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Session: Technology Maturity

Linking Systems Engineering Artifacts with Complex System Maturity Assessments

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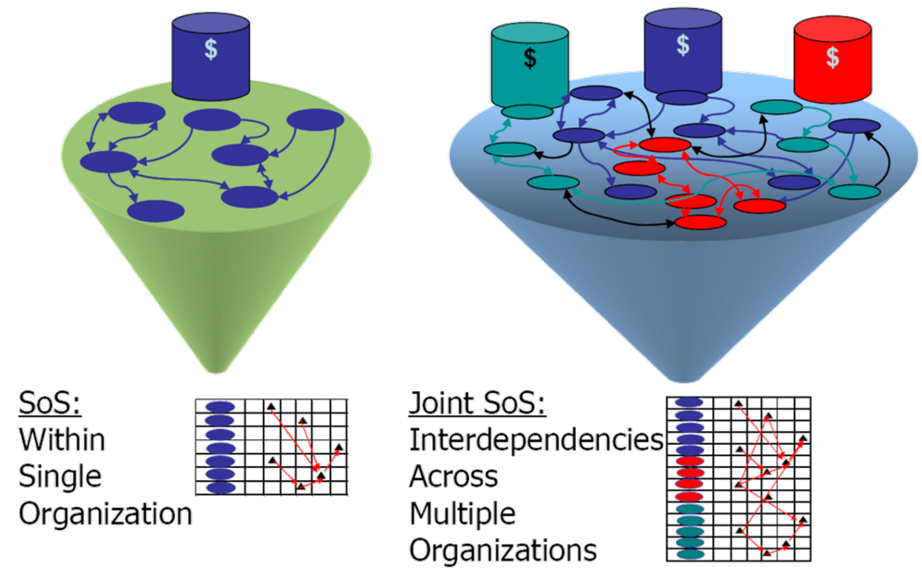
Overview

- Motivation
- System Acquisition Management Approach
- System Readiness Level Concept Overview
- System Maturity Assessment Process
- System Performance Level Monitoring
- System Availability
- System Capability Satisficing
- Future Work and Applications

Motivation

- Development and acquisition activities continue to be challenged by the formulation of larger and more complex systems

- This is compounded by the emergence of *Acknowledged Systems of Systems* which are characterized as having multiple stakeholders with competing interests and priorities



Source: DoD Systems Engineering Guide for Systems of Systems, Version 1.0, August 2008

- Traditional management tools continue to be applied, but do not provide a holistic view of development

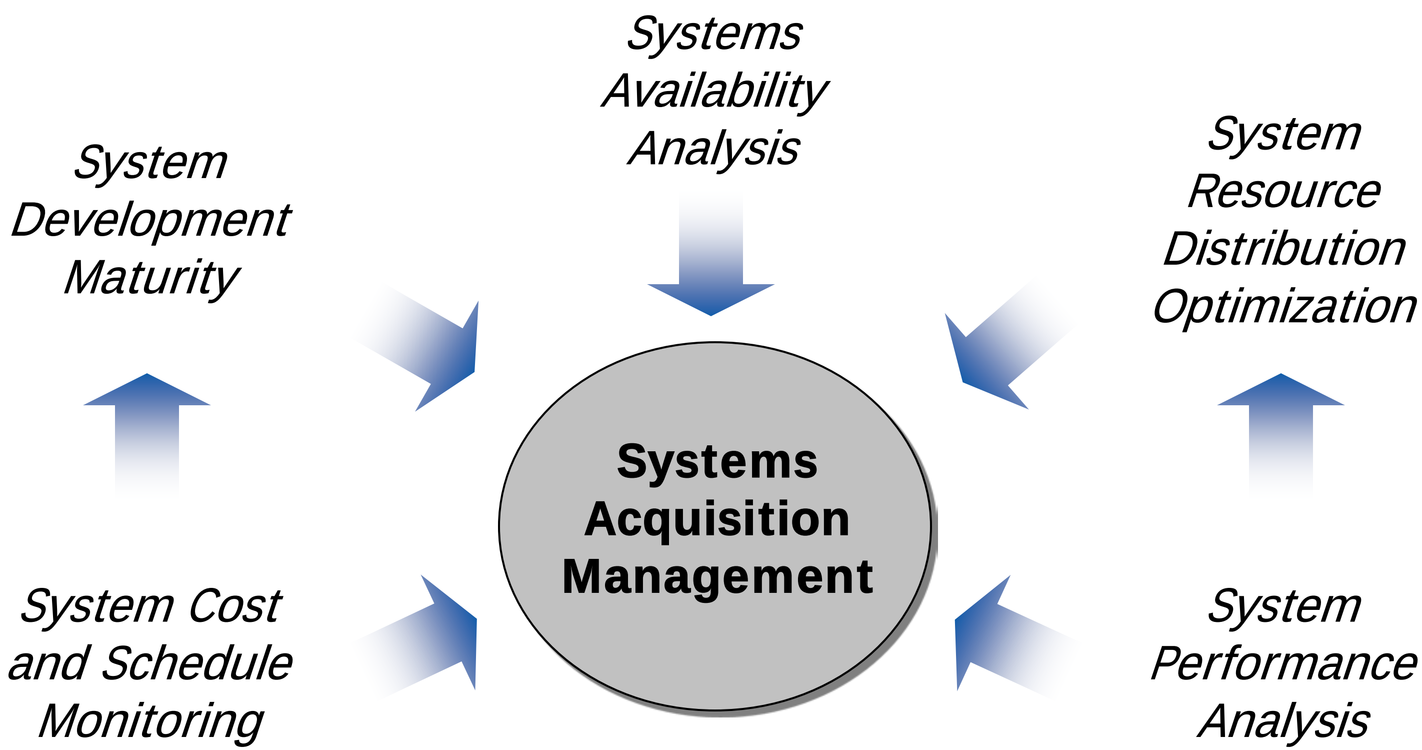
- Failure to adequately consider all systems integration challenges has led an environment of cost overruns, schedule slips, and degraded performance

System Level Program Management Tools

- New methods, processes, and tools are needed in order to effectively manage and optimize complex system development
- Significant management tools exist at the individual technology level, but are limited in application for systems development
  - Technology Readiness Levels:
    Do not consider integration of components into a system
  - Technical Performance Measures:
    Individual component performance does not translate to system level
  - Availability Analysis:
    Multiple system sub-capabilities present different availability options
  - Risk Management:
    Additional unanticipated risk areas are introduced through the linkage of formerly independent systems
- Emerging systems management resources have been few and far between
- DoD's Systems Engineering Guide for Systems of Systems *"acknowledges these issues, but does not make any recommendations for changes to existing management and control structures to resolve inter-system issues".*

