Schedule Risk at Early Acquisition

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Schedule Risk at Early Acquisition

1. Introduction

It can be difficult to construct a realistic schedule early in the acquisition lifecycle due to the limited certainty of requirements, design decisions, and other key elements of program planning. Understanding risk and uncertainty in a schedule is essential, and the GAO Scheduling Guide includes "Conducting a Schedule Risk Analysis" as one of the 10 Best Practices. A schedule risk analysis (SRA) can provide quantitative insight into potential areas of delay along with associated cost impacts. However, a well-formed SRA requires clear input and structured analysis of risk events and uncertainty. This paper discusses how to address schedule risk in low maturity projects by identifying the unique challenges in early acquisition environments, investigating different risk modeling techniques, and analyzing how uncertainty must be interpreted and applied early in the project lifecycle.

1.1. Early Acquisition

There is no singular definition for "Early Acquisition". The term is relative and may be used to describe a wide range of projects throughout this paper. For example, consider two programs started at the same time but following different Department of Defense acquisition pathways. A rapid prototyping program may mature more quickly than a traditional major acquisition program due to an accelerated timeline.

The level of detail that a schedule contains will be driven by the priorities of program leadership and their buy-in to schedule management effectiveness. This paper will use the term schedule broadly and not presume that a program integrated master schedule (IMS) exists. One schedule may consist of a list of milestones; another may be a detailed program roadmap schedule (PRS) – commonly referred to as a "taco chart" – for key activities. A schedule could also be a detailed IMS or one with great detail for the first fiscal year (FY) and high-level objectives in the remaining FYs. As a note, "project" and "program" will be used interchangeably in this paper to broadly refer to any specific effort with defined scope and an associated schedule.

1.2. Low Maturity Environment

There are two factors that could produce a low maturity environment: low schedule maturity and low technical/acquisition maturity.

- Low Schedule Maturity

  In this environment, a schedule may exist but it lacks definition. This can present in the form of a high-level WBS or IMS, for example a milestone schedule. Typically a schedule with low maturity will capture major deliverables and key milestones but it will not be constructed to include task level detail. Alternatively, low schedule maturity could present as an integrated program IMS with the government portion of work defined but the "integrated" contractor portion left largely underdeveloped. Projects with low schedule maturity are often planned "backwards", using a top-down approach to meet a specific end milestone date rather than utilizing a bottom-up approach which is driven by durations or sequencing. Ultimately, schedule maturity only involves the schedule product.

- Low Technical/Acquisition Maturity:

  This type of environment stems from a lack of maturity outside of the schedule. For example, definition of requirements and the acquisition strategy, the maturity of the design concept, the program's funding status, and whether the team is operating at full scale or on a skeleton crew all impact the technical/acquisition maturity. Importantly, these factors prevent a clear and comprehensive understanding of the project scope. Without this definition, it is impossible to construct a detailed schedule, but more importantly, it is not clear what major milestones, performers, and deliverables should be included in the schedule. In this environment, an evaluation of schedule uncertainty is often seen as superfluous, however given the many unknowns around technical and acquisition outcomes, a realistic understanding of potential schedule impacts linked to each possibility is essential.

It is important to understand that no matter what the maturity of a program may be, there is a need to understand schedule risk and uncertainty to properly plan the effort.

1.3. Risk vs Uncertainty

Risk and uncertainty are closely coupled but they do not have the same meaning and cannot be used interchangeably. For the intentions of this paper, risk and uncertainty will be defined as follows:

- Risk: A discrete event with an estimated probability of occurrence; there is an estimated duration impact and mitigations plans can be placed to reduce the probability of occurrence or lessen the impact if it were to occur. Risks are typically defined as having a negative impact on the project with "Opportunity" used to describe events that could positively impact the project.
- Uncertainty: The total range of outcomes (i.e. duration) a schedule task or program may have based on unknowable factors

A schedule that has not been adjusted for risk or uncertainty is often called a "deterministic schedule".

1.4. Programmatic Utilization of Schedule Risk

The following scenario is intended to illustrate the importance of schedule risk and uncertainty in early acquisition. Assume that a schedule analyst is tasked with estimating the completion date for two different programs that have just recently been formed. The analyst will be provided with the current program schedules and knows that in order to estimate an accurate completion date, they must account for any risk and uncertainty within the schedule. Ultimately, the analyst decides to do an SRA to help account for any "unknown unknowns".

