Army Materiel Systems Analysis Activity

# TECHNICAL REPORT NO. TR-19-02

# AMSAA SCHEDULE RISK GUIDEBOOK

**OCTOBER 2018**

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**U.S. ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY**
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The purpose of the AMSAA Schedule Risk Guidebook is to concisely document and socialize AMSAA's schedule risk methods and bring awareness to other areas in which Schedule Risk Assessments (SRAs) could be applied. Serving as the principal authority of SRAs for Army-led Analysis of Alternatives (AoA), AMSAA typically performs risk analyses to provide insight into a program's, project's, and/or system's detailed scheduling needs and risks. AMSAA's SRA framework is flexible, thereby allowing for the schedule risk methodology to be tailored to each study's unique circumstance and to be applied to any effort where critical schedule objectives exist. As such, opportunities exist to further expand the scope of SRAs to various areas, which are described within this document.

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## LIST OF ACRONYMS

| | |
|---|---|
| ACAT | - Acquisition Category |
| ACC | - Army Contracting Command |
| AMSAA | - U.S. Army Materiel Systems Analysis Activity |
| AoA | - Analysis of Alternatives |
| ATEC | - Army Test and Evaluation Command |
| CDF | - Cumulative Density Function |
| CDR | - Critical Design Review |
| CT | - Critical Technology |
| DAMIR | - Defense Acquisition Management Information Retrieval System |
| DoDI | - Department of Defense Instruction |
| ECP | - Engineering Change Proposal |
| FRP | - Full Rate Production |
| FUE | - First Unit Equipped |
| GAO | - Government Accountability Office |
| IOC | - Initial Operational Capability |
| IPT | - Integrated Product Team |
| IRL | - Integration Readiness Level |
| IT | - Information Technology |
| JCIDS | - Joint Capabilities Integration Development System |
| KPP | - Key Performance Parameter |
| KSA | - Key System Attribute |
| KT | - Key Technology |
| LRIP | - Low-Rate Initial Production |
| MCS | - Monte Carlo Simulation |
| MDA | - Milestone Decision Authority |
| ML | - Most Likely |
| MRL | - Manufacturing Readiness Level |
| MS | - Milestone |
| PEO | - Program Executive Office |
| PM | - Program/Project Manager |
| QRC | - Quick Reaction Capability |
| RDEC | - Research, Development, and Engineering Center |
| S&T | - Science and Technology |
| SME | - Subject Matter Expert |
| SRA | - Schedule Risk Assessment |
| SREDM | - Schedule Risk Event-Driven Methodology |
| TR | - Technical Report |
| TRA | - Technology Readiness Assessment |
| TRL | - Technology Readiness Level |
| WSARA | - Weapon Systems Acquisition Reform Act |

## EXECUTIVE SUMMARY

The U.S. Army Materiel Systems Analysis Activity (AMSAA) performs independent, in-depth, and actionable Schedule Risk Assessments (SRAs) to enable senior Army leaders to make sound materiel acquisition decisions for the timely delivery of future capabilities. Serving as the principal authority of SRAs for Army-led Analysis of Alternatives (AoAs), AMSAA's risk analyses are performed to provide insight into a system's detailed scheduling needs and risks, inform decisions on appropriate acquisition strategies, address the impacts of schedule acceleration opportunities, and support requirements development.

The purpose of this Guidebook is to concisely document and socialize AMSAA's schedule risk methods and bring awareness to other areas in which SRAs could be applied. Section 2 provides the recommended approach to conduct an SRA. However, AMSAA's SRA framework allows the method to be tailored for each study's unique circumstance and can be applied to any effort where critical schedule objectives exist (to include those outside the scope of acquisition system development and associated risk). The scope of AMSAA's independent SRAs can also be expanded, to include (but not limited to) providing dedicated schedule risk support for Program/Project Managers (PMs), Program Executive Offices (PEOs), and for Technology Readiness Assessments (TRAs). SRAs could also be applied to Science and Technology (S&T) and sustainment areas to inform future materiel readiness.

Schedule risk, as it relates to defense acquisition, is defined as the likelihood and consequence of a system not achieving critical schedule milestones and/or events by objective dates. AMSAA conducts SRAs by using event-driven models that consider risk and uncertainty in order to provide estimated times for a program/project to achieve key schedule milestones. A critical component of schedule risk is technical risk. AMSAA's methodology primarily focuses on capturing technical risk by analyzing the schedules and risks associated with maturing and integrating technologies from the component through the system-of-systems level. This includes considering the development of the technology, along with its manufacturing and integration into a larger system. Focusing on these areas, AMSAA's SRA process is applied to investigate the estimated time required to complete system development (e.g., technology maturation, individual technology tests, etc.) and programmatic tasks (e.g., contract awards, documentation, etc.) to achieve key milestones. AMSAA also evaluates risks and opportunities that may delay or accelerate each task. A unique feature of AMSAA's SRAs is the use of a structured, consensus-based approach to gather data and build schedule networks amongst qualified Subject Matter Experts (SMEs) from the acquisition S&T, testing, requirements, and program office communities. This is an iterative process that typically includes a Schedule Risk Workshop, where SMEs are gathered to build consensus on the assumptions and inputs that will inform the SRA.

Through AMSAA's SRA construct and subsequent risk analysis, AMSAA provides the analytical link between the technical, programmatic, and testing SMEs and senior Army leaders. The main outputs of the SRA include, but are not limited to: forecasts of the estimated time to achieve program milestones; the probability of meeting objective fielding dates; identification of major schedule and technical drivers and risks; and risk mitigation analysis. The remainder of this document defines the SRA in greater detail, provides an overview of the recommended SRA approach, and details potential applications of the schedule risk methodology to various areas.

# 1. INTRODUCTION

## 1.1 Preface

Schedules provide a road map for program/project execution, to include a sequential understanding of the activities (and associated durations) required to reach key milestones. Building integrated schedules provides awareness regarding the activities that drive the schedule, the estimated completion timeframes, and the necessary background information to adequately consider trades between schedule, cost, and performance. Based on the guiding principles in the 2009 Weapon Systems Acquisition Reform Act (WSARA) and the Department of Defense Instruction (DoDI) 5000.02, AMSAA led the Army Risk Integrated Product Team (IPT) in 2011 in order to develop methods to conduct technical, schedule, and cost risk assessments. Since that time, AMSAA has continued to develop schedule risk methods and has established a standard, quantitative, and repeatable SRA process. Additionally, a 2009 Government Accountability Office (GAO) Report also found that acquisition programs that completed AoAs with comprehensive risk assessments "…tended to have better cost and schedule outcomes than those that did not." [1] In many cases, the reliability of a schedule determines credibility with senior decision makers. As such, SRA results help to construct and inform an executable event-driven schedule that considers the potential for risks and delays.

This Guidebook replaces the "Army Independent Risk Assessment Guidebook," published in April 2014. [2]

## 1.2 Background

The intent of AMSAA's SRA methodology is to provide estimated times for a program/project to achieve key milestones by using event-driven schedule models that consider risk and uncertainty. SRAs also identify schedule and technical risk drivers, inform risk mitigation planning, and detail the impacts of schedule acceleration opportunities.

AMSAA employs a standard SRA methodology that is accepted across government, private industry, and academia. As an independent analytic organization, AMSAA uses statistical techniques to perform SRAs, while using inputs generated from a robust data collection approach that assists in challenging and removing biases. Notably, AMSAA employs a unique, structured, and consensus-based data collection approach, which serves as the foundation for AMSAA's risk assessments. Based on the information collected, AMSAA analyzes and interprets the results to enable senior Army leaders to make risk-informed decisions. The results are also used by PEOs/PMs to optimize acquisition strategies, justify maintaining or adjusting existing schedules, and develop specific and targeted risk mitigation plans to reduce the likelihood of schedule delays.

Through incremental improvements, AMSAA has developed a repeatable, quantifiable, and flexible SRA method that has been applied to analyses addressing pre-Milestone (MS) A through post-MS C systems in the defense acquisition sector. AMSAA serves as the principal authority of SRAs for Army-led AoAs, and has applied the SRA methods listed in Section 2 of this Guidebook to numerous Army acquisition systems/programs since FY12. Analysis results are primarily used to forecast when a system will meet key schedule milestones, along with identifying the associated schedule and technical risk drivers. However, the flexibility within AMSAA's SRA method enables it to be tailored for application to the individual study or program/project under evaluation.

Opportunities also exist to expand and slightly modify the SRA methods for application to other areas, which include (but are not limited to) providing dedicated schedule risk support for the PEO/PM, contract, and test communities; conducting pre-MS B TRAs; identifying technical risks for S&T activities; and evaluating the effects of technology development on sustainment areas to inform future materiel readiness. The SRA framework could also be further enhanced by developing a robust historical program schedule database inclusive of Acquisition Category (ACAT) I, II and III programs for use in schedule analysis. This information (if available) could be used in regression analysis to further substantiate SRA results and/or provide PMs with additional information to build informed schedules based on historical programs.