System Acquisition Management Approach

The US Navy's Littoral Combat Ship Mission Modules Program (PEO LMS) in collaboration with the Northrop Grumman Corporation and Stevens Institute of Technology is developing a holistic System Maturity Model for systems development management



System Maturity Monitoring - TRL Shortcomings

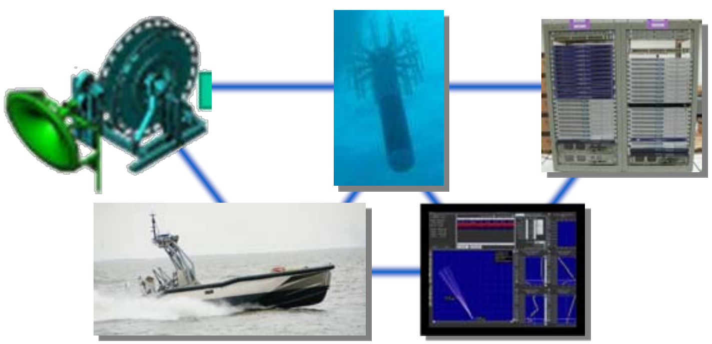
- Application of TRL to systems of technologies is not sufficient to give a holistic picture of complex system of systems readiness
  - TRL is only a measure of an individual technology
- Assessments of several technologies rapidly becomes very complex without a systematic method of comparison
- Multiple TRLs do not provide insight into integrations between technologies nor the maturity of the resulting system
  - Yet most complex systems fail at the integration points

Individual Technology

Can TRL be applied?

Yes

System of Technologies



Can TRL be applied?

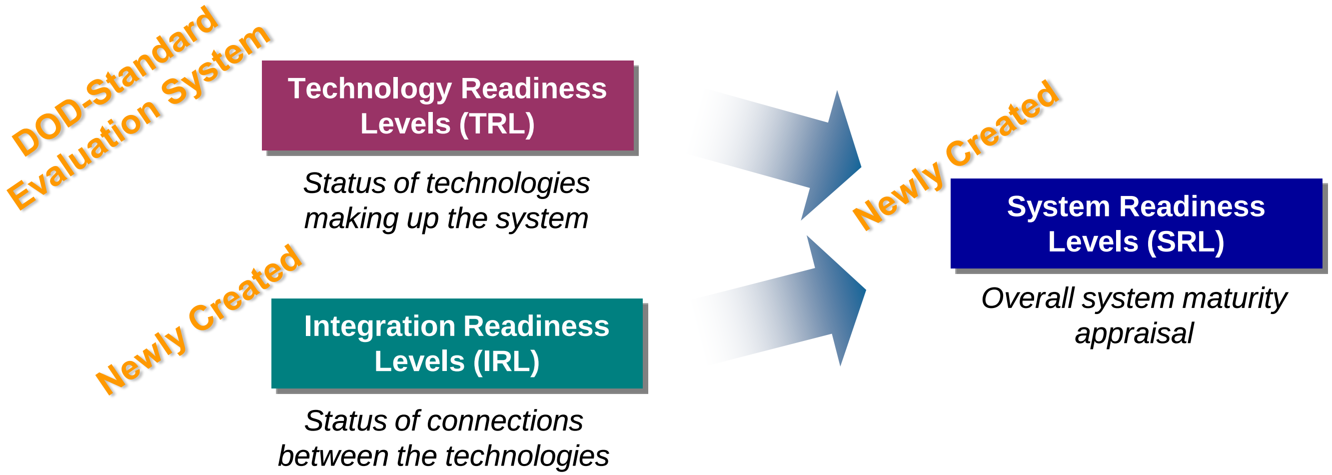
NO

System Readiness Level Concept Overview

Goal: Institute a robust, repeatable, and agile method to monitor / report system development and integration status

APPROACH

Create a System Readiness Level (SRL) that utilizes SME / developer input on technology and integration maturity to provide an objective indication of complex system development maturity



- Provides a **system-level** view of development maturity with opportunities to drill down to element-level contributions
- Allows managers to evaluate system development in real-time and take **proactive** measures
- Highly **adaptive** to use on a wide array of system engineering development efforts
- Can be applied as a **predictive** tool for technology insertion trade studies and analysis

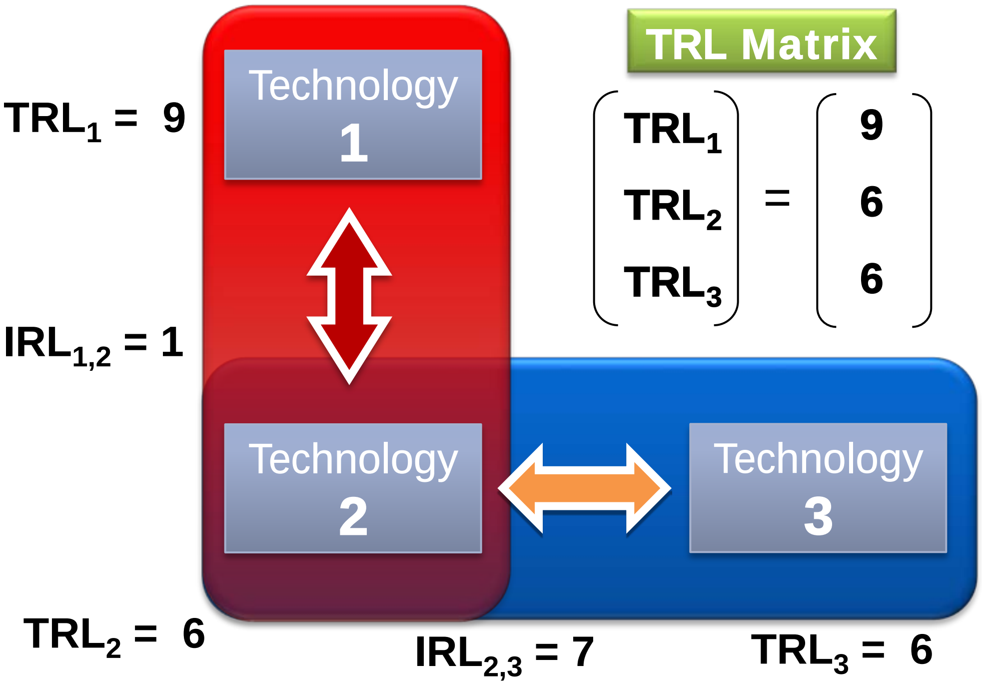
What is an IRL?