When the analyst receives the schedule products, they realize that they are vastly different:

- Program A: The schedule is only a visual PRS of high-level milestones and the project runs throughout 1 FY.
- Program B: The schedule is 100 lines in an IMS and the project runs throughout 5 FYs.

Given the differences between the programs, the objectives of the SRA will differ based on what the program manager (PM) is intending to do with the outcomes. The results can be utilized to inform different stakeholders of the projects such as their leadership or external parties. They can be used to identify potential friction points within the schedule to proactively develop risk mitigation strategies. Maybe the PM wants to hold the vendor to a more realistic reporting. Whatever the case, there are many unknowns early in the lifecycle and risk and uncertainty analysis can be used to assess a realistic range of outcomes. The same technique that may work to forecast Program A will most likely not be the best tool to utilize for Program B. This is also apparent in real-world programs. When assessing risk, the level of maturity, duration of the program, and managerial use-cases will all need to be accounted for. If done correctly, the SRA can help support cost planning, inform external dependencies, and notify PMs on frictional areas within their program.

In a real-life application, Augur Consulting ran a modified risk and uncertainty analysis for a Navy acquisition effort. Utilizing subject matter expert (SME) input as well as analogous program data, we were able to project a milestone date that was 8.5 months later than the deterministic date in the vendor IMS with a 0% probability of meeting the milestone baseline date. Once trending analysis in execution reinforced the likely delay, a schedule re-baselining effort commenced to create a more achievable path forward. The analysis results demonstrated impact to range time, budget planning, and timing of interdependent activities which ultimately resulted in adjustments to the technical scope. Even with these mitigations, the delay was realized and to date has exceeded those 8.5-months. Currently, we conduct a monthly schedule uncertainty analysis to be able to regularly forecast the anticipated event completion dates. Due to our previous ability to forecast a major delay, leadership is invested in the outcomes of the uncertainty analysis and has utilized it to plan the program budget in the next fiscal years.

1.5. Estimating Methodology in Low Maturity Environments

Identified by Best Practice #8 in the GAO Schedule Assessment Guide, it is important to conduct an SRA to ensure the schedule is defendable and executable. GAO highlights that an SRA is imperative because, "[..] unless a statistical simulation is run, calculating the completion date from schedule logic and duration estimates in the schedule tends to underestimate the overall program critical path duration." [1] The SRA process helps program managers plan for schedule reserve, create backup contingency plans if there are unexpected outcomes, identify areas where schedule risk is significant, and encourages SMEs to think in greater detail about the range of time a task could take to complete. As stated above, in early acquisition, there may not be a full IMS or sufficiently detailed project plans to support conducting a traditional SRA as recommended by GAO. Due to programs having differing levels of schedule, technical, and acquisition maturity, the methodology used to assess risk and uncertainty may need to be tailored to fit program needs. Section 2 below discusses techniques based on schedule maturity in more detail along with the benefits and limitations inherent to each method.

1.6. Schedule Risk in Relation to Cost Estimating

Cost estimation and schedule analysis use many of the same techniques for modeling risk and uncertainty. However, there are some nuances to consider when first approaching risk and uncertainty in a schedule. Understanding this background will be useful in the analysis of scheduling techniques and the recommendations that follow in later sections of this paper. First, project schedules are, ideally, dynamic networks consisting of tasks with a defined duration linked together by logical relationships. When uncertainty is applied in a schedule, it is typically applied to task durations. Schedule task durations are often based on SME input, and uncertainty distributions can be used to model a range of possible actual durations that may be observed. Risks can also be incorporated into a schedule analysis, typically as events with some defined probability of occurrence and delay that may impact multiple tasks. For example, failure to receive approval on a document waiver request may delay the start of multiple tasks in a schedule. Because tasks are linked together in a schedule, the finish date for any given task is driven by its duration, the impact of risk and uncertainty on its duration, and the impact of risk and uncertainty on the duration of all of its predecessors. This means that the likely finish date of a project milestone is determined by all of the tasks linked to it directly or indirectly, tracing all the way back to the schedule start date.

Additionally, schedule risk is impacted by a phenomenon called “merge bias”. When multiple predecessor activities lead into a single task, delays to any single predecessor could push the task’s start date. Conceptually this is intuitive; the more predecessors a task has, the more likely at least one of them will be late. In practice, this means that activities in the schedule network where many task paths converge, such as major milestones, are almost always modeled as being late. This effect does not have a clear analogy in cost estimation, where negative outcomes can be partially mitigated by positive results elsewhere. In a schedule, a task can begin only as soon as its latest predecessor permits, and reductions to task durations off of the critical path will not impact the project finish date.

