources need to be distinguished only by being time-dependent and time-dependent.

The results from a Level 5 analysis include all results from Level 4 that provide a risk-influenced schedule contingency estimate. Output at maturity Level 5 adds to those of Level 4 by providing a contingency of cost that reflects cost risks and knock-on effects of schedule risks affecting cost. In addition, Level 5 provides a way to analyze the results of cost and schedule together using a scatter diagram to identify the finish date and total project cost achieving target level of confidence both time and cost targets simultaneously. This latter capability, the ICSRA, has been called the joint confidence level (JCL) by the US National Aeronautics and Space Administration (NASA). [24]

2.8.2. Capabilities Required at Level 5

Often the project schedule is not loaded with resources, or those resources are not associated with costs matching the budget without contingency. To place the costs on the schedule the cost estimators and the schedulers need to communicate at a common detailed level. The most obvious way cost and time data can be compared is if the estimators and the schedulers are using the same work breakdown structure (WBS). This communication is not always easy since the estimate and schedule may have diverged from an original common WBS along the way.

The risk practitioner should also be alert to traditional cost risks that could increase or decrease the daily expenditure rate on time-independent resources and increase or decrease time-independent material costs, which do not vary because of activity durations. These risks will vary the cost even if the schedule follows the baseline schedule.

2.8.3. Benefits / Strengths at Level 5

In each iteration, the Monte Carlo simulation will compute the cost that is generated at the same time and with the same assumptions for which the schedule is calculated. The costs and durations for any iteration will be affected by that iteration's assumptions. In this way, the cost and finish date results would be correct for the same project structure, uncertainty, and risk parameters.

The risk analysis does not identify which party must pay the extra costs. Depending on the contract, there may be a presumption that the owner or the contractor pays the cost. However, the risk analysis just computes the costs irrespective of the contract language and does not contribute to the debate about who pays.

Probabilistic histograms for the schedule are the same as at Level 4. Histograms for cost, which are introduced at Level 5, are comprehensive since they reflect both the indirect effect of schedule-generating costs of time-dependent resources, as well as cost-risks on labor's burn rate and on time-independent resources.

Because cost and schedule are the results of the same iterations during simulation, a new concept of project risk is available at Level 5. The result, representing both the project's finish date and total cost, is the scatter diagram with time on the X-axis and the comparable cost on the Y-axis. The scatter diagram allows the user to select a pair of cost–time points and calculate the likelihood that they will both occur, given the schedule, the estimates, and the risk data used in the model.

Most projects have both cost and schedule targets or propose both cost and schedule values to management or the customer. At Level 4, the simulation results for schedule risk are shown as a 2-dimensional histogram and cumulative distribution. At Level 5, a similar distribution is provided for cost. Specifying a confidence target, e.g., the P80, and using the values from the histogram / cumulative distributions for each objective will not provide for achieving both the time and cost targets with an 80 percent likelihood. This is because, for any schedule date at P80 there are many cost possibilities, and some of those are 80 percent or more likely, but some are not. The same situation applies starting with a P80 cost estimate from the cost histogram and cumulative distribution. Notice that above in Figure 7 the cost (without contingency) was estimated at $1,721,200 thousand. Examples of these 2-dimensional time or cost risk-informed solutions are shown in Figure 14 for this RP's case study, the *Offshore Gas Production Platform Construction and Installation Project*.