A systematic measurement reflecting the status of an integration connecting two particular technologies

	IRL	Definition
Pragmatic	9	Integration is Mission Proven through successful mission operations.
	8	Actual integration completed and Mission Qualified through test and demonstration, in the system environment.
Syntactic	7	The integration of technologies has been Verified and Validated with sufficient detail to be actionable.
	6	The integrating technologies can Accept, Translate, and Structure Information for its intended application.
	5	There is sufficient Control between technologies necessary to establish, manage, and terminate the integration.
	4	There is sufficient detail in the Quality and Assurance of the integration between technologies.
Semantic	3	There is Compatibility (i.e. common language) between technologies to orderly and efficiently integrate and interact.
	2	There is some level of specificity to characterize the Interaction (i.e. ability to influence) between technologies through their interface.
	1	An Interface between technologies has been identified with sufficient detail to allow characterization of the relationship.

Source: Sauser, B., E. Forbes, M. Long, and S. McGrory. (2009). Verification of an Integration Readiness Level Assessment. *International Symposium of the International Council of Systems Engineering*, July 20-23, Singapore

SRL Calculation Example



TRL Matrix

$$\begin{pmatrix} TRL_1 \\ TRL_2 \\ TRL_3 \end{pmatrix} = \begin{pmatrix} 9 \\ 6 \\ 6 \end{pmatrix}$$

IRL Matrix

$$\begin{pmatrix} IRL_1 & IRL_{12} & IRL_{13} \\ IRL_{12} & IRL_2 & IRL_{23} \\ IRL_{13} & IRL_{23} & IRL_3 \end{pmatrix} = \begin{pmatrix} 9 & 1 & 0 \\ 1 & 9 & 7 \\ 0 & 7 & 9 \end{pmatrix}$$

SRL = IRL x TRL
(Normalized)

$$\textbf{Component SRL} = \begin{pmatrix} SRL_1 & SRL_2 & SRL_3 \end{pmatrix} = \begin{pmatrix} 0.54 & 0.43 & 0.59 \end{pmatrix}$$

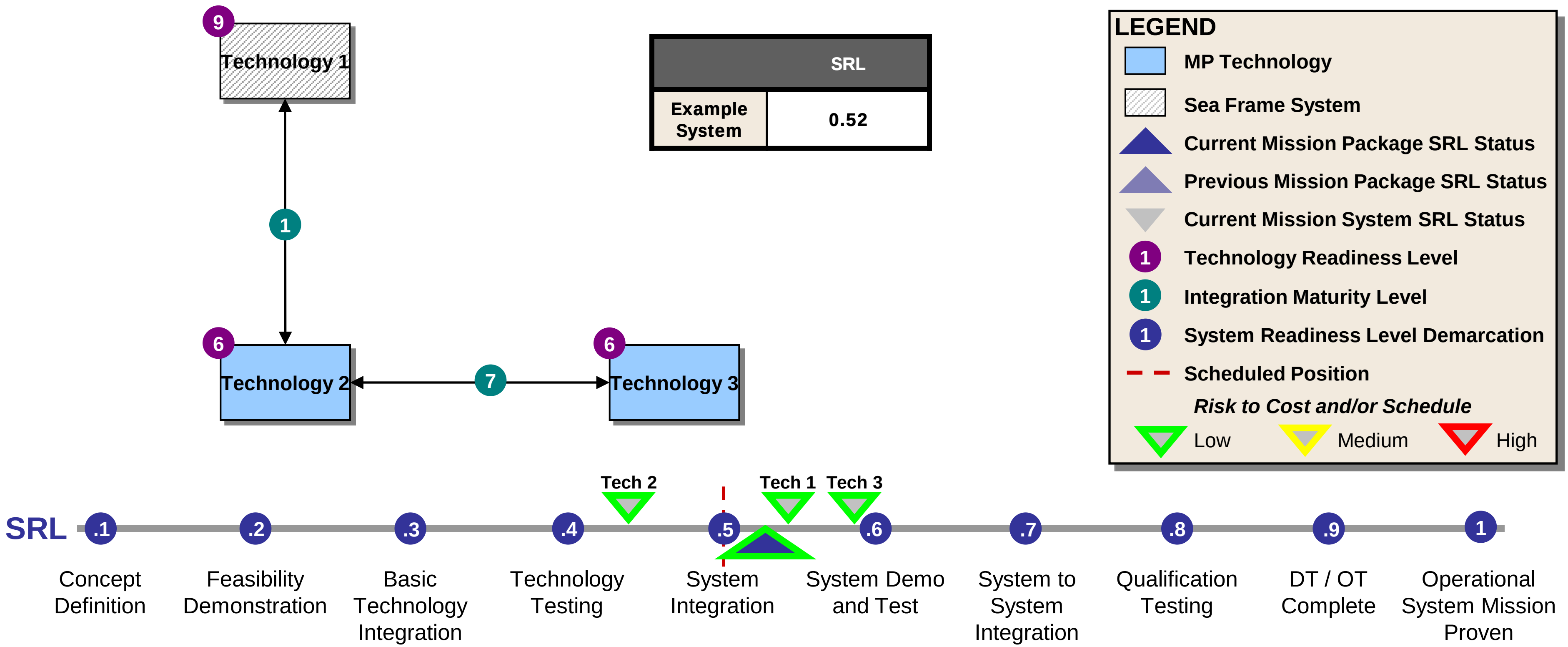
Component SRL_x represents Technology "X" and its IRLs considered

$$\textbf{Composite SRL} = 1/3\ (0.54 + 0.43 + 0.59) = 0.52$$

The Composite SRL provides an overall assessment of the system readiness

Source: Sauser, B., J. Ramirez-Marquez, D. Henry and D. DiMarzio. (2007). "A System Maturity Index for the Systems Engineering Life Cycle." *International Journal of Industrial and Systems Engineering*. 3(6).