Finally, schedule uncertainty can be difficult to model due to a lack of reliable historical data. Many sources for cost data fail to include schedule information, and some data gathering techniques, such as market research, are not easily applied to durations. Additionally, schedules can include granular detail in the near term. Schedulers typically try to make task durations as short as possible while still being meaningful for updating project status. This granularity combined with the frequency of schedule updates can make application of risk and uncertainty at the task level difficult. The model results may also be worse as tasks are too detailed and too transitory for rigorous uncertainty modeling. This last challenge can often be overcome by analyzing risk and uncertainty at a higher level (i.e. a parent level) of the WBS. The ability to change the WBS level at which schedule risk and uncertainty is evaluated should be considered when reviewing the techniques described in this paper.

1.7. Literature Synopsis

There are a number of guides and best practice documents that define schedule risk and uncertainty analysis and discuss how to conduct a traditional SRA with an IMS. These guides typically focus on mature schedules and programs. The framework of this paper is focused on schedules at different levels of maturity i.e. schedules that may or may not be detailed at the task level. This study was informed by a review of existing literature as well as programmatic experiences to develop the techniques and recommendations described below. Common themes and best practices were considered. This review was done primarily from a government perspective, and guidance may vary by agency. See the References in Appendix B for more details.

2. Schedule Risk & Uncertainty Modeling Techniques

There are many methods that can be used to quantify risk and uncertainty in a project schedule. At any stage of the acquisition lifecycle, the choice of technique will be dependent on a number of factors, including the level of detail available in the schedule, the maturity of the project's strategy and documentation, and the quality of input provided to the schedule. In an early acquisition environment, schedule analysts may need to be flexible in their choice of technique, as these factors can change rapidly. The list of techniques identified here is not all inclusive, however, the techniques can be modified or combined into hybrid models, giving project teams and schedulers substantial ability to tailor their risk and uncertainty modeling to their particular circumstances.

2.1. Technique #1: Traditional SRA

A traditional SRA utilizes a Monte Carlo simulation to model uncertainty and risk events within an existing IMS. For this practice, an uncertainty distribution or range is applied at the lowest level task. In a traditional SRA, all tasks should be evaluated to determine whether an uncertainty distribution is needed. Ideally historical data would be used to inform uncertainty distributions. In practice, subject matter experts usually provide input for the low, middle, and high duration estimates for each task. These inputs are used to create a triangular or beta PERT distribution around task durations. In addition to uncertainty, a traditional SRA includes risks which are integrated into the schedule through logic, and they are assigned a percentage likelihood of occurrence when calculated within the simulation.

When choosing to do a traditional SRA, one must consider the time commitment as well as existing resources at their disposal. Of all of the techniques, a traditional SRA will be the most time consuming due to the amount of information required to run the Monte Carlo simulation, but it can provide the most detailed results. This process typically is best applied to a program with a mature, well-constructed IMS and existing risk register, making it difficult to apply in early acquisition.

Pros

- Ability to apply uncertainty and view results at lowest level
- Well-informed forecasted program dates
- Provides insight into impact to critical path or alternative critical paths

Cons

- Needs a lot of data to support simulation
- Program risk knowledge must be available
- Must have SME buy-in to inform uncertainties
- Time consuming
- Requires specialized software

2.2. Technique #2: Modified SRA

The process for a modified SRA is very similar to that of a traditional SRA with a few key differences. An IMS and understanding of risk events is still required, however the schedule is "flattened" such that tasks are captured in less detail than in the IMS needed for a traditional SRA. Tasks may be bucketed into common groups or rolled up to their parent task. This means that risks and uncertainty are applied at the "intermediate level" or on summary level tasks. In a modified SRA, uncertainty may also be applied more generally. Rather than gathering best case, worst case, and most likely durations from SMEs, the project may pre-define uncertainty distributions and apply them to many tasks in the schedule. Probability distributions could be backed by actual historical performance data or defined nominally. As an example, assume schedule duration variances for all hardware tasks on a project have generally aligned to normal distribution. This distribution can be modeled and applied to all future hardware tasks. In a modified SRA, not all tasks need to have uncertainty distributions assigned to their durations. Projects may opt to only assign distributions to critical or near-critical tasks along with those deemed important by leadership. A modified SRA can be useful when a program IMS is very large and the benefit to running a traditional SRA is outweighed by the costs (time, effort, etc.).