Regardless of the SRA's specific application, AMSAA's methodology allows for risk-informed schedules to be built and analyzed to provide needed scheduling information to support system and/or project decisions for various acquisition strategies.

## 2. SCHEDULE RISK ASSESSMENT METHODOLOGY

### 2.1 Standard Four-Step SRA Process

The approach utilized to conduct an SRA can be broken down into four simple, repeatable steps: 1) Form the schedule network; 2) Define uncertainty; 3) Conduct Monte Carlo Simulation (MCS); and 4) Interpret the output. This process has the distinct advantage of having applicability to any type of SRA, whether to support a detailed AoA or another type of quick turn analysis process. Figure 1 provides a brief depiction of the process.

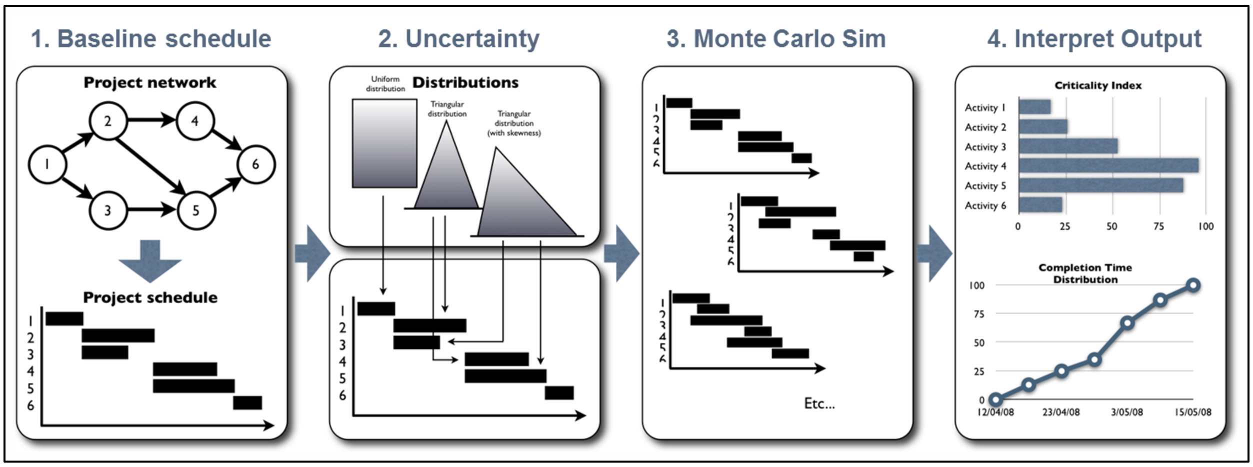


**Figure 1. Four-Step SRA Process**

The core of AMSAA's four-step SRA process is the Schedule Risk Event Driven Methodology (SREDM), which is used to build schedule networks and define the MCS inputs. SREDM is an event-driven schedule modeling procedure that identifies and sequences specific critical tasks that a system must complete to reach Initial Operational Capability (IOC), First Unit Equipped (FUE), Full Rate Production (FRP), or another similar schedule end point. The process leverages technical and programmatic SMEs to assist in the development and completion of the necessary analysis. The use of Key Technologies (KTs), SMEs, targeted surveys, and Schedule Risk Workshops (explained below) differentiates SREDM from other schedule modeling techniques.

The SME-provided schedule data feeds a statistical simulation to produce a distribution of possible completion dates and identify high-priority schedule risk drivers through critical path analysis. Potential reductions in schedule risk are investigated by examining how mitigation strategies and acceleration opportunities impact simulation outputs.

Conducting SRAs in this nature highlights and quantifies the potential risks, given the best information on prospective system details at the time of the analysis. This alerts senior leaders to focus on obtaining information and generating feasible requirements, which can reduce adverse consequences from occurring later in the process. The following sub-sections detail the typical steps of an SRA in greater detail.

### 2.1.1 Form the Baseline Schedule Network (Step 1)

The objective of this step in the process is to develop schedule network models that are representative of a system's development process. Schedule networks consist of:

- Programmatic activities (e.g., contracting, source selection, etc.)
- Technology development and integration activities (e.g., technology maturation, testing, integration, building prototypes, etc.) that must be completed for a system to reach key program milestones
- System-level testing activities
- Manufacturing test articles (e.g., Low-Rate Initial Production (LRIP), FRP)
- Activity relationships/dependencies that specify the sequence of activity completion
- Risk events that have the potential to impact development activities

#### 2.1.1.1 Define Key Efforts, Schedule Assumptions, and Technical Maturity Level Consensus

The schedule networks built in this step begin with developing an understanding of the KTs within a system. KTs are normally identified to address component level maturation and are usually important schedule risk discriminators between systems. They also serve as an important factor in trades analysis. SRAs can still be performed without identifying KTs, especially in instances in which a system's technical development cannot be broken down into individual component maturation activities or if less detail regarding technical maturation is required for the SRA. General criteria to determine KTs are as follows:

1. Does the technology pose major technological or integration risk during development?

*If the answer to question 1 is "Yes", then the technology is key.*

2. Does the system depend on this technology to meet Key Performance Parameters (KPPs), Key System Attributes (KSAs), or designed performance?

3. Is the technology or its application new or novel or is the technology modified beyond the initial design intent?

*If the answer to question 2 and 3 is "Yes", then the technology is key.*

Schedule networks account for the process required for a KT to be matured and integrated. Information regarding current KT maturity levels helps to identify what activities need to be completed to mature the technology and integrate it within the overall system. Frequently, SMEs discuss each system's Technology Readiness Level (TRL), Integration Readiness Level (IRL), and Manufacturing Readiness Level (MRL) based on set definitions to form a starting point for schedule analysis. Appendix A provides the TRL/IRL/MRL definitions that are normally used to support readiness level discussions. The readiness levels identified are meant to begin discussions for schedule modeling and the maturation activities that need to take place. The readiness level maturity assessment typically conducted to inform an SRA does not serve as a formal TRA. However, the SRA framework and methodology could be applied to conduct a formal TRA and determine the estimated time in which technologies would reach TRL 6. The application of the SRA framework to formal TRAs is further discussed in Section 3.

In addition to defining the KTs for each system, the schedule assumptions for the SRA should be carefully thought out during upfront discussions. Schedule assumptions are certain criteria that impact when a system can begin development, testing, or production. These assumptions can determine how schedule models are built and can define the parameters for how MCS are run. Some common schedule assumptions include, but are not limited to:

- The timeline for when funding for development, testing, or production is available and from what entity it is derived.
- Each system's acquisition entry point (MS A, MS B, or MS C) and estimated date for entry.
- Requirements to reach the key schedule milestone or endpoint (e.g., certain number of manufactured products to reach IOC, etc.).
- The current acquisition strategy. This will determine if the system follows the typical Joint Capabilities Integration Development System (JCIDS) process or utilizes a different acquisition approach (Engineering Change Proposal (ECP), Quick Reaction Capability (QRC), Information Technology (IT) Box, Capability Drops, etc.) in order to field the system at an earlier date.
- The criteria for a KT to achieve TRL 6. TRL 6 is defined as a system/subsystem model or prototype demonstration in a relevant environment. The requirements for a realistic prototype and the specifics behind the definition of "relevant environment" can differ from system to system. For example, a ground test may be sufficient to achieve a relevant environment test for a rotary wing aircraft sensor, whereas new rotor blades may need to be flown through various winds and weather to achieve this same standing.
- Who the Milestone Decision Authority (MDA) will be. This can determine whether the entrance criteria for milestones will be kept to the typical strict acquisition process or if there may be waivers to exclude certain requirements.

#### 2.1.1.2 Develop Schedule Network Models

Once the schedule assumptions have been agreed upon by all stakeholders, SREDM can be utilized to develop a sequenced network of tasks needed to advance each system from its current level of maturity to the objective end point. This schedule network is broken down into two main areas. The first area is the individual technology development stage. This will determine the path of activities necessary to progress each technology, within a system, from its current agreed upon maturity level to the maturity required for a combined prototype build or testing activity. Each technology will form its own swim lane of activities until the point at which individual technology development is complete. In the typical acquisition process, this would be sometime around Milestone B or Critical Design Review (CDR). In general, technologies progress independently in this area of the schedule network, but interdependencies between technologies are taken into account within schedule models, as needed.

After each technology has progressed to the point where they are ready for combined system-level testing and development, the schedule network will condense from several technology swim lanes to one system-level lane. In Figure 2, this is illustrated in the "KT Integration" block.