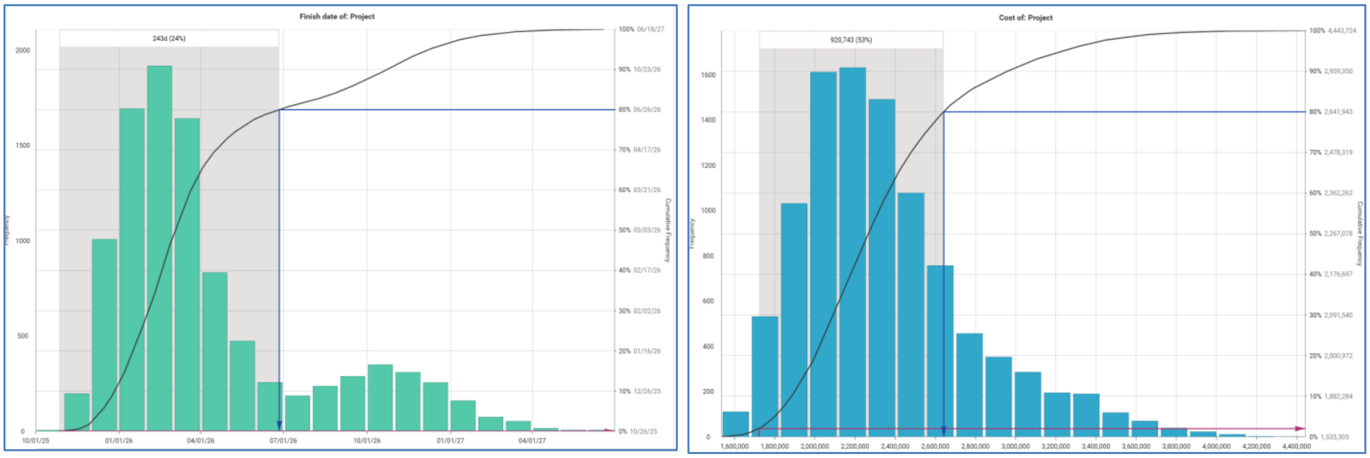


Figure 14: Simultaneous Finish Date and Project Cost Results from the Case Study

The scatter diagram in Figure 15 shows that the joint confidence of achieving the P80 time and cost results for each individually, shown in Figure 14, is only 76 percent. This figure, which is presented in the southwest quadrant in Figure 15, shows the percentage of all 10,000 iterations for which the points are in that quadrant. This difference, 76 percent rather than 80 percent is not large because the schedule and cost scatter points are correlated 76 percent, largely due to the predominance of labor resources in the case study model.