Many times, there are multiple stakeholders contributing to a program. Each stakeholder may possess their own schedule focused on their assigned tasks or responsibilities. This results in schedules with varying levels of quality and detail. When this is the case, it can be difficult to ascertain the true level of risk and uncertainty to the program. A modified SRA can help account for this by rolling all of the schedules up to an intermediate level and applying risk and uncertainties at the same level in a single flattened schedule.

To understand the outcomes of a modified SRA, a scheduler needs to understand critical program events and their driving paths. It is easy for information to be lost when tasks are being combined and the schedule has less detail than before. When applying project risks to an intermediate schedule, the scheduler should be careful to consider the underlying schedule logic and sequencing, so impacts are correctly modeled in the risk analysis results.

The benefits and disadvantages of a modified SRA are comparable to the traditional SRA technique. While it may be done more quickly and with less effort than a traditional SRA, it still requires more time and expertise than most other techniques. Similarly, while the outputs can be more detailed and informative than most methodologies, a traditional SRA provides more comprehensive results. In this way, a modified SRA may be a good middle-ground solution, when a traditional SRA is impractical, and it may be applied in early acquisition environments.

Pros

- Similar outputs to traditional SRA
- Supports the SRA process on large program schedules
- Provides the ability to assess risk of two integrated schedules on the same level
- Flattened schedule allows faster implementation of uncertainty than a traditional SRA

Cons

- More difficult to apply risk events when working with intermediate schedule
- Less informed critical path than traditional SRA
- Program risk knowledge must be available
- Data requirements less than traditional SRA, but still significant
- Extra effort required to flatten schedule
- Specialized software likely required

2.3. Technique #3: Added Risk Factor

One step down from an SRA is to calculate an added risk factor. This factor is a flat percentage of total duration (or percentage of duration for a sub-element of the project) that is applied to account for any uncertainty or risks the program faces.

For example:

- A program is set to take 2 years or the equivalent of 480 work days. To account for risk and uncertainty, the program would like to add 20% to the current duration.

480 [Work Days] * 1.2 [Flat Rate Risk Factor] = 576 [Risk-Adjusted Work Days]

- In this case the risk factor is predicting that the program will need an additional 96 working days to account for any risks or uncertainties which brings the actual total program duration to 2.4 years.

Whenever possible the risk factor should be based on historical project data. Duration growth beyond baseline or approved durations for comparable projects can be analyzed or modeled. In the absence of data, a fixed percentage may be chosen. This technique can be applied to major project elements, such as development contract durations, or to the project in its entirety.

This process is typically best used in cases when program timelines and schedules have been repetitive and follow a standard format, such as the time between common, well-defined milestones and phases. It also works well in instances where work may extend for long periods of time with little detailed performance data or task definition to track progress data.

As an example, consider building 100 houses in a retirement community. Over time, risk and uncertainty trends will emerge relative to the baselined build timeframe. Once trends can start to be assessed, they can then be utilized to calculate the risk factor which is then applied to the remaining houses. As more houses are completed, the risk factor will become more informed and improve in accuracy.

With this type of risk analysis, there is no insight into specific critical path drivers, detailed risks, or understanding of friction points within the schedule. This method is not recommended for projects with little historical information or limited repetition. Marginal benefit in these cases is not likely to be ascertained.

Pros

- Can be applied in almost any scheduling environment
- Can be based on data, but can also be applied based on rules of thumb or fixed rates
- Easily combined with other techniques
- Works well with modeling repetitive processes
- Not time consuming

Cons

- No insight into discrete critical path drivers or schedule friction points
- No identification of task level uncertainty or impact of risk events

2.4. Technique #4: What-If Analysis

What-if analysis is the modeling of discrete scenarios within a project schedule. "Scenarios" is used broadly here and may include:

- Possible outcomes of unknown future strategy decisions or Courses of Action (COAs). For instance, the results of a planned vendor down-selection.
- Occurrence of a particular risk or combination of discrete risk events from the program risk register (e.g. Risk Register Items #1, #4, and #9 all occur)
- Results at key milestones or the impact of catastrophic events, such as the rework following a major test failure

This type of "What-if" analysis should be considered throughout a project's execution, but it can be used especially well early in the project lifecycle when there are many unknowns surrounding the major elements of the project. The scheduler should work closely with project managers and other stakeholders to identify scenarios, and these discussions should also encourage the project team to think critically about where there is risk or uncertainty in the project plan. Once scenarios are modeled, results should be thoroughly documented and presented to the project team, ensuring that the assumptions feeding each result are clearly understood.