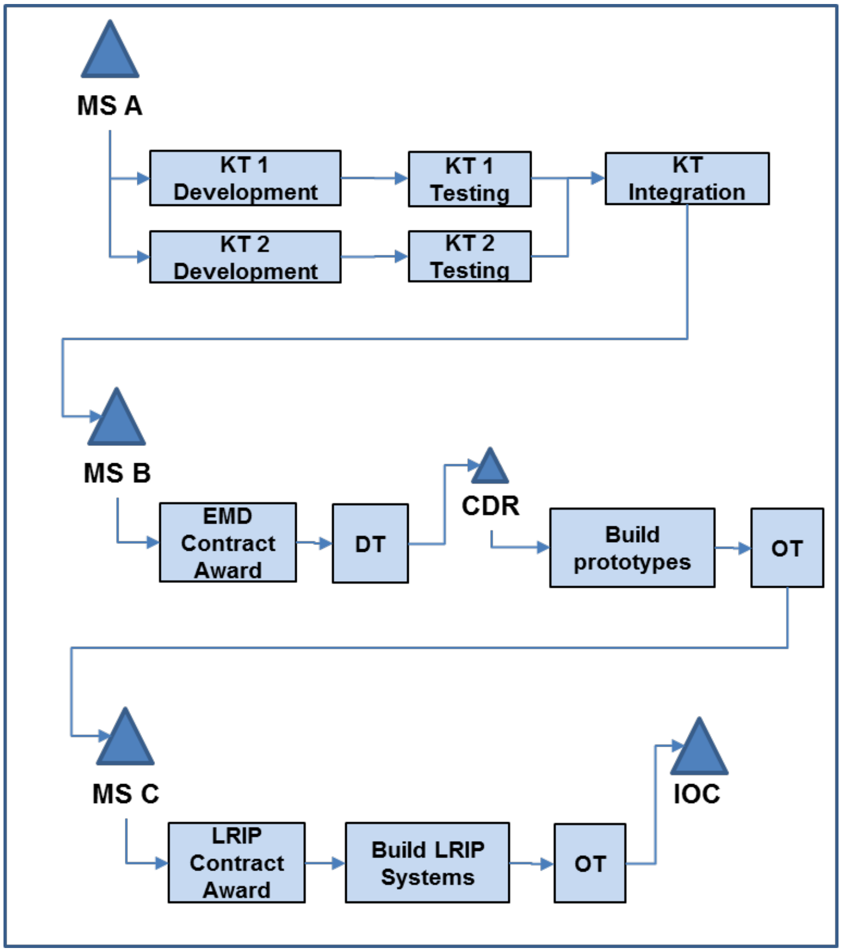


**Figure 2. Notional Schedule Network Example**

Once progressing past the "KT Integration" area of the schedule network and establishing a system-level swim lane, individual technology development is no longer a schedule driver unless there are performance failures and significant redesign is required. Incorporating the probability and consequence of a technical risk, such as performance shortfalls or integration challenges, will be discussed in Section 2.1.1.3. For the most part, activities that are identified within or after the "KT Integration" area are system level in nature (e.g., Developmental Testing with pre-production prototypes, LRIP builds, overall design documentation, qualification testing, logistics demonstrations, manufacturing processes, etc.), so the timelines will naturally coalesce into one or a few concurrent paths of events and activities.

Schedule network development should consider activities that typically occur, or are expected to occur, and dependencies that represent the amount of overlap/parallel completion that occur between activities. Schedule development continues until the activities required to reach the agreed upon end point have been identified. The next step is to incorporate risk events in the schedule in order to accurately reflect program behavior.

#### 2.1.1.3 Incorporate Risk Events

At this point in the SRA four-step process, there is a solid base schedule network from which to expand. The first addition is including technical/integration/programmatic risk events into the network. A risk event is defined as an uncertain event or condition that, if it occurs, has a negative impact to the schedule, cost, or performance of the system. The goal is to identify risk events that would have a significant impact on the time required for a system to meet key milestones and, more specifically, which modeled activities would be affected. The risk events identified in this stage are those that can be modeled probabilistically and are incorporated into the schedule model (see orange blocks in Figure 3). Other risk events that may impact performance or cost, but not necessarily schedule, should be documented as well in order to inform the appropriate analysis areas.

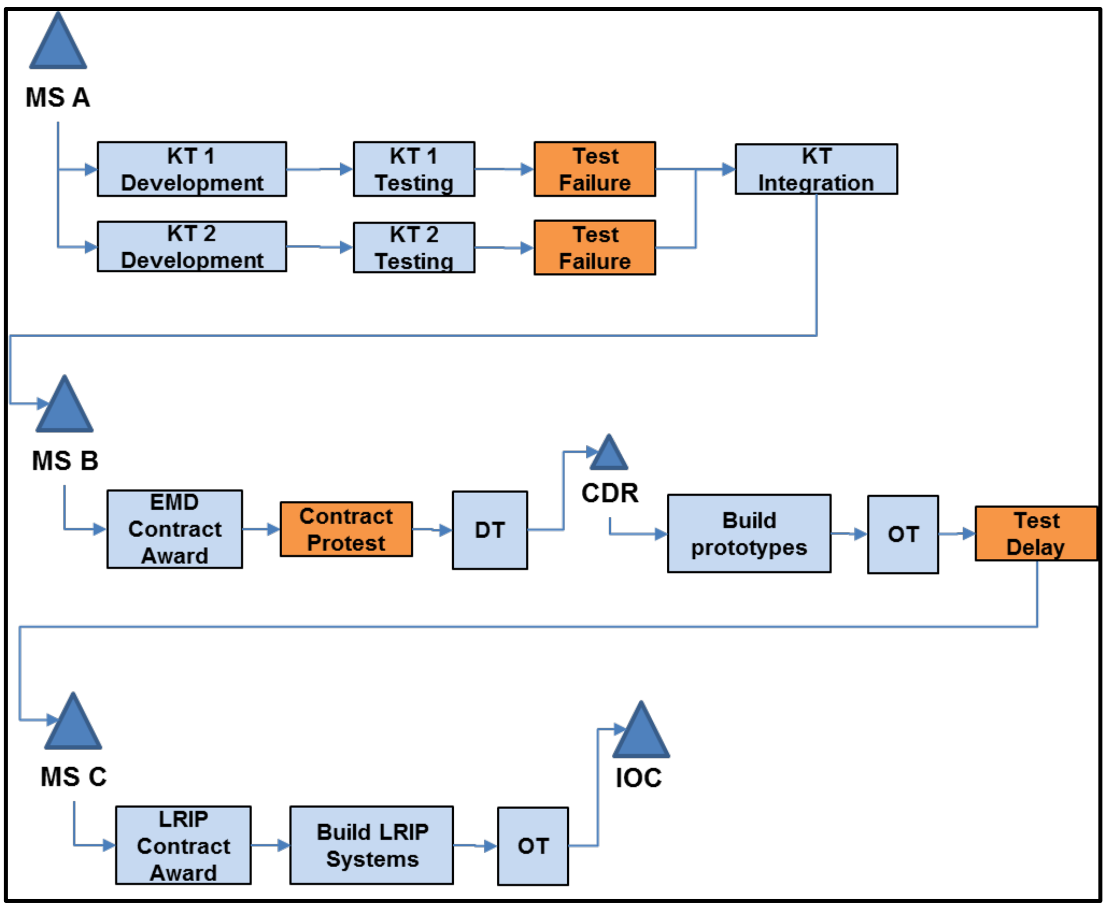


**Figure 3. Notional Schedule Network (with Risk Events)**

Incorporating risk events within the schedule network provides a 'baseline' schedule model that represents the activities (within the planned acquisition strategy) to mature and field the system, along with the risks that could delay the schedule. This 'baseline' schedule model serves as the backbone for the analyst to elicit information from SMEs regarding potential schedule acceleration/reduction opportunities (Section 2.1.1.4) and to define the uncertainty for each activity identified within the schedule networks (Section 2.1.2).

#### 2.1.1.4 Schedule Acceleration/Reduction Opportunities and Associated Changes to Assumptions/Risks

In addition to including risks that may lengthen the schedule, it is important to identify schedule acceleration/reduction opportunities — places within the sequence of activities where the potential for schedule reduction exists. Based on the opportunities identified, a separate 'accelerated' schedule network can be created to identify the impact of the acceleration/reduction opportunities, document any changes in schedule, cost, and/or performance assumptions, and compare 'accelerated' schedules against 'baseline' schedules. Some schedule acceleration/reduction examples include:

- Increase Performance Risk – reduce/eliminate schedule activities and accept more performance risk. For example, reduce a developmental test by six months, but the schedule reduction may raise the probability of not achieving a performance goal.
- Relax Performance Requirements – reduce/eliminate specific technical performance requirements. There may be time savings if the system no longer needs to meet certain performance standards.
- Relax Acquisition Requirements – reduce/eliminate acquisition requirements. Depending on the MDA for the system, there may be waivers granted for specific acquisition activities.
- High-Risk Technologies – remove or replace high-risk technologies with more mature technologies. This could lead to a reduction in performance, but may allow the schedule objectives to be met.
- Schedule Strategy – change sequencing/location of schedule activities, to include adjusting activities so that they occur in parallel fashion (vice in sequence). For example, if a MS B entry is desired, much of the development work normally performed in the Technology Maturation and Risk Reduction acquisition phase (pre-MS B) could be moved into the EMD phase (post-MS B). This could reduce the schedule, but increase the risk of issues later in the acquisition cycle.
- Increase Cost – apply more resources (e.g., increase test assets) to schedule activities or invest more heavily in technical development early in order to reduce risk in the future.
- Other Acquisition Strategies – assess the impact of other acquisition strategies outside of the typical JCIDS process.