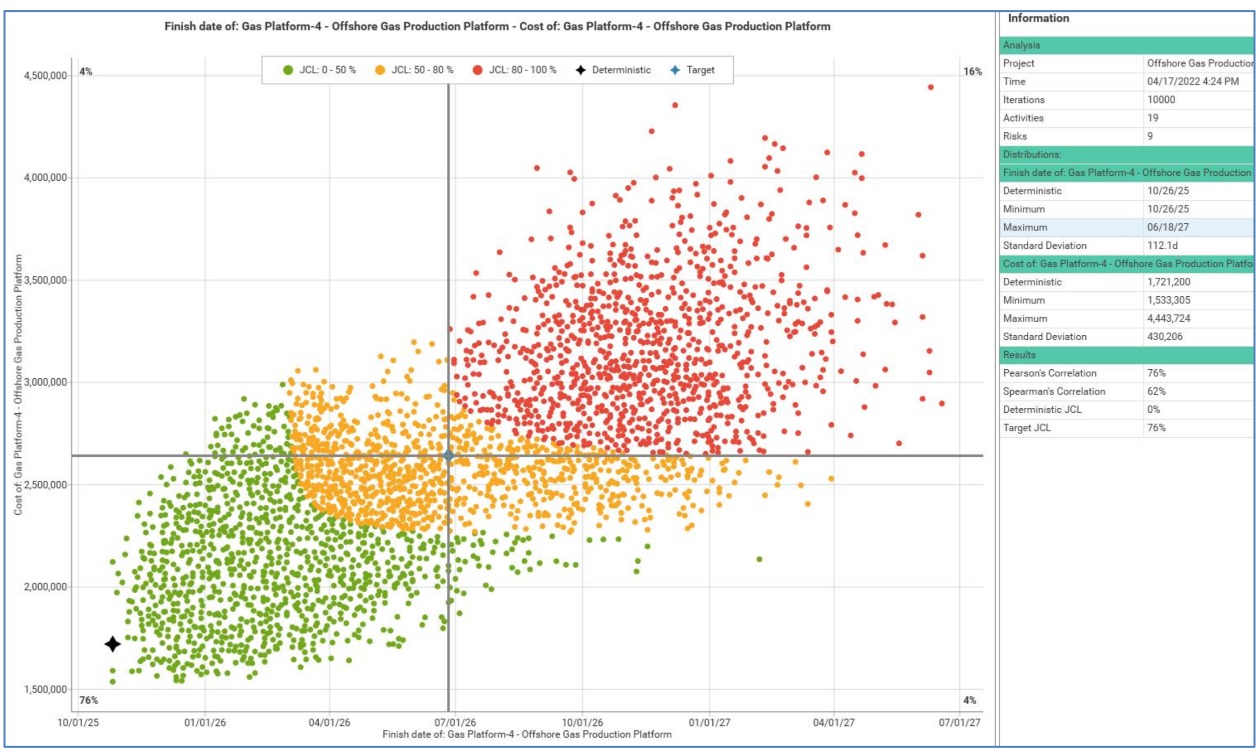


Figure 15: Scatter Diagram for the Case Study with the P-80 Cost and Schedule Cross-Hairs

At Level 5 the cost risk results are calculated using the Monte Carlo simulation. To achieve the 80 percent likelihood of achieving both cost and schedule targets the project manager needs to add time and cost to find a point that provides a joint success rate of 80 percent. Providing for both time and cost jointly, using the scatter diagram that shows consistent cost-time iteration results, is the Joint Confidence Level, or JCL–80 point. [24] Since there are many point combinations that yield a JCL-80 confidence level, the analyst should choose one that is more likely than any other to occur. Think of the scatter diagram as representing a 3-dimensional ridge of JCL points. Imagine a topological map and find the highest elevation contour line where the JCL-80 points hit the ridge. That defines the most likely JCL-80 (or whatever confidence target is desired) point.

One such JCL-80 point is shown to be captured in Figure 16.