Pros

- Targets areas of high interest to project stakeholders
- Works well for modeling major changes to project strategy or catastrophic events
- Easy to communicate assumptions and results
- Works well when project strategies are immature
- Forces critical assessment of where risk or uncertainty exists within the program

Cons

- Limited in scope; does not address risk or uncertainty outside of the COA definition
- Difficult to establish probabilities for each potential outcome

2.5. Technique #5: Risk Register

If a project risk register exists, it can be used to model risk and uncertainty within a schedule. Ideally, the project scheduler would work closely with the risk management team to understand risks and quantify their impact on timeline by modeling them in the project schedule. In this way, schedule analysis may precede formal entry of a risk into the risk register. Risk registers should include a detailed definition of each risk along with the assessed impact and likelihood of occurrence. The use of risk cubes to monitor and report risks has the benefit of directing leadership attention to the most critical areas of the project.

With this technique, mitigation strategies can be included in the schedule as well. This not only improves the quality of the schedule modeling, it may also lead to better risk mitigation. As mitigation steps are built into the schedule, discrete actions with specific performers are identified and tracked, improving the likelihood of successful mitigation. Similarly, opportunities can also be modeled and tracked, leading to improvements in cost, schedule, or technical performance.

While this technique has many benefits, its truest form requires the project to have a mature risk management process in place, which can be uncommon in early acquisition environments. However, even without a formal risk management team or project risk register, the principles of risk management could still be applied at a high level to understand project risks. For instance, the project could still hold recurring risk meetings to brainstorm potential project risks along with their likelihood of occurrence and potential mitigation strategies. While the scheduler may not be able to model all risks within the project schedule, a rough order of magnitude assessment of impact could be used to identify the most significant risks facing the project.

Pros

- Models risks identified by stakeholders and documented in project artifacts
- Leverages analysis and rigor applied by risk management team
- Incorporates probability of occurrence and potential cost/schedule impacts
- Mitigation strategies can be incorporated into schedule

Cons

- Requires a mature risk management process
- Some risks may be difficult to model within schedule
- Does not capture duration uncertainty

2.6. Technique #6: Schedule Estimating Relationships (SERs)

Parametric analysis can be applied to schedules using methods similar to those used in cost estimation. Typically this is done through development and application of SERs. Usually derived through regression analysis, SERs are mathematical formulas expressing a relationship between technical and programmatic factors and schedule durations. As a purely hypothetical example, the development contract for an IT system may be modeled as a function of estimated source lines of code (SLOC) required, the number of software engineers assigned to the project, and a binary variable representing a requirement to integrate the system into an existing platform. While SERs are often used as a method of schedule construction rather than "risk analysis", they can be effectively applied to calculate schedule margin, contingency, or potential project outcomes in early acquisition environments.

Because SERs are based on regression and mathematical models, there are two methods where risk and uncertainty can be applied. First, results of the regression analysis can be used to generate a prediction interval for the target duration (the dependent variable in the equation). This range of outcomes is backed by data, rigorously derived, and easily explained to project stakeholders as best case/worst case durations. Second, the SER formula allows the scheduler to change inputs and assumptions feeding the equation to see the impact on the duration result. Using the same IT system example from above, a project may have only a rough estimate for the SLOC that will be required on the development contract. The SER could be used to generate both an optimistic and a conservative estimate for the contract duration based on engineering input. In this way the SER allows for rapid modeling of uncertain inputs.