### 2.1.2 Define Uncertainty (Step 2)

The next step in the SRA process is to define the timelines for each schedule activity in the network. Each identified schedule activity has an uncertainty duration that depends in part on uncertainties about required effort, task complexity, and expected resources. Risk events include uncertainty durations (consequences), along with a probability of occurrence (likelihood of the risk event occurring). Estimates of uncertainty are forecasted based on the best information available at the time. SME assumptions regarding each system design (such as current maturity, required maturation needed, productivity, and availability of manufactured materials) factor into these uncertainty determinations. If historical data is available at this detailed level, it can be used to inform SME estimates and serve as an initial timeline to expand upon. Uncertainty estimates are elicited for both 'baseline' and 'accelerated' schedule network tasks and risk events.

#### 2.1.2.1 Activity Duration Estimates

Each schedule activity has a distribution of possible completion times, which serve as the primary input data into the MCS. SME three-point estimates (minimum [min], maximum [max], most likely [ML]) on activity completion times are used to fit triangular (or beta-PERT) distributions that are then inputted into the MCS. It is critical that these estimates are well thought out as they will drive the final distribution of schedule outcomes. As such, SMEs should consider the following assumptions when making schedule judgments on activity duration estimates:

**Table 1. Assumptions to Support SMEs in Developing Activity Duration Estimates**

| Assumption Area | Minimum Estimate Assumptions | Most Likely Estimate Assumptions | Maximum Estimate Assumptions |
|---|---|---|---|
| History | Best case scenarios and anything that makes the activity unique | Typical scenarios and anything that makes the activity unique | Poor scenarios (not including major risk events or issues) |
| Efficiency | Fast acquisition pace; Assume no major schedule, technical, and/or programmatic issues | Expected/normal acquisition pace | Poor acquisition pace |
| Resources | Best skilled, funded, and/or quantity of people | Typically skilled, funded, and/or quantity of people | Poorly skilled, funded, and/or quantity of people (no major funding issues) |
| Complexity | Activity is easier than expected | Activity is as complex as expected | Activity is more complex than expected |
| Fidelity of Requirements | Metrics are well-defined | Expected level of clarity | Poorly defined metrics |

SMEs can provide single point estimates (e.g., 3 months) or uniform distribution estimates (e.g., 3 to 6 months) if they are more or less confident in their ability to predict an activity timeline. In general, SMEs should attempt to consider all assumptions and historical experience in developing the estimates for min, max, and ML times. However, it is critical to note that the chance of major delays or realization of risks (e.g., unplanned redesign) should not be factored into the activity duration estimates. Risk events and associated impacts to each schedule activity are assessed and modeled separately and are discussed in the next section. Figure 4 gives an overview of the process for estimating activity duration.

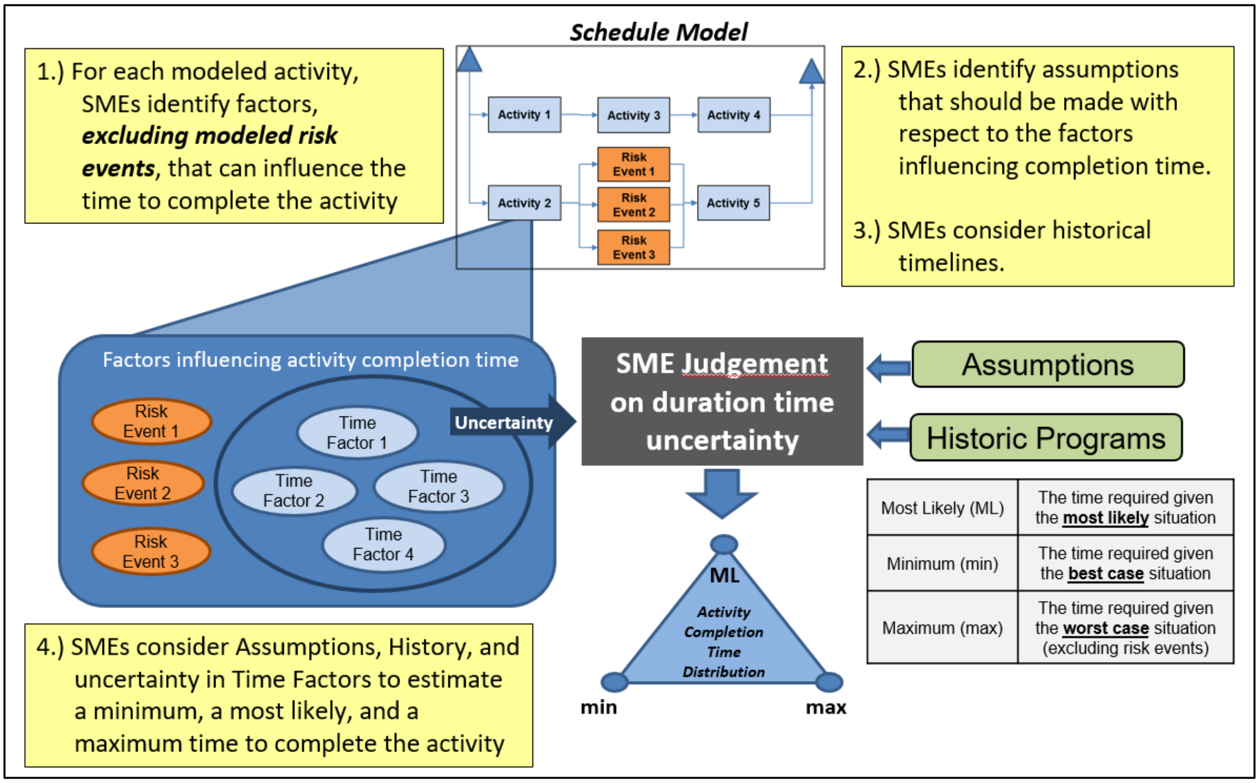


**Figure 4. Activity Duration Estimates Process**

Activity duration estimates include inherent uncertainty, estimating error, and perhaps, estimating bias. For instance, if an SME was conservative about current design maturity when assessing the duration of maturing a sub-system, then the data may have a pessimistic bias. Conversely, other schedule estimates may include an optimism bias based on schedule-driven objectives. Activity durations and logic in a time-based acquisition strategy schedule may be overly optimistic if there is pressure to finish earlier than unbiased duration estimates imply. Understanding these issues is critical in developing realistic schedule estimates.

### 2.1.2.2 Risk Event Estimates

In addition to the activity duration estimates, the likelihood and consequence of a risk event occurring needs to be assessed. Consequence is measured as the expected impact on schedule activity durations if the risk event is realized. Figure 5 illustrates how a risk event would appear on the schedule network model.

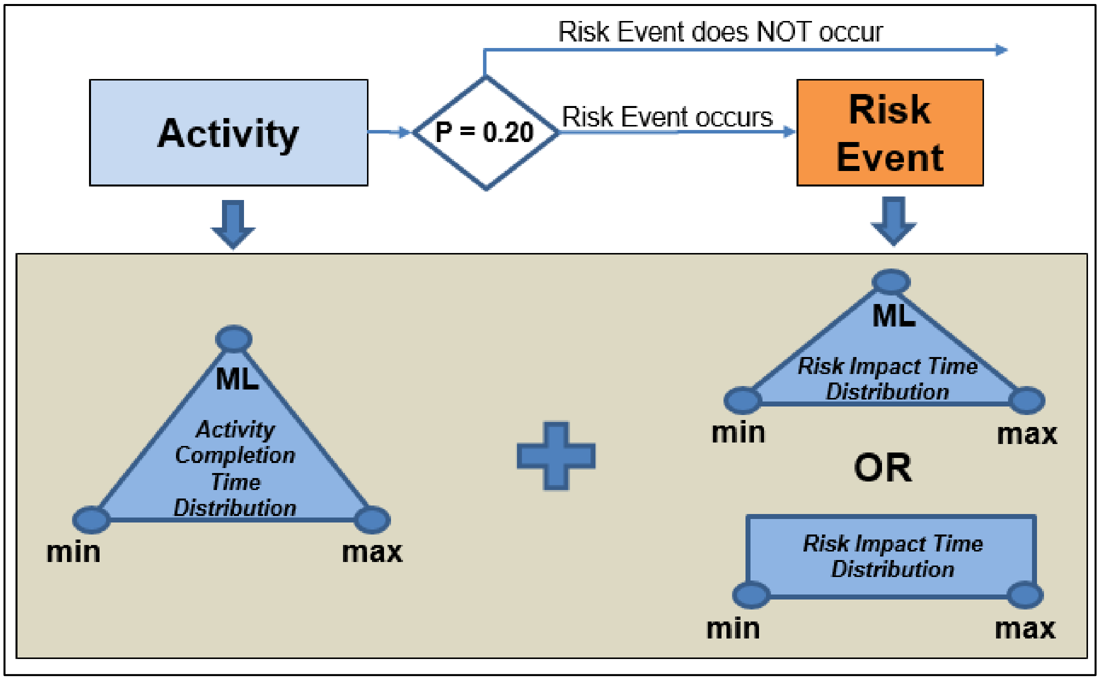


**Figure 5. Risk Event Estimates**

Modeling the impact of risk events separately allows the analysis to better capture how risk events contribute to the overall uncertainty in activity duration. It also removes the possibility of over inflating the timelines for a specific activity. For example, if SMEs considered the set of technical/integration/programmatic risks in the maximum activity estimate, the resulting distribution could unfairly skew to the right (generating MCS results that show longer schedule estimates than what is truly expected). Removing these risks from consideration for typical activity durations allows for a more realistic timeline.