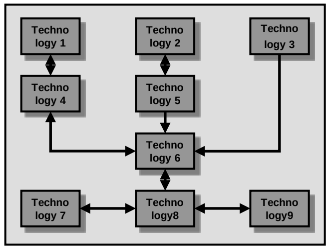
SRL Reporting Method



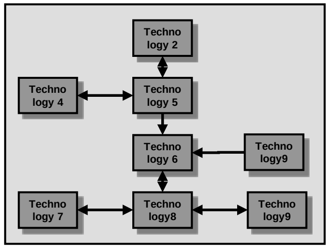
- For complex systems, the amount of information obtained from the SRL evaluation can be overwhelming
- To maximize applicability SRL outputs are tied to key, program- specific development milestones
- Progress against these milestones provide key insight to the user regarding current program status, risk and progress

System Maturity Assessment Process

1. Develop System Architectures



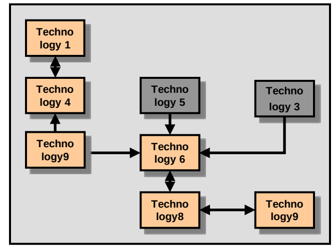
Functional
Capability



Physical
Software/ Hardware

System architecture provides the foundation for system maturity assessments

2. Determine Criticality



Critical Elements

Identification of critical elements and interfaces to be evaluated

3. Build Assessment Process

Systems Engineer

- Customize applicable TRL / IRL criteria
- Build SRL advancement schedule
- Tie criteria to program test events / milestones

Systems Engineering IPT

- Review proposed criteria, schedule, and milestones

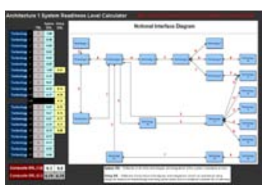
PM

- Approve assessment framework

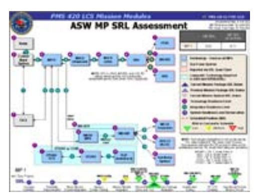
Architectures and framework are locked after approval and will remain so unless the program is re-baselined

4. Conduct System Maturity Analysis w/ SRL

Evaluate and Justify TRLs / IRLs



Calculate SRL



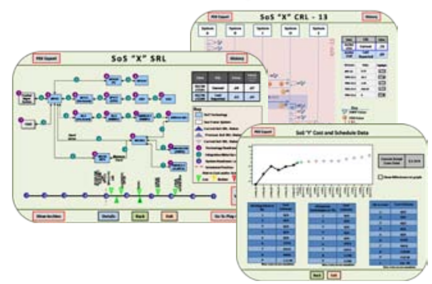
Build Maturity Reports

Iterate

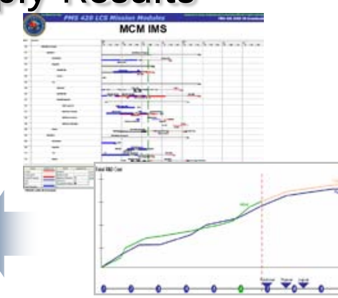
Identify Risks Against Schedule

- (Green) SRL assessment and test events / milestone gates are at or in advance of schedule
- (Yellow) SRL assessment is at or in advance of schedule, but test events / milestone gates remain to be closed
- (Red) SRL assessment and test events / milestone gates are behind schedule

5. Interpret and Apply Results



Maturity Analysis Outputs



EVMS and Schedule Data Inserted

Outputs of the analysis are analyzed against projected cost and schedule data to determine current development status

Future planning can also be conducted through trade-off analyses and risk management activities

Iterate

System Performance Level Monitoring (PLM)

Goal: Predict the ability of a complex systems to achieve required performance

1. Map the Systems to their impacts on key performance parameters

Notional System of Systems				
	KPP Impacted			
Capability/MS	**Search**	**Detect**	**Classify**	**Engage**
Tech 1	X	x	X	
Tech 2		x	X	
Tech 3	X	x	X	X
Tech 4				X
Tech 5	X	x		

2. Map the maturity development of the Systems to the SoS development schedule

	Notional Maturity				
	MP Impacted				
Capability/MS	MP1	MP2	MP3	MPn	MPn+1
Tech 1	EDM	PROD	PROD	PROD	PROD
Tech 2	ADM	EMD	EDM	PROD	PROD
Tech 3	EDM	PROD	PROD	PROD	PROD
Tech 4	PROD	PROD	PROD	PROD	
Tech 5	PROD	PROD	PROD	PROD	PROD

Detect	Tech 1	Tech 2	Tech 3
T_{1n}		x	
$Tm_{(1,2)n}$	x	x	
$Tm_{(2,3)n}$		x	x
T_{1n}			x

$T_{1n} = \omega_n * \alpha$

$Tm_{(1,2)n} = \omega_n * \alpha$

$Tm_{(2,3)n} = \omega_n * \alpha$

$T_{4n} = \omega_n * \alpha$

3. Develop a relationship between system usage satisfying a KPP in a SoS and its maturity (in terms of a weighted value) against anticipated performance

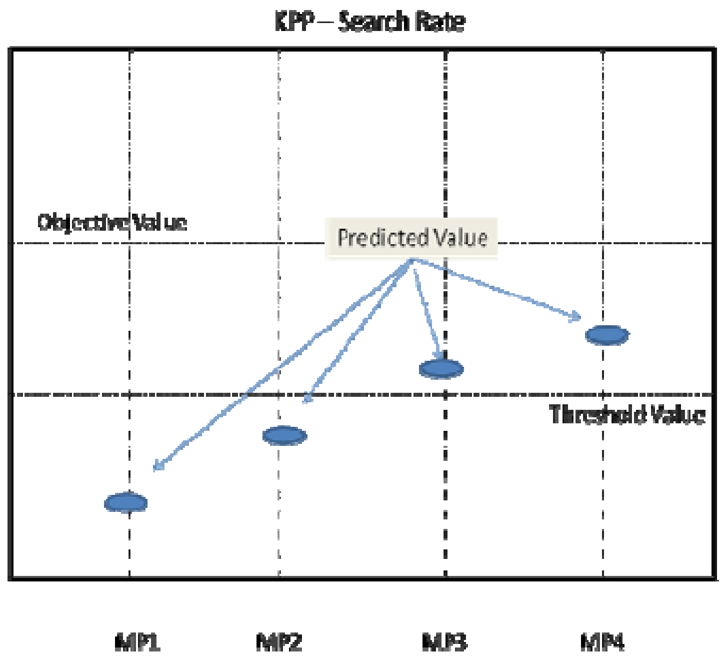
Performance Level Monitoring (PLM)