Pros

- Analysis is backed by actual data
- SERs, once developed, may be used for future projects
- Easy to model the impact of changing assumptions
- Works well as a crosscheck/secondary methodology

Cons

- Difficult to gather data that is reliable and relevant
- Unlikely to be applicable to task level analysis

2.7. Technique #7: Subjective Assessment

A subjective assessment is high-level input based on leadership, SME, or scheduler input that can be used as a last resort if no additional information is available to conduct a more informed risk analysis. When creating a program schedule, risk and uncertainty need to be considered, even in an early acquisition environment. If Techniques #1-6 cannot be conducted, a subjective assessment is the minimal amount of effort that can be put towards quantifying program unknowns. The process consists of looking at major program elements, such as milestones, and having a project stakeholder estimate a reasonable range of outcomes. The process is efficient and can be done within a single session where the SMEs provide their "best guess" to the best case/worst case/most likely case for each of the milestone dates. This strategy does not provide much insight into the justifications behind the variance of the milestone dates, but it also does not require a mature IMS or information on specific program risks. This is most applicable for programs very early-on in the acquisition process and should be built upon as the program matures.

Pros

- Can be done in a single sitting
- Does not require mature schedule products

Cons

- Limited justifications in forecasted dates
- Bare-bones estimate
- Requires SME to have a deeper understanding of program milestones

3. Informed Recommendations

There are many factors that should be considered to determine the best technique for a schedule risk and uncertainty assessment on a project schedule. In the end, one technique might not be a perfect fit and a hybrid of two or more will better meet program needs.

Schedules should continue to be refined throughout the program lifecycle. Similarly a schedule risk analysis is not a "one and done" effort. As the program grows and matures, the assessment of schedule risk should be refined with more reliable and accurate information as it becomes available. Through this iterative process, the technique(s) used in the schedule risk analysis can change. An initial risk analysis may be based on a very high-level subjective assessment and then, as the schedule is built out, transition into a modified or traditional SRA. Table 1 below provides an example of how multiple schedule risk analysis techniques can be combined in a single schedule. This schedule risk methodology matrix shows a program WBS alongside the selected schedule risk technique for each element with supporting rationale. While this is an extreme example of blending techniques, it is meant to be illustrative of how a hybrid model can be constructed with some considerations that may inform the choice of risk and uncertainty analysis technique.

WBS Description	WBS Lvl	Risk & Uncertainty Application	Scenario
Sample Program Name	**1**		
Development	**2**		
Government Design	3		
Warfare Center	4	Traditional SRA	A detailed IMS exists with historical and SME information to inform applicable uncertainty distributions and risks
Contractor Support	4	Modified SRA	A very detailed IMS exists but common groupings of designs can be identified for Software, Hardware, and Electrical. Tasks are bucketed and assigned an uncertainty distribution. Risks are still captured within the SRA
Vendor Development Contract	3		
Systems Engineering	4	Applied Risk Factor	Analysis of 10 analogous contracting efforts shows an average delay of 15% of the baseline duration
Prototype HW Fabrication	4	Risk Register	Parts procurement risk identified, and mitigation steps built into schedule if part delayed
Integration	4	Subjective Assessment	A SME identifies 50 days/100 days/250 days as the low/most-likely/high duration estimates for integration
Vendor Test	4	Schedule Estimating Relationship	A regression analysis considering the team size, test range availability duration, and test type generates a worst case of 40-days and best case of 15-days for the duration of the test event
Government Test	3	What-If Analysis	As a major milestone event, the system cannot be fielded if the test fails and there is a rework necessary. Two scenarios are modeled; one where the system passes and one where it does not

Table 1: Applications of Techniques

This also brings up the concept of “rolling wave planning” and applying it to the schedule risk process. Rolling wave planning can be described as an iterative process in which portions of the schedule are detailed out over time as new or better information becomes available. It allows detail to be focused on near-term performance while setting up long-term objectives. In the case of programs in the early acquisition phase, there may be greater schedule and risk information in the nearer half of the program, so a more in-depth SRA can be done. To start, a higher-level assessment can also be done on the latter half of the schedule and as it matures and develops, there can be a more in-depth risk analysis applied to that portion of the schedule.

4. Additional Considerations

In addition to the techniques described above, there are other schedule factors to be taken into consideration when doing a risk and uncertainty analysis.

A major aspect of scheduling is critical path management. When running a risk and uncertainty analysis, the scheduler may opt to focus on the critical path, directing attention to elements most likely to drive the project end date. It should be noted, however, that the critical path in execution is not necessarily the one that currently exists within the schedule. Near critical tasks can easily become critical when factoring in risk and uncertainty. Once schedule variation is accounted for, new potential critical paths and near critical path elements can be identified. This information will help program managers know what items to track more closely and where friction points and heightened risk may exist within the schedule.