#### 2.1.2.3 Risk Mitigation / Schedule Acceleration

SMEs may be able to mitigate the risks outlined in Section 2.1.1.3 ahead of time and reduce the likelihood of occurrence, the impact to the schedule, or both. SMEs should spend significant time during this step discussing which risk events are most crucial to address and how best to mitigate them. Once risk mitigation strategies have been developed, a new likelihood and consequence for the risk event should be estimated. Additionally, SMEs can use the acceleration opportunities identified in Section 2.1.1.4 to identify the impacts on the sequence of activities and any changes to the uncertainty distributions. During this time, SMEs will also need to consider how these risk mitigations and acceleration opportunities change the schedule assumptions and/or the completion of other activities throughout the schedule. Schedule modelers can use this information to make additional simulation runs, which in turn inform senior leaders on the importance of developing proper risk mitigations. ‘Accelerated’ schedule simulation runs can be performed and then compared to the ‘baseline’ schedule simulation runs to highlight how the application of risk mitigation strategies could potentially influence schedules, determine which risks are most influential in the schedule, and advise decision makers on areas of focus.

#### 2.1.2.4 Correlation

Correlation is inherent within schedule activities. Positive correlation is when two activity durations (i.e., activity pairs) are influenced by the same external force and can be expected to vary in the same direction. For example, assumptions on the maturity of a design and contractor productivity/capability may also affect fabrication and testing timelines. All these activities are assumed to be longer or shorter together (i.e., positively correlated). Specifying correlations between activities ensures that each of the MCS (discussed in Section 2.1.3) represent scenarios in which correlated activity durations are consistently long or short together. Correlation primarily affects the low and high values in the MCS results, with little effect on values near the median. Appropriate correlation coefficients are determined throughout the data gathering process and applied to the MCS to maintain fair comparisons between systems.

### 2.1.3 Conduct Monte Carlo Simulation (MCS) (Step 3)

Because activity durations are uncertain, the probability distribution of each system's total duration must be determined statistically by combining the individual probability distributions of all schedule activities according to their risks and the logical structure of the schedule. An accepted way to do this is to perform a MCS of the schedule with uncertainty and risk applied.

The objective of the MCS is to generate a distribution of potential dates (see Figure 6) for key milestone(s). There are various methods and tools used to conduct MCS, but this report will focus on the use of Microsoft Project and Palisade's @Risk product. These programs were chosen due to their integration abilities with Microsoft products. Microsoft Project is compatible with Microsoft Excel and @Risk is an Excel add-in. Schedules can initially be built in Microsoft Project based on the previous schedule network models from Section 2.1.1.2. They can then be imported directly into Excel using the @Risk add-in. From there, the analyst incorporates the uncertainty (activity duration estimates and risk event estimates) gathered in previous steps into the schedule and MCS runs are made using the @Risk product.

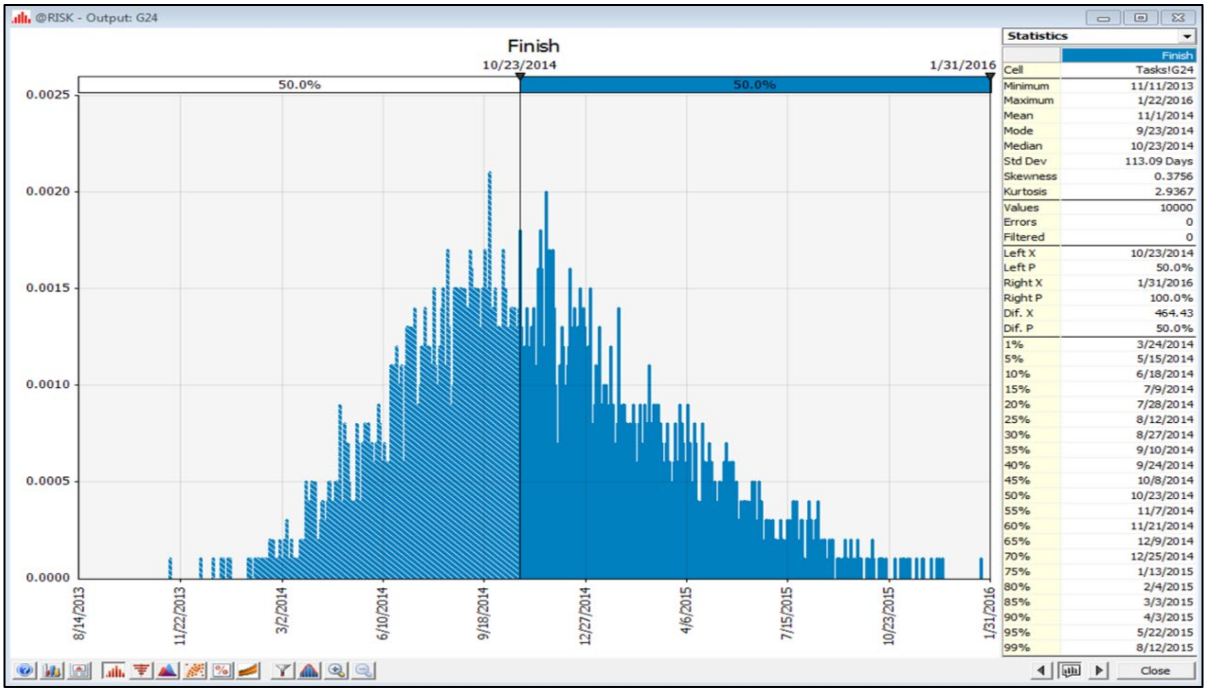


**Figure 6. @Risk MCS Output Example (Distribution of Key Milestone Dates)**

### 2.1.4 Interpret Output (Step 4)

The schedule distributions created from the MCS demonstrate the respective probabilities of meeting potential milestone dates. Cumulative Density Function (CDF) curves can provide valuable information to senior decision makers. A system can match schedule completion dates to a degree of risk tolerance. For instance, senior leaders may want to adopt a completion date that provides at least a 20% chance (i.e. 20% likelihood) that it will finish on or before the objective date. The MCS results can also provide insight into the consequences of not meeting an objective date. Analysts can further evaluate the MCS runs that exceed the objective schedule date to provide an estimate of the delay time (consequence) for the system to reach its end point. Additionally, the MCS results can also identify key schedule drivers and assess the impacts of potential risk mitigation strategies and schedule reduction options. Using various types of analyses (e.g., Critical Path Analysis, Cruciality Analysis, Tornado Diagrams, etc.), each modeled schedule activity and risk event's influence on the final outcome can be determined. Analysts can give leaders a general idea for the expected completion timelines using point estimates (e.g., mean, median, etc.) from the final distribution or can provide box-and-whisker type plots for greater detail. The latter can display the amount of variability in schedule outcome for each system and can influence the suggested path forward. For example, two options may have similar median milestone dates, but have drastically different spreads of possible outcomes. A risk averse leader may choose an option with a slightly longer time to completion if there is better predictability around its finish date.

Lastly, in order to ensure consistency, detailed schedule results should be shared with cost analysts. It is crucial that the cost and schedule analyses use the same assumptions in their respective models. These areas have much overlap and a change in schedule assumptions or results may result in a correlated change in cost.

## 2.2 Data Gathering Technique

In order to ensure that the simulation models and associated output reflect system development appropriately, the data gathering technique for all inputs needs to follow a sound and repeatable process. Historical data at the *detailed activity level* can be difficult to obtain. When historical data at the activity level is available, it can provide insights to assist SMEs in developing uncertainty estimates. Regardless of the availability of historical data, SME consensus is used to gather the SRA inputs needed. Stakeholders from different organizations with varying views on the system development process need to be involved in the estimation of inputs; however, the process to gather and compile data from multiple sources can be convoluted. To combat this issue, AMSAA applies a Delphi Method, or a structured, consensus-based approach for SME estimation, to obtain the data needed to execute the SRA. The Delphi Method works by an SME first developing an estimate alone and then going through iterations of sharing their estimates with a community of experts and receiving feedback. The input is revised until consensus is reached across the community or an SME states that their estimate is final after taking into account all other opinions.