4. Adjust for usage impact under various employment options

$$CONOPS_{An} = \beta T_{1n} + \gamma T_{5n}$$
$$CONOPS_{Bn} = \delta T_{1n} + \varepsilon T_{3n} + \gamma T_{5n}$$
$$CONOPS_{Cn} = \theta T_{3n} + \eta T_{5n}$$

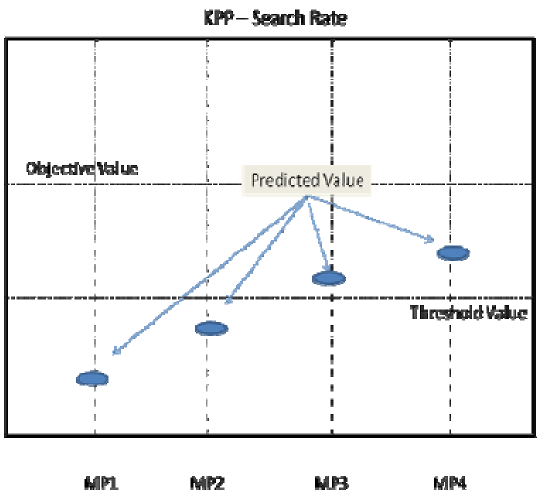
5. Average the results from individual employment options to obtain insight into ability to achieve obtainment of the desired performance parameter

6. Use predictions of improved maturity (SRL) over time to derive a predicted growth path of performance for SoS



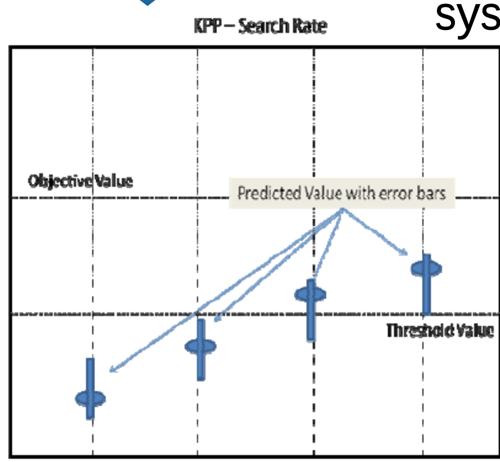
$$KPP_{SEARCH} = [CONOP_A, CONOP_B, CONOP_C] = AVG(CONOP_A + CONOP_B + CONOP_C)$$

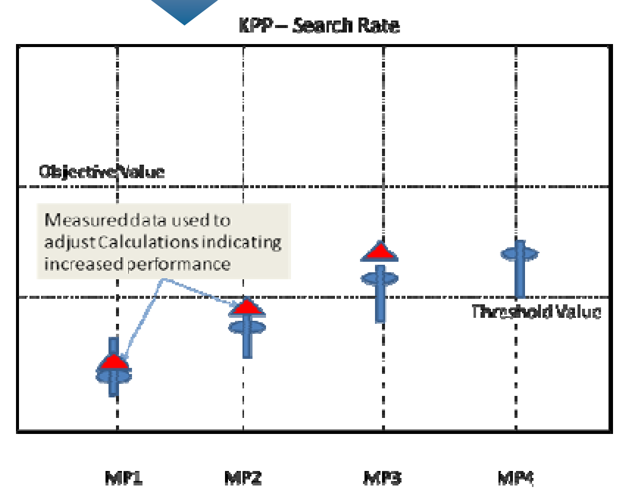
Performance Level Monitoring (PLM)



7. Use estimates of performance and maturity to define predictions of performance

8. Use variances of the usage rates to establish bands of performance based on varying usage options of the individual systems/modules