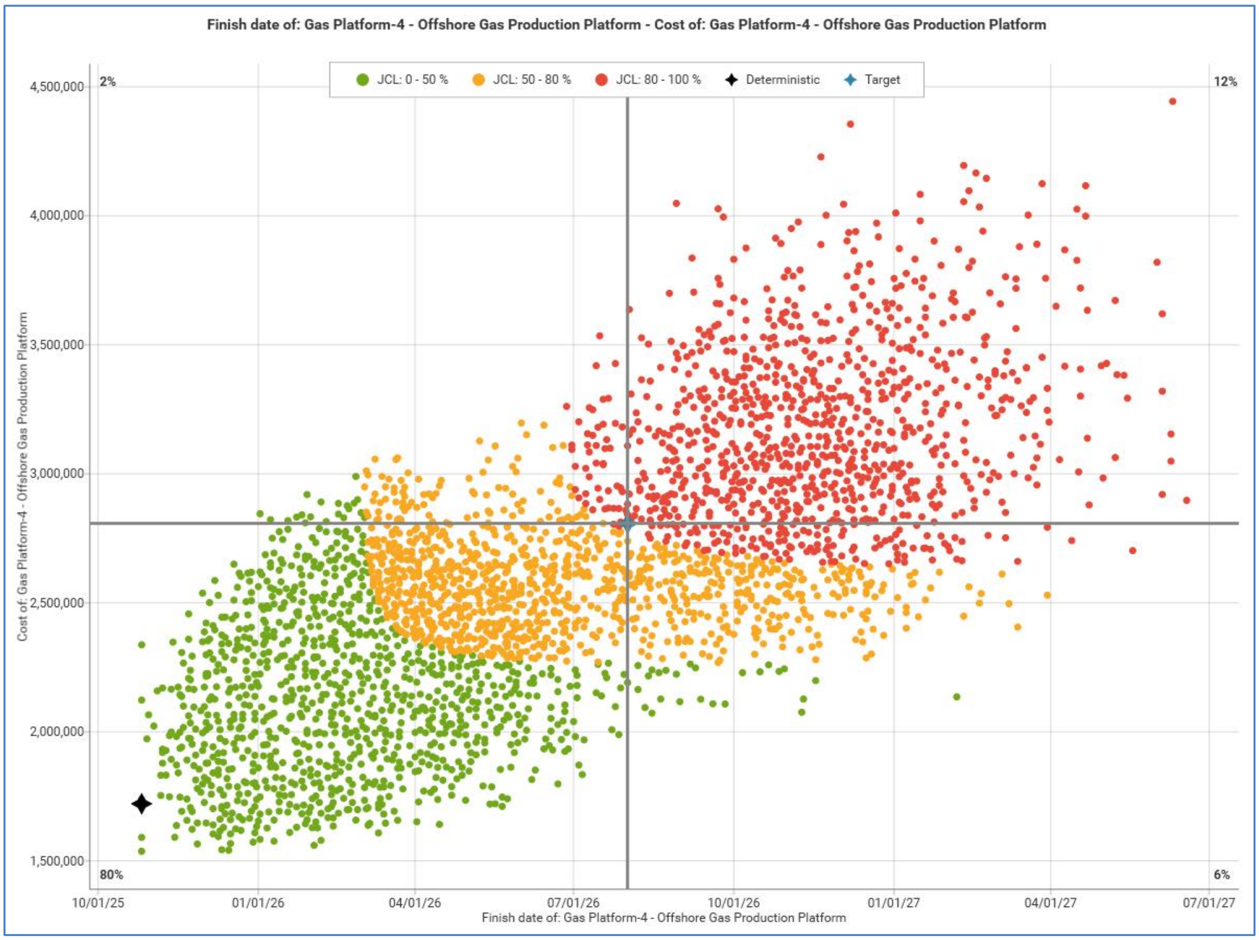


Figure 16: Finding the Most Likely JCL-80 combination of Finish Dates and Project Costs

<table>
<tr><th colspan="6">Using the Scatter Diagram to Achieve an 80% Likelihood of Joint Cost and Schedule Success</th></tr>
<tr><th></th><th>From histograms</th><th>JCL</th><th>From Scatter Diagram</th><th>Add</th><th>JCL</th></tr>
<tr><td>Finish Date</td><td>06/26/2026</td><td rowspan="2">76 %</td><td>08/01/2026</td><td>1.2 month</td><td rowspan="2">80 %</td></tr>
<tr><td>Project Cost</td><td>2,641,943</td><td>2,807,986</td><td>$166,043 million</td></tr>
</table>

Table 1: Finding the P80 Cost and Schedule with the Integrated JCL for an 80 Percent Success Rate for Both

Figure 16 shows that adding 1.2 months to the P80 schedule and $166,043 million to the P80 cost can achieve an 80% likelihood of succeeding with both targets. As mentioned before, the higher the correlation of time and costs the less adjustments need be made to achieve a JCL level. Time and cost will be correlated because time risk affects the cost of time-dependent resources. In this case study, labor contributes the largest share of the cost.

NASA fully formalized the JCL policy to develop its proposals of time and finish date to US Congress for approval and funding in 2012 after having introduced it in 2007 and 2009 in different directives. In 2018 an analysis of the success of the JCL policy of achieving the dates and cost estimates submitted to Congress was possible since some of these long projects had been completed. comparison of cost and schedule growth shows that growth, before the JCL policy was in place was a higher percentage than under JCL. “The data demonstrates that the policy has helped NASA manage to its budget which increases the confidence that missions will be delivered at or below cost and on schedule.” [25, p. Slide 5] It should be clear that using the JCL leads to proposing higher cost and schedule target values to Congress, so coming closer to or beating the new, higher estimates means that the agency is making better projections. But, that was the point of using JCL, to make projections.

2.8.4. Weaknesses at Level 5

The weaknesses at Level 4 are present at Level 5.