Friction points exist for resources as well as tasks. A risk and uncertainty analysis done on a fully resourced schedule can identify potential conflicts not evident in the deterministic schedule. For example, a schedule risk and uncertainty analysis may reveal that a labor resource has a 25% chance of being assigned to two full time tasks simultaneously. This type of analysis can be performed for personnel, key equipment, facilities, and other limited resources.

An integrated master schedule is distinguished by the word "integrated". To form a program IMS, there are inputs from multiple sources. As stated in Section 2.2 Technique #2: Modified SRA, an input could be individual schedules with varying levels of quality and detail. The level of maturity of inputs can change the way the results are interpreted. The outcomes of an uncertainty and risk analysis for a more immature schedule do not hold as much weight as the outputs from one that is done on a fully developed IMS with informed inputs. Different techniques may need to be applied to portions of the schedule or the schedule should be rolled up to the same level and mature with the development of the most immature portion.

Results from the risk and uncertainty analysis can be presented differently based on the technique used as well as the maturity of the schedule. A PRS, Gantt chart, or other graphic should be produced to represent the IMS along with impacts of risk and uncertainty in a clear and digestible manner. A traditional or modified SRA can produce an S-curve to show major program dates at different confidence levels. As an alternative, an overarching milestone PRS could be helpful to show where all of the major program dates fall at varying confidence levels. There is no set guidance for the best method to showcase schedule risk, but all visuals should communicate a story on the impacts the risk and uncertainty outcomes have on the project plan.

Ultimately, cost and schedule within a project will have a relationship. Cost and schedule are tightly linked in program execution, and schedule extensions will drive cost growth through duration increases to level of effort (LOE) tasks. Many elements in a cost model may have time dependent components, and performing a schedule risk and uncertainty analysis can improve cost uncertainty modeling by demonstrating the impact of schedule changes on cost results. Additionally, if a project shifts work into different funding periods, then the cost estimate will have to be adjusted to reflect the changes to the required budget. The schedule risk and uncertainty analysis can be used in this case to ensure funding is aligned to planned execution and identify potential shortfalls early. Finally, an advantage of performing an integrated cost and schedule risk assessment is the ability to model and quantify the relationship between cost and schedule. Joint confidence levels (JCLs) can be identified, allowing the project to plan for combined cost and schedule outcomes that are truly achievable. While many of these benefits may be difficult to obtain in an early acquisition environment, immediate attention to schedule risk and uncertainty analysis will help the project gain maximum benefit from the schedule as the effort matures.

5. Conclusion

Schedules are fundamentally models of work that will be performed to complete a program. Like all models, schedules are based on ground rules, assumptions, inputs, and calculations that try to predict real world outcomes, but in large, complex acquisition efforts, these model elements are never fully known. GAO's Scheduling Best Practices recognize the importance of understanding schedule risk, but their guidance is focused on a robust schedule risk analysis requiring a detailed integrated master schedule and substantial time to construct. In early acquisition, conducting a traditional SRA may not be feasible, or even advisable. This does not make it any less critical to develop an understanding of schedule risk and uncertainty. At all phases of a project lifecycle, leadership and schedulers should be cognizant of the assumptions and input driving their finish dates. Without some assessment of schedule risk and uncertainty, project managers will be unable to report realistic completion dates for their projects, there will be little opportunity for proactive risk identification and mitigation, and stakeholders may be surprised when deadlines are missed, and handoffs fail to be completed when needed.

Estimating schedule risk and uncertainty in an early acquisition environment may require creativity on the part of the project scheduler. This paper has attempted to identify techniques that could be useful when a traditional SRA cannot be completed. These techniques all have advantages and drawbacks, and it is important to consider the nuances of a project before selecting any appropriate methodology. Importantly, projects should consider a hybrid methodology, combining techniques as needed to achieve a realistic understanding of potential project outcomes. When used effectively, schedules can reflect reality, anticipating challenges and identifying setbacks while leadership still has time to act.

Appendix A: Table of Acronyms

Acronym/Abbreviation	Meaning
AS	Acquisition Strategy
COA	Course of Action
FY	Fiscal Year
GAO	Government Accountability Office
IMS	Integrated Master Schedule
IT	Information Technology
LOE	Level of Effort
PM	Program Manager
PRS	Program Roadmap Schedule
SER	Schedule Estimating Relationship
SLOC	Source Lines of Code
SME	Subject Matter Expert
SRA	Schedule Risk Analysis
WBS	Work Breakdown Structure

AUGUR

Appendix B: References

References

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