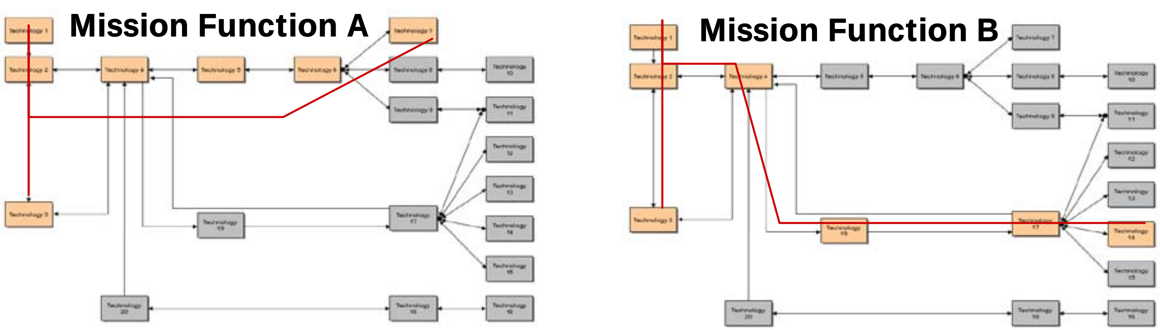


9. As data is gathered, updated predictions/ calculations to verify if development is proceeding as desired

System Availability

Goal: Adapt availability analysis to systems with multiple capabilities

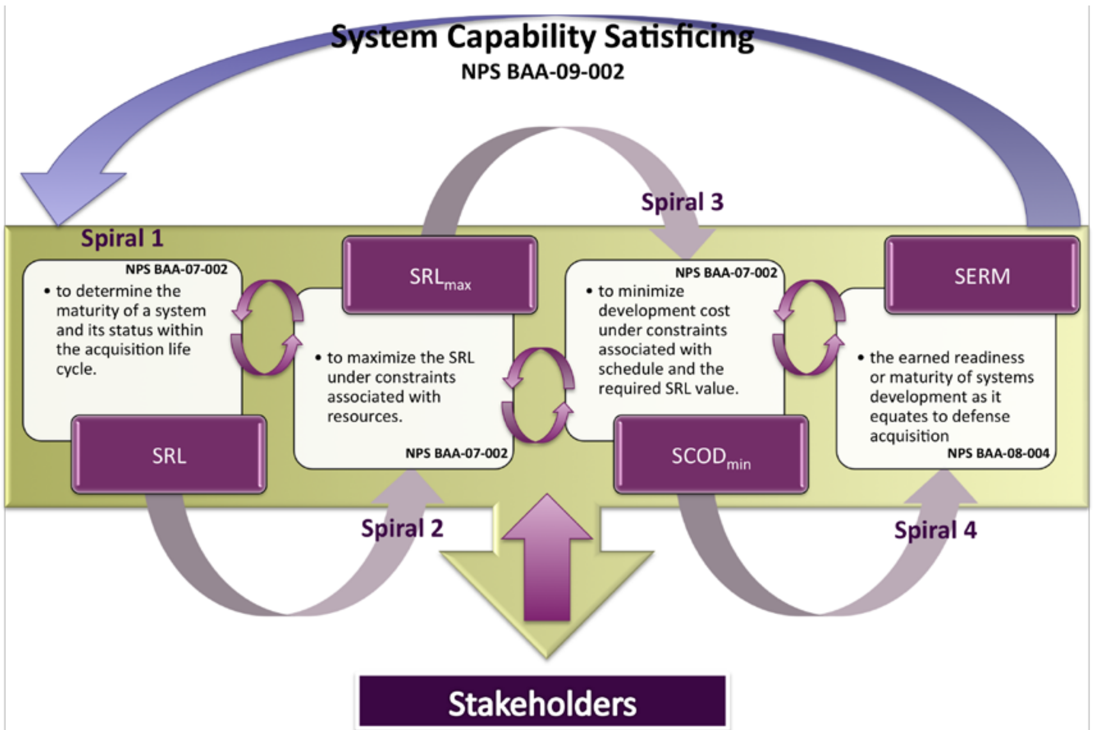
- Defining a subset of system components that contribute to the mission will vary the Availability
  - Increased number of system components weighs heavily on mission function availability
  - Statistical combination of CONOPS and a blending of the contributions will identify the critical components and provide insight into which provide better availability
- Through mission string analysis we gain insight into system functional performance and availability insight linked to CONOPS



- Alternative System/Mission components or CONOPS can help achieve System availability
  - Plan Availability Evolution (Improved Technology Insertion or Obsolescence Removal)
  - Trade improvement options with Program Cost and Schedule, so that in the system roadmap availability increases over the program life cycle
- Modular concept components enable functional expansion across system
- Using Reliability Block Diagram's as a method for picking component insertion/replacement by looking at the available and functional impact across a mission

System Capability Satisficing

Goal: Optimize system resource allocation across multiple variables



Builds upon the foundational approaches previously defined to maximize system capability for every dollar spent

"*What technologies and integrations are important or critical to each architectural view to achieve a functionality or capability?"… "How will the systems maturity vary depending on the architectural variants?*"

"*What functionalities or capabilities are sufficient, critical, or important to achieving a level of system maturity that can satisfy a warfighter's needs?*"

"*What impact does this have on system maturity and ultimately the acquisition of a deployable system?*"

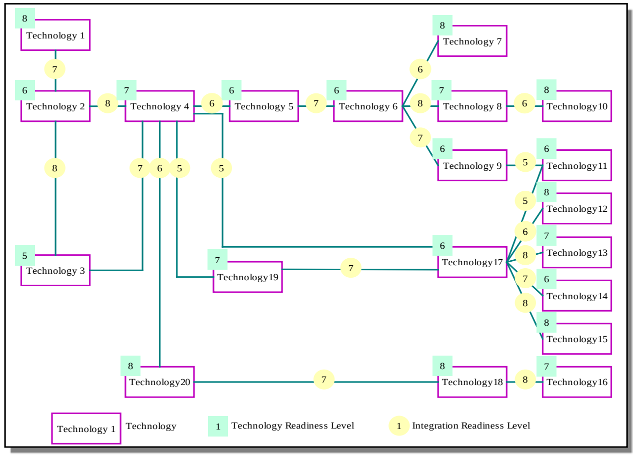
"*Can we use multi-attribute decision making/techniques in systems maturity assessment; parametric sensitivity analysis on how various TRL/IRL combinations drive SRL; and sensitivity analysis to determine what the most critical technologies are?*"

Analyzing Component Importance

- Analytical approach provides insight into which components and integrations provides greatest contribution to maturity

- This can then be used to ensure some level of functionality can be attained while full system continues to develop

- Factors can include performance, schedule, cost, etc...



	Function	Capability	Top Three Most Important Components					
			1st		2nd		3rd	
			Component	I^P	Component	I^P	Component	I^P
Increasing by One Level	F_1	C_{11}	2	1.0298	4	1.0246	6	1.0239
		C_{12}	2	1.0255	8	1.0212	4	1.0210
		C_{13}	2	1.0276	4	1.0227	9	1.0208
	F_2	C_{21}	2	1.0305	4	1.0275	17	1.0246
		C_{22}	2	1.0290	4	1.0262	17	1.0249
		C_{23}	2	1.0287	17	1.0275	4	1.0260
		C_{24}	2	1.0297	17	1.0269	4	1.0268
		C_{25}	2	1.0282	17	1.0270	4	1.0255
	F_3	C_{31}	2	1.0270	18	1.0242	4	1.0222

Future Work and Applications

SRL methodology can be used not only to assess current system maturity status, but also to roadmap and assess future development options along with cost and performance

Future work will focus on the creation and integration of applications which continue to leverage the SRL foundation to provide a holistic management dashboard and decision environment

Key Aspects:

- Development of a cost discretization across maturity increments using historical data
- Validation of an approach to monitor planned versus actual system maturity, cost, and schedule
- Linking of requirements and testing to performance and maturity

Applications:

- Future technology insertion, obsolescence, and evolution planning

QUESTIONS?

Back-up

Abstract

In a collaborative research effort that has involved Stevens Institute of Technology's Systems Development & Maturity Laboratory, the Northrop Grumman Corporation, and the U.S. Navy (PMS 420 / SSC-P), a measure of complex system development maturity entitled System Readiness Level (SRL) has been created. This measurement methodology builds upon the pre-existing Technology Readiness Level (TRL) and incorporates an Integration Readiness Level (IRL) in its formulation and practice. Unfortunately, the use of TRL, and subsequently IRL, in the formulation of SRL means that all of the drawbacks associated with the inherent subjectivity of their evaluation and assessment are carried forward. To address this issue, work was previously done to grow the readiness level definitions from a somewhat ambiguous, single line per level to a series of program tailored guides delineating tasks to be completed to achieve each maturity increment. Though the guides have been a significant step forward, additional work remains to be done in linking these TRL and IRL attributes and SRL increments with system architectures, technical performance measures, and development milestones (i.e. systems engineering artifacts). This is a critical step for two reasons: 1) it enables the tracking of development performance via the number and degree to which the artifacts have been satisfied; 2) it provides the decision maker with insight into the current level of system performance achieved and an understanding of what employment of the system (or a subsystem) at its current level of maturity will provide in terms of overall performance against requirements. Furthermore, a more accurate linkage to program costs can be established by tracking projected versus actual expenditures required to meet each successive level of development maturity. This presentation will review the development, implementation, and verification and validation of this concept as it is being executed with the U.S. Navy's PMS 420 Program Office.