In addition, there is an unresolved issue in picking the specific cost and finish date that is the most likely combination to provide a probability of achieving both cost and finish date targets at the chosen JCL level of confidence. Figure 16 shows a combination chosen to be in the area of the scatterplot where the simulation results are most concentrated. Such a point would be more likely than any other cost/date combination that provides the desired level of confidence. If the scatterplot were viewed as a 3-dimensional ridge of possible results, this point would be the one on the “necklace” of connected dots, each being a combination of cost and finish date with the desired joint result. At this point, the choice of a particular JCL combination of cost and finish dates is judgmental to some extent. While there is some level of uncertainty with choosing a single, most likely JCL point, some uses, including reports to Congress for funding or to the Board of Directors, might require more precision in this choice’s values. There are ways to make this selection less judgmental for those purposes needing more precision. [26]

3. CONCLUSION

The levels of risk analysis maturity from “no awareness” to “full integrated cost-schedule risk analysis” have been described, capabilities required, benefits and strengths and weaknesses at a general level. Illustrations are given for the main inputs and outputs at Levels 2 – 5. Table 2 is shown below for the main characteristics of risk maturity levels. Note that only at maturity levels 4 and 5 do these methodologies match AACE International’s first principles of recommended practice 40R-08, *Contingency Estimating – General Principles*, of “starts with identifying risk drivers,” “links risk drivers and cost/schedule outcomes,” “employs empiricism” and “experience/competency.” [4] The maturity levels in this model generally apply to projects with Class 3 or better plan maturity. Reference class forecasting and parametric models are more suitable for projects that have cost estimate maturity levels at Class 4 or Class 5.

December 6, 2023

ESSENTIAL ANALYTICAL PROPERTY	0. Unaware of Schedule Risk Issues	1. Risk Awareness	2. Qualitative Risk Analysis	3. Basic Quantitative Schedule Risk Analysis	4. Modern Quantitative Schedule Risk Analysis	5. Advanced Integrated Cost-Schedule Risk Analysis
Management alert to possibility of risk		X	X	X	X	X
Uses organized analytical framework for risk analysis			X	X	X	X
Uses a model of the project in the analysis				X	X	X
Produces statistical probability distribution of finish dates for schedule contingency days and probability of finishing on schedule				X	X	X
Identifies risk drivers that could affect schedule results			X		X	X
Assesses probability and impact of risk drivers			X		X	X
Requires sophisticated specialty software tools				X	X	X
Models the correlation between activity durations					X	X
Identifies high-priority risks for mitigation			X		X	X
Distinguishes between types of risks (e.g., uncertainty, project-specific risks, and systemic risks)					X	X
Links cost risk with schedule risk						X

Table 2: Summary of the Characteristics Provided at Different Levels of Schedule Risk Analysis Maturity [2]

REFERENCES

[1] H. L. Stephenson, Ed., Total Cost Management Framework: An Integrated Approach to Portfolio, Program and Project Management, 2nd ed., Morgantown, WV: AACE International, 2015.

[2] D. T. Hulett, "Journey Map to a More Mature Schedule Risk Analysis (SRA) Process," *Cost Engineering,* vol. 61, no. 02, 2019.

[3] AACE International, Recommended Practice No. 57R-09, Integrated Cost and Schedule Risk Analysis Using Monte Carlo Simulation of a CPM Model, Morgantown, WV: AACE International, Latest revision.

[4] AACE International, Recommended Practice No. 40R-08, Contingency Estimating – General Principles, Morgantown, WV: AACE International, Latest revision.

[5] AACE International, Recommended Practice No. 27R-03, Schedule CLassification System, Morgantown, WV: AACE International, Latest revision.

[6] AACE International, "Recommended Practice No. 122R-22, Quantitative Risk Analysis Maturity Model," AACE International, Fairmont, WV, USA, Latest Revision.