### 2.2.1 Structured, Consensus-Based Approach using the Delphi Method (Iterative Process)

The most important step in gathering data to support the SRA process is to conduct a Schedule Risk Workshop. Prior to the workshop, targeted schedule risk surveys can be sent to SMEs with the purpose of gathering initial individual input on readiness levels and schedule networks for each system (with initial estimated schedule timelines). The survey feedback serves as a starting point for workshop discussions. Appendix B provides a notional survey example in a Microsoft Excel format, although the survey could be administered in a variety of ways. Through the survey feedback and input received at the Schedule Risk Workshop, SMEs also identify and evaluate technical and programmatic risks that may cause schedule delays. When conducting an SRA, it may not be feasible to hold a formal Schedule Risk Workshop. In these cases a consensus-based approach would still be applied, but it may require obtaining the necessary data through other means (e.g., teleconferences, e-mail exchanges with SMEs, etc.).

### 2.2.2 Gather Independent SMEs

When identifying SMEs that will support the assessment, it is important to include individuals from various areas who can bring different perspectives to the problem. For example, it is crucial to have an SME from the testing community involved to provide data regarding testing activities, and also to serve as a check against overly optimistic or pessimistic schedules. Below is an example list of SMEs that normally contribute to the SRA.

**Table 2. SMEs and Roles that Support SRAs**

| SME Type | Role |
|---|---|
| Program Manager | Provides valuable insight into which specific activities are going to be crucial for each system. Experience with other programs is useful in determining system schedule paths. PMs also provide the planned acquisition strategy for the program, to be expounded upon later. |
| Testing SME | Illustrates which testing activities may take longer or which can be waived under certain circumstances. |
| Technical SME | Provides development timelines for key technology maturation. |
| Acquisition Expert | Informs which acquisition strategies are most appropriate for each system under evaluation and how timelines may be accelerated. |
| User Representative | Provides input and clarification regarding system requirements that must be met in order for technologies and/or systems to be deemed effective. |
| Cost Analyst | Uses discussions during workshop to inform cost analysis. |
| Study Lead | Addresses study-specific questions, which can help scope the SRA. |

### 2.2.3 Conduct Schedule Risk Workshop

Once the final SME list has been determined and any pre-Schedule Risk Workshop surveys have been collected, the Schedule Risk Workshop can be conducted. Pre-Workshop teleconferences and/or meetings can be conducted to gather additional data to support the risk surveys. While pre-Workshop surveys are not required prior to conducting the actual Workshop, they facilitate discussions and provide a starting point for schedule network development and duration estimates. Therefore, it is recommended that they are included in this process.

At the Schedule Risk Workshop, the process begins with SMEs discussing each technology's TRL, IRL, and MRL to form a starting point for schedule analysis. Unlike an official TRA where well supported documentation of TRLs are needed, the readiness level discussions during the Workshop are only meant to begin discussions for schedule modeling and are not as well supported with documentation. Readiness level discussions set the assumptions for remaining technology development, integration, and manufacturing efforts that are needed in the schedule network builds for each KT. The readiness level overview is also used to prioritize KTs for workshop discussion by eliminating schedule discussions for KTs that are highly mature and pose little integration or manufacturing risk.

Once the readiness levels have been agreed upon, the group works to logically sequence and link technology maturation, systems integration, testing, and manufacturing tasks. These tasks form the schedule network models used for the SRA. AMSAA leads and facilitates discussions amongst the SMEs, while also visually displaying the schedule networks, so that the appropriate experts are able to collectively review and discuss the information to reach consensus. It is important to note that AMSAA's SRA approach supports SMEs making suggested changes to the schedule network as the networks are being built. The changes to the schedule networks continue until SMEs reach consensus. In addition to identifying the activities and their sequence for the schedule network, SMEs also identify schedule risk events. From there, estimated task durations, including uncertainty (e.g., through the use of a three-point estimate: min, max, and ML times) are elicited. This includes having SMEs evaluate the schedule risk events in terms of their likelihood of occurrence and expected impact on schedule activity durations. Lastly, SMEs identify and discuss schedule acceleration opportunities and their associated impact on the schedules.

At all points in this data gathering process, disagreements between different groups of SMEs can occur. It is important to allow these conversations to continue as needed until consensus is reached, as long as they do not significantly delay the workshop flow. In order for SMEs to provide accurate data, they sometimes need to discuss differences of opinion until a mutual understanding of schedule assumptions is reached. From that point, they will be able to provide data more efficiently, rather than stopping at several points along the way for additional clarification.

In summary, the essential pieces of data to gather at the Workshop are as follows:

- Schedule Networks: Sequenced and linked design, programmatic, manufacturing, and testing activities needed to develop systems to the objective end point.
- Durations: Estimated durations (e.g., min, max, ML) for each activity.
- Risk Events: Identify and evaluate risk events that may delay critical path activities. This includes the likelihood of the risk occurring, the expected impact (consequence) on schedule if the risk occurs, and the modeled activities that are affected.
- Schedule Acceleration/Risk Mitigation Opportunities: Identify and evaluate schedule acceleration and/or risk mitigation opportunities.

After the Workshop, the results are compiled and the schedule networks (along with the risk events, activity durations, likelihood and consequence of risk events, and schedule acceleration opportunities) are sent back to the SMEs for final agreement. Once SMEs provide final concurrence, the data is then prepared for MCS and subsequent analysis.

## 2.3 Use of Historical Data

As mentioned in previous sections of this Guidebook, historical data at the detailed activity level can be difficult to obtain. Also, there is little data readily available on historical schedules at the technology level (e.g., historical schedule to develop and qualify individual system components). However, if historical data at the activity or technology level is available, it can provide valuable insights for SMEs to consider when providing inputs for the assessment. Historical development timelines can inform SME estimates and serve as a baseline for the min, max, and ML times. This data can also be used pre-Workshop to conduct an initial schedule comparison between the system being analyzed and previous analogous systems (see Figure 7). The data can be used post-Workshop as well to objectively compare historical programs to the

SRA results and address similarities and differences. AMSAA is currently working on additional data analysis tools for future use. However, these tools are dependent on establishing a more formal, robust set of schedule data including information from ACAT I, II, and III programs.