From a System to an Acknowledged System of Systems

Table 2-1. Comparing Systems and Acknowledged Systems of Systems

Aspect of Environment	System	Acknowledged System of Systems
Management & Oversight		
Stakeholder Involvement	Clearer set of stakeholders	Stakeholders at both system level and SoS levels (including the system owners), with competing interests and priorities; in some cases, the system stakeholder has no vested interest in the SoS; all stakeholders may not be recognized
Governance	Aligned PM and funding	Added levels of complexity due to management and funding for both the SoS and individual systems; SoS does not have authority over all the systems
Operational Environment		
Operational Focus	Designed and developed to meet operational objectives	Called upon to meet a set of operational objectives using systems whose objectives may or may not align with the SoS objectives
Implementation		
Acquisition	Aligned to ACAT Milestones, documented requirements, SE with a Systems Engineering Plan (SEP)	Added complexity due to multiple system lifecycles across acquisition programs, involving legacy systems, systems under development, new developments, and technology insertion; Typically have stated capability objectives upfront which may need to be translated into formal requirements
Test & Evaluation	Test and evaluation of the system is generally possible	Testing is more challenging due to the difficulty of synchronizing across multiple systems' life cycles; given the complexity of all the moving parts and potential for unintended consequences
Engineering & Design Considerations		
Boundaries and Interfaces	Focuses on boundaries and interfaces for the single system	Focus on identifying the systems that contribute to the SoS objectives and enabling the flow of data, control and functionality across the SoS while balancing needs of the systems
Performance & Behavior	Performance of the system to meet specified objectives	Performance across the SoS that satisfies SoS user capability needs while balancing needs of the systems

Ref: DoD System Engineering Guide for Systems of Systems, V1.0, Aug 2008

System of Systems Challenges

SoS increases the complexity, scope, and cost of both the planning process and systems engineering, and introduces the need to coordinate inter-program activities and manage agreements among multiple program managers (PMs) as stakeholders who may not have a vested interest in the SoS. The problems that need to be addressed are large and complex and are not amenable to solution by better systems engineering alone. Without a solid governance and management approach for an SoS, independent authorities who oversee the multiple governance processes of DOD are unlikely to accept guidance from a systems engineer they do not control, placing the systems engineer in an untenable position in attempting to support an SoS. An administrative/governance structure that addresses these realities will enable SoS SE to be more effective in all phases of the processes as outlined in this document. This document acknowledges these issues but does not make any recommendations for changes to existing management and control structures to resolve inter-system issues,

Ref: DoD System Engineering Guide for Systems of Systems, V1.0, Aug 2008

SRL Calculation

- The SRL is not user defined, but is instead based on the outcomes of the documented TRL and IRL evaluations

- Through mathematically combining these two separate readiness levels, a better picture of overall complex system readiness is obtained by examining all technologies in concert with all of their required integrations

SRL = IRL x TRL

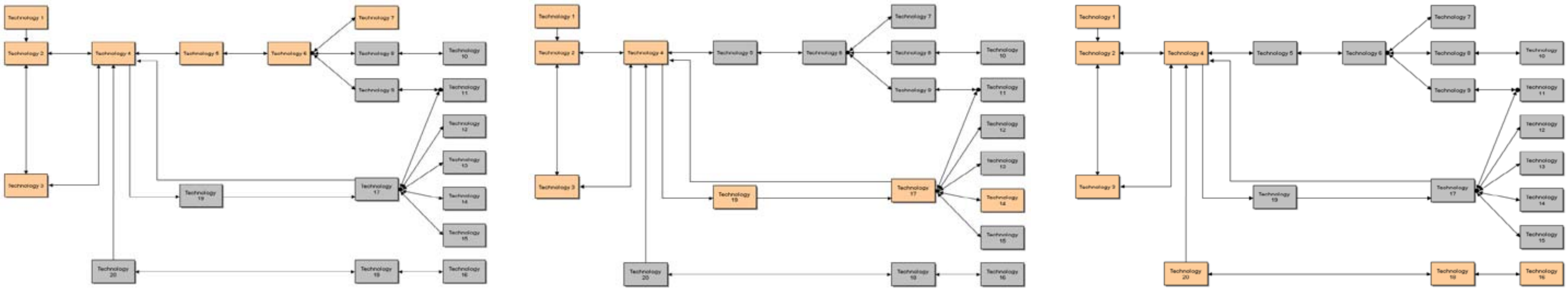
$$\begin{bmatrix} SRL_1 & SRL_2 & SRL_3 \end{bmatrix} = \begin{bmatrix} IRL_{11} & IRL_{12} & IRL_{13} \\ IRL_{12} & IRL_{22} & IRL_{23} \\ IRL_{13} & IRL_{23} & IRL_{33} \end{bmatrix} \times \begin{bmatrix} TRL_1 \\ TRL_2 \\ TRL_3 \end{bmatrix}$$

$$\text{Composite SRL} = 1/n\left(SRL_1/n + SRL_2/n + SRL_3/n\right)$$
$$= 1/n^2\left(SRL_1 + SRL_2 + SRL_3\right)$$

- These values serve as a decision-making tool as they provide a prioritization guide of the system’s technologies and integrations and point out deficiencies in the maturation process

“String” Analysis Incorporated

Complex systems often offer numerous options for conducting operations



- Operational strings were created that identified the components required to utilize a single function of the system
- Assessment of the SRL for each of these options allows for a better understanding of the maturity of each operating configuration
- Understanding the true status of the system on an operational string level allows for the opportunity to field initial capability earlier and then add to it as other strings mature