[7] AACE International, "Recommended Practice No. 117R-21, Integrated Cost and Schedule Risk Analysis and Contingency Determination Using a Hybrid Parametric and CPM Method," AACE International, Morgantown WV, Latest revision.

[8] AACE International, "Recommended Practice No. 10S-90, Cost Engineering Terminology," AACE International, Morgantown, WV, Latest revision.

[9] Y. Salim and D. T. Hulett, "Assessing Project Maturity in a Large Energy Company," *PMI Global Congress Asia Pacific,* 2008.

[10] A. Tversky and D. Kahneman, "Judgement Under Uncertainty: Heuristics and Biases," *Science,* vol. 185, no. 4157, 1974.

[11] Project Management Institute (PMI), A Guide to the Project Management Body of Knowledge (PMBOK® Guide), 5th Edition, Newton Square, PA: Project Management Institute, 2013.

[12] Project Management Institute (PMI), A Guide to the Project Management Body of Knowledge (PMBOK® Guide), 6th Edition, Newton Square, PA, PA: Project Management Institute, 2017.

[13] D. Hillson, Effective Opportunity Management for Projects: Exploiting Positive Risk, CRC Press, 2004.

[14] D. Rumsfeld, "There are Known Knowns," Wikipedia, [Online]. Available: https://en.wikipedia.org/wiki/There_are_known_knowns. [Accessed 24 12 2017].

[15] AACE International, Recommended Practice No. 41R-08, Understanding Estimate Ranging, Morgantown, WV: AACE International, Latest revision.

[16] AACE International, Recommended Practice No. 66R-11, Selecting Probability Distribution Functions for Use in Cost and Schedule Risk Simulation Models, Morgantown, WV: AACE International, Latest revision.

[17] US Government Accounting Office (GAO), "Schedule Assessment Guide: Best Practices for Project Schedules, GAO-16-89G," US Government Accounting Office (GAO), Washington, 2015.

[18] J. K. Hollmann, "(RISK-1027) Estimate Accuracy: Dealing with Reality," in *AACE International Transactions*, 2012.

[19] J. K. Hollmann, Project Risk Quantification, Sugarland, TX: Probabilistic Publishing, 2016.

[20] B. Flyvbjerg, "From Nobel Price to Project Management; Getting Risks Right," *Project Management Journal,* August 2006.

[21] E. Druker, G. Gilmer and D. Hulett, "(RISK-1662) Using Stochastic Optimization to Improve Risk Mitigation," in *AACE International Transactions*, Morgantown, 2014.

[22] US DOE/EIA, "Annual Report to Congress, Volume III, Rep. No. DOE/EIA-0173(79)/3," GPO, Washington DC, 1979.

[23] D. T. Hulett, Integrated Cost-Schedule Risk Analysis, Gower Publishing Limited, 2011.

[24] National Aeronautics and Space Administration, "Appendix J: Joint Cost and Schedule Level (JCL) Analysis," in *NASA Cost Estimating Handbook*, 2015.

[25] B. Bitten, B. Kellogg, E. Mahr, S. Lang, D. Emmons and C. Hunt, "The Effect of Policy Changes on NASA Science Mission Cost & Schedule Growth," Presented at the NASA Cost & Schedule Symposium 14 August 2018.

[26] S. Steiman and D. T. Hulett, "Identifying the Most Probable Cost – Schedule Values from a Joint Confidence Level (JCL) Risk Analysis," *Cost Engineering,* vol. 62, no. 04, 2020.

[27] S. Book, "A Theory of Modeling Correlations for Use in Cost-Risk Analysis," in *Third Annual Project Management Conference*, Galveston, 2006.

[28] D. T. Hulett, Practical Schedule Risk Analysis (starting at chapter 8), Gower Publishing Limited, 2009.

CONTRIBUTORS

Disclaimer: The content provided by the contributors to this recommended practice is their own and does not necessarily reflect that of their employers unless otherwise stated.

Dr. David T. Hulett, FAACE (Primary Contributor)
Francisco Cruz Moreno, PE CCP