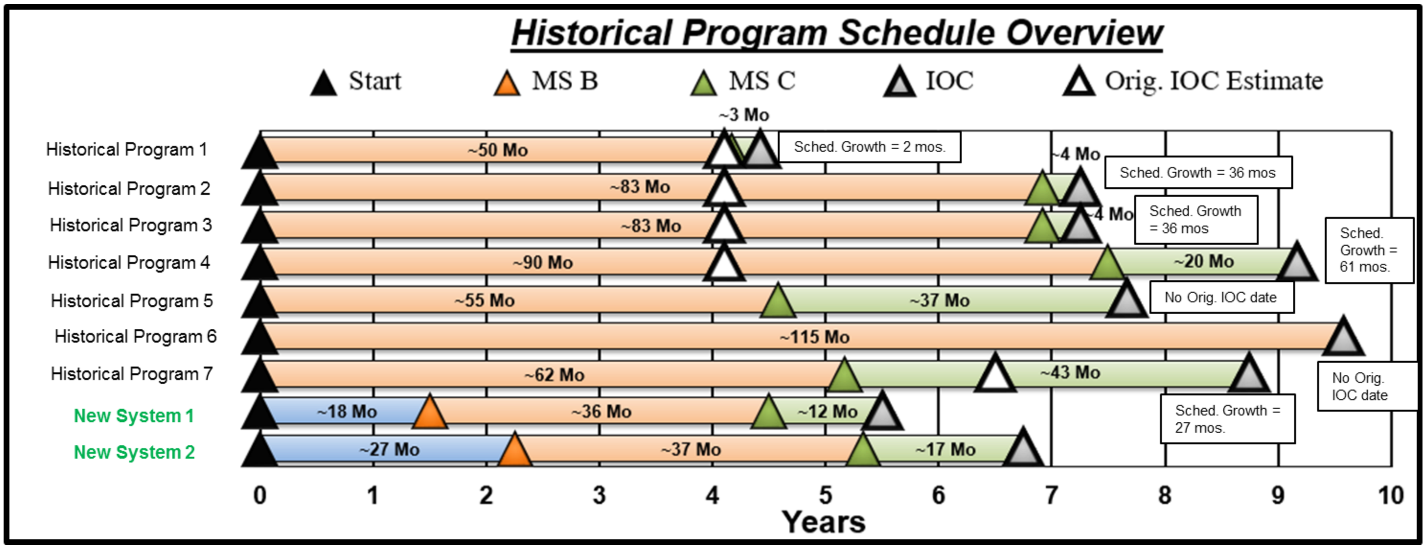


**Figure 7. Notional Historical Program Comparative Analysis**

## 3. APPLICATIONS OF THE SCHEDULE RISK METHODOLOGY

The methodology listed in Section 2 of this Guidebook is the recommended approach to perform an SRA, and is the standard process that AMSAA uses for Army-led AoAs and acquisition studies. These AoAs span across a wide range of system-types and portfolios, including specific hardware and software technologies and programs. In order to conduct these SRAs, AMSAA leverages the most applicable acquisition regulations (e.g., DoD 5000.02, DoD 5000.75, etc.) to help guide the schedule model development. As noted previously, the SRAs consider both technical and schedule risks, which ultimately enable PEOs/PMs to modify program acquisition strategies and established schedules; consider schedule acceleration opportunities, and; more strategically implement risk mitigation. As part of the AoA process, the SRA methodology supports trades analyses that consider possible trade-offs between system cost, schedule, and performance objectives. Trades analyses allow for stakeholders to consider associated schedule risks and develop an understanding of the schedule impacts if key assumptions are adjusted. Overall, SRAs performed in support of trades analyses provide senior decision makers with an understanding of the value of the trade, including the impacts to technical risk and schedule duration.

As mentioned previously, the SRA methodology can also be applied beyond traditional AoAs to support other areas. Specifically, AMSAA has the ability to provide dedicated schedule risk support for PEOs/PMs. This includes conducting a typical SRA (program's ability to meet schedule objectives, identification of risk drivers, etc.), along with providing insight and distinct recommendations for PEOs/PMs regarding techniques to build initial schedules or adjust existing schedules for efficiency and effectiveness, while also minimizing the risk profiles for the system under evaluation. AMSAA's tailored analyses allow PEOs/PMs to build informed risk mitigation plans and conduct pre-planning in order to reduce the chances of significant schedule delays.

Additionally, AMSAA has modified and applied the SRA framework in order to conduct independent, formal TRAs for PEOs/PMs to support MS B decisions. Ultimately, these efforts enable PMs to apply valuable resources and manpower toward other critical program activities and milestone requirements. Overall, TRAs are meant to enable decision makers to understand the current readiness levels and risk associated with maturing Critical Technologies (CTs) to TRL 6 and do not address activities beyond this point. Specifically, AMSAA modifies the SRA method for application to TRAs by serving as the Independent Review Team and working with SMEs to collect the needed data. This includes determining CTs for the system being analyzed, collecting the documentation necessary to justify TRL claims, and performing the analysis to build the body of evidence required for the TRA. The DoD TRA Guidance defines CTs as those technologies that may pose major technological risk during development, particularly during the EMD acquisition phase. [3] Applying AMSAA's SRA methodology to TRAs, AMSAA assesses the schedule risk of each CT to reach TRL 6, in accordance with the DoD Risk Management Guide for Defense Acquisition Programs. Through this assessment, AMSAA is able to help quantify the schedule risk of maturing technologies to TRL 6 against an objective date, and provide PEOs/PMs with recommendations regarding the development of mitigation plans to address high risk technologies maturing to TRL 6.

Further, opportunities exist to apply the SRA methodology to address S&T, contract, and/or testing schedules. AMSAA has investigated using a modified SRA approach to support identifying the schedule and technical risks associated with S&T initiatives in order to assess the expected timeline associated with maturing potential future technologies. Additionally, AMSAA can apply the SRA method to provide schedule estimates for contracting and test activities that consider various risks (e.g., risk of contract delay, risk of failed test, risk of time associated to build additional reliability into technologies, etc.). This information could be leveraged by Research Development and Engineering Centers (RDECs) to understand the activities required, durations, and technical and schedule risks associated with developing specific technologies to appropriate maturation levels. Additionally, SRAs performed in the contracting and testing realms can support organizations, such as the Army Contracting Command (ACC) and the Army Test and Evaluation Command (ATEC), by providing specific programmatic risks and how each of the organization's activities will impact overall system schedules.

Moreover, SRA results could be used to provide risk assessments for the sustainment community. Specifically, the SRA framework could be applied to evaluate and compare time and risk impacts between implementing new sustainment policies, procedures, or processes as compared to existing processes. Additionally, SRAs could be used to help the sustainment community pre-plan sustainment activities and schedules earlier in the acquisition cycle. This would enable better planning, alignment, and integration of sustainment schedules with the planned schedules for new technologies and systems in development. By performing these types of analyses, sustainment customers (e.g., Army Materiel Command, Lifecycle Management Commands, etc.) could better understand the risks in adjusting sustainment policies and/or conduct better supply-chain planning based on anticipated technology development and schedule risks.

Lastly, the SRA methodology could be enhanced by acquiring specific schedule program data for ACAT I, II, and III programs. AMSAA has developed a historical program schedule database that can be used to compare previous program schedules to the estimated forecasts for new programs/systems. AMSAA's historical database is mainly built from ACAT I program schedule information obtained from the Defense Acquisition Management Information Retrieval (DAMIR) system. DAMIR provides enterprise visibility to acquisition program information, to include planned and completed acquisition milestone dates. However, ACAT II and III programs are currently not required to formally report program schedule baselines and/or updates. Establishing a robust and vast set of historical ACAT II and III schedule data would allow AMSAA to further enhance its existing analytical toolset and conduct a more detailed comparative analysis of analogous programs to the systems under evaluation. Additionally, this data would be useful to PEOs, PMs, and other stakeholders, as it would provide key acquisition, schedule, cost, and performance-based lessons learned from previous ACAT II and III programs.

Ultimately, the SRA methodology is able to be adjusted to support any type of program/project with a pre-defined objective endpoint. Provided that the information available is representative of the technology development, integration, manufacturing, and programmatic activities and risk events that may occur, the SRA is able to provide decision makers with risk-informed analysis to support program/project decisions.

## 4. CONCLUSION

Through the SRA approach detailed in this Guidebook, AMSAA continues to provide high-quality, independent, and robust SRAs for Army-led AoAs. The overview of AMSAA's SRA methodology included in this Guidebook serves to provide key stakeholders with a general understanding of SRAs and how AMSAA's analysis could benefit future efforts. AMSAA's flexible SRA approach allows for the methodology to be adjusted, expanded, and applied in a manner that is most appropriate to the study. Beyond its typical application, other opportunities to apply the SRA framework include providing dedicated schedule risk support for PEO/PMs, further expanding AMSAA's TRA support, and investigating the application of SRA methods directly to S&T, contracting, testing, and/or sustainment areas. Moreover, growing AMSAA's Historical Schedule Risk Database could be used to further enhance the SRA framework.

Since the SRA methods described in this Guidebook will be further developed and incrementally improved over time, it is recommended that AMSAA be consulted regarding any applications of future SRAs.

## REFERENCES & DOCUMENTS


[1] "GAO-09-665, Many Analyses of Alternatives Have Not Provided a Robust Assessment of Weapon System Options," September 2009.

[2] T. Bounds, A. Clark, T. Henry, J. Nierwinski, S. Singleton and B. Wilder, "Army Independent Risk Assessment Guidebook," AMSAA, 2014.

[3] "DoD Technology Readiness Assessment (TRA) Guidance," April 2011.

# APPENDIX A – TRL/IRL/MRL MAPPING TO ACQUISITION MILESTONES

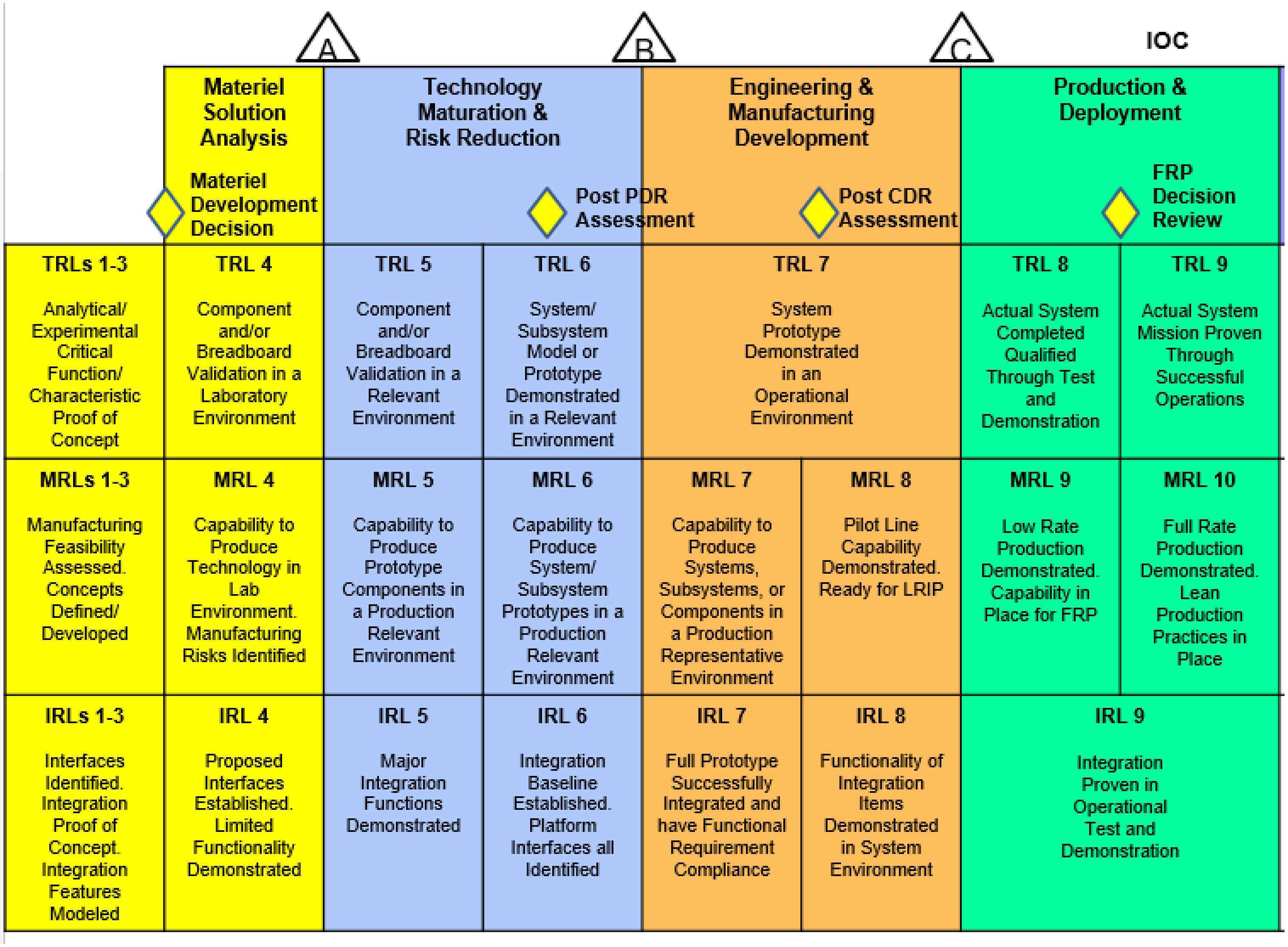


**Figure A-1. TRL/IRL/MRL Mapping to Acquisition Milestone**

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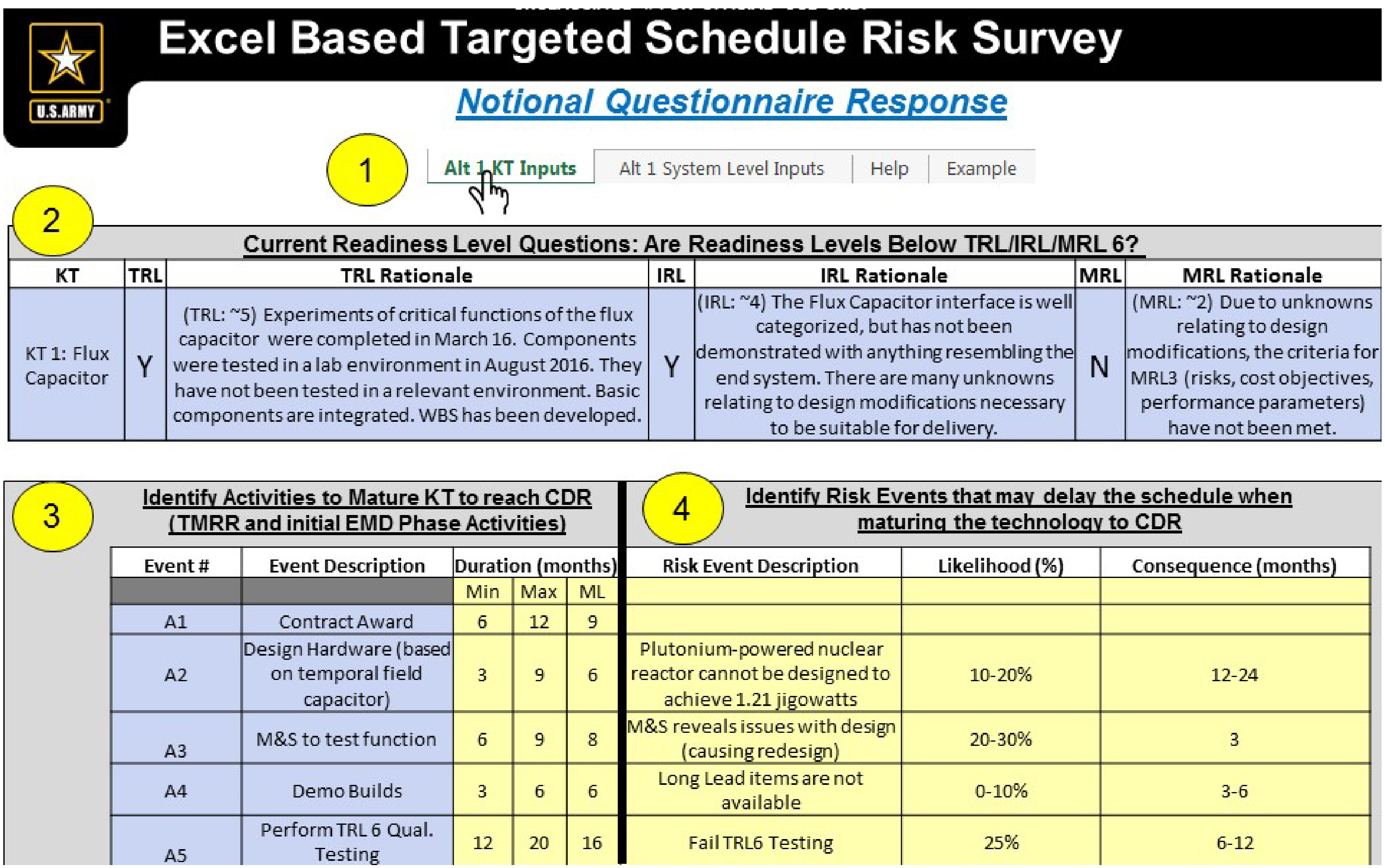
# APPENDIX B – TARGETED SCHEDULE RISK SURVEY EXAMPLE



# Excel Based Targeted Schedule Risk Survey

U.S. ARMY

***Notional Questionnaire Response***

1 — Alt 1 KT Inputs | Alt 1 System Level Inputs | Help | Example

2 — **Current Readiness Level Questions: Are Readiness Levels Below TRL/IRL/MRL 6?**

| KT | TRL | TRL Rationale | IRL | IRL Rationale | MRL | MRL Rationale |
|---|---|---|---|---|---|---|
| KT 1: Flux Capacitor | Y | (TRL: ~5) Experiments of critical functions of the flux capacitor were completed in March 16. Components were tested in a lab environment in August 2016. They have not been tested in a relevant environment. Basic components are integrated. WBS has been developed. | Y | (IRL: ~4) The Flux Capacitor interface is well categorized, but has not been demonstrated with anything resembling the end system. There are many unknowns relating to design modifications necessary to be suitable for delivery. | N | (MRL: ~2) Due to unknowns relating to design modifications, the criteria for MRL3 (risks, cost objectives, performance parameters) have not been met. |

3 — **Identify Activities to Mature KT to reach CDR (TMRR and initial EMD Phase Activities)**

4 — **Identify Risk Events that may delay the schedule when maturing the technology to CDR**

| Event # | Event Description | Duration (months) | | | Risk Event Description | Likelihood (%) | Consequence (months) |
|---|---|---|---|---|---|---|---|
| | | Min | Max | ML | | | |
| A1 | Contract Award | 6 | 12 | 9 | | | |
| A2 | Design Hardware (based on temporal field capacitor) | 3 | 9 | 6 | Plutonium-powered nuclear reactor cannot be designed to achieve 1.21 jigowatts | 10-20% | 12-24 |
| A3 | M&S to test function | 6 | 9 | 8 | M&S reveals issues with design (causing redesign) | 20-30% | 3 |
| A4 | Demo Builds | 3 | 6 | 6 | Long Lead items are not available | 0-10% | 3-6 |
| A5 | Perform TRL 6 Qual. Testing | 12 | 20 | 16 | Fail TRL6 Testing | 25% | 6-12 |

**Figure B-1. Notional Targeted Schedule Risk Survey Example**

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# APPENDIX C – DISTRIBUTION LIST

Organization

U.S. Army Materiel Systems Analysis Activity
AMXAA-GL/Reports Processing
AMXAA-GP/Project Management
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Aberdeen Proving Ground, MD  21005-5071

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8725 John J. Kingman Rd.
Fort Belvoir, VA 22060-6218