Verification and Validation Activities

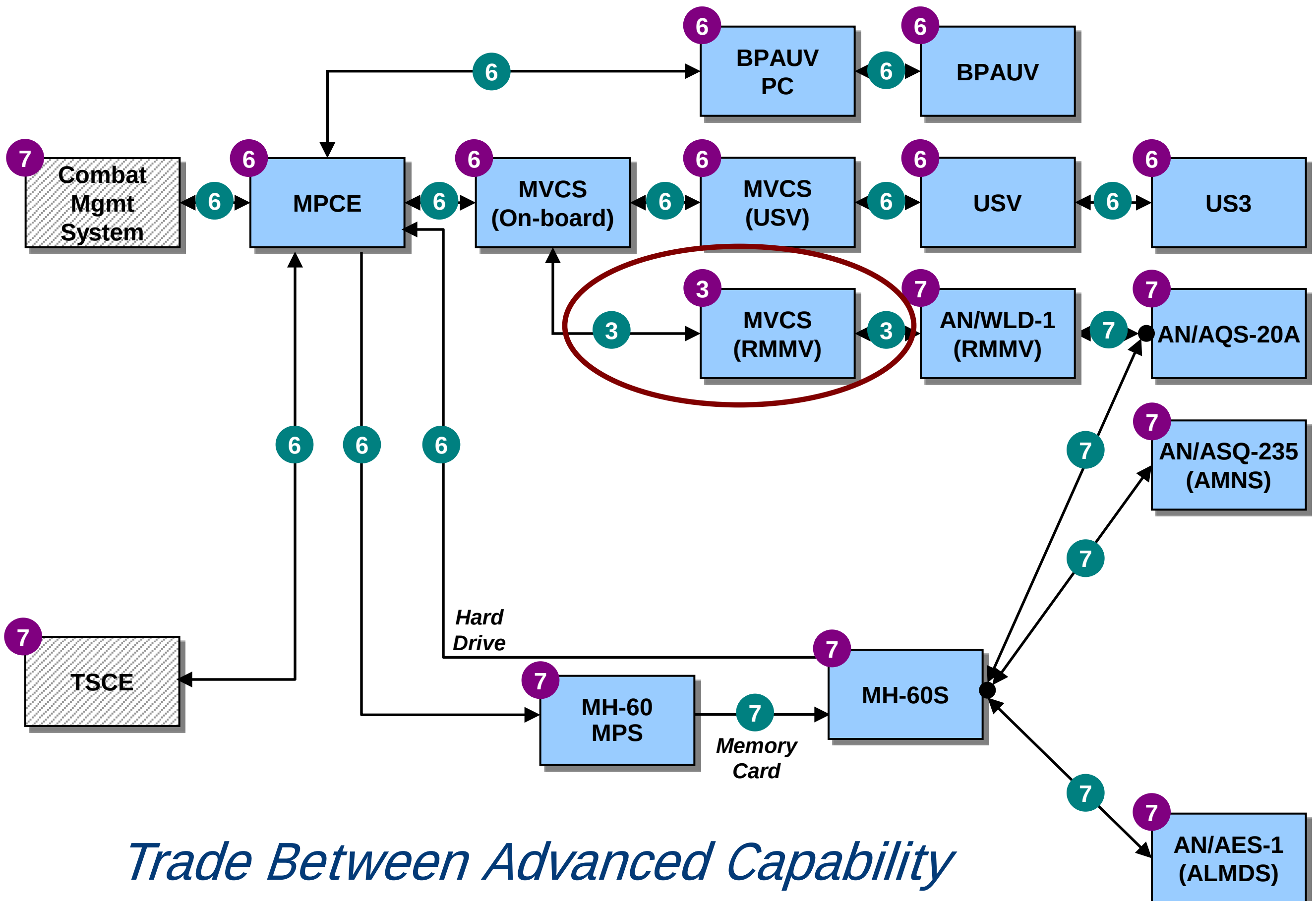
IRL Criteria

- Created expanded list of IRL criteria for each readiness level
- Goal was to capture the key elements of the integration maturation process
- Presented to 30 integration SMEs from across government, academia, and industry
- Asked to assess importance of each criterion
- Results show solid buy-in among SMEs that identified criteria are key factors in successful integration

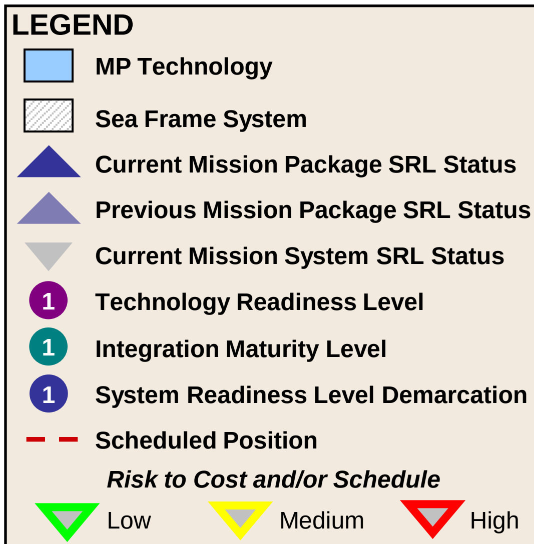
SRL Evaluation Process

- Conducted a "blind trial" of SRL methodology and evaluation process
- User's Guide and evaluation criteria were sent to key system SMEs
- From just these resources SMEs were asked to conduct the evaluation and report on the results
- Compiled results and iterated on lessons learned to improve the process

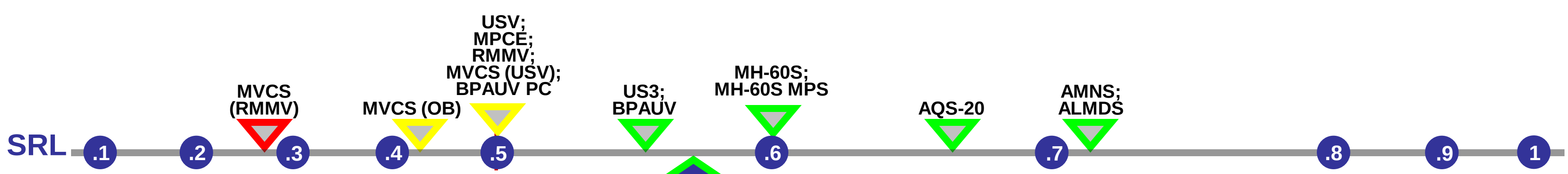
Trading Off Technology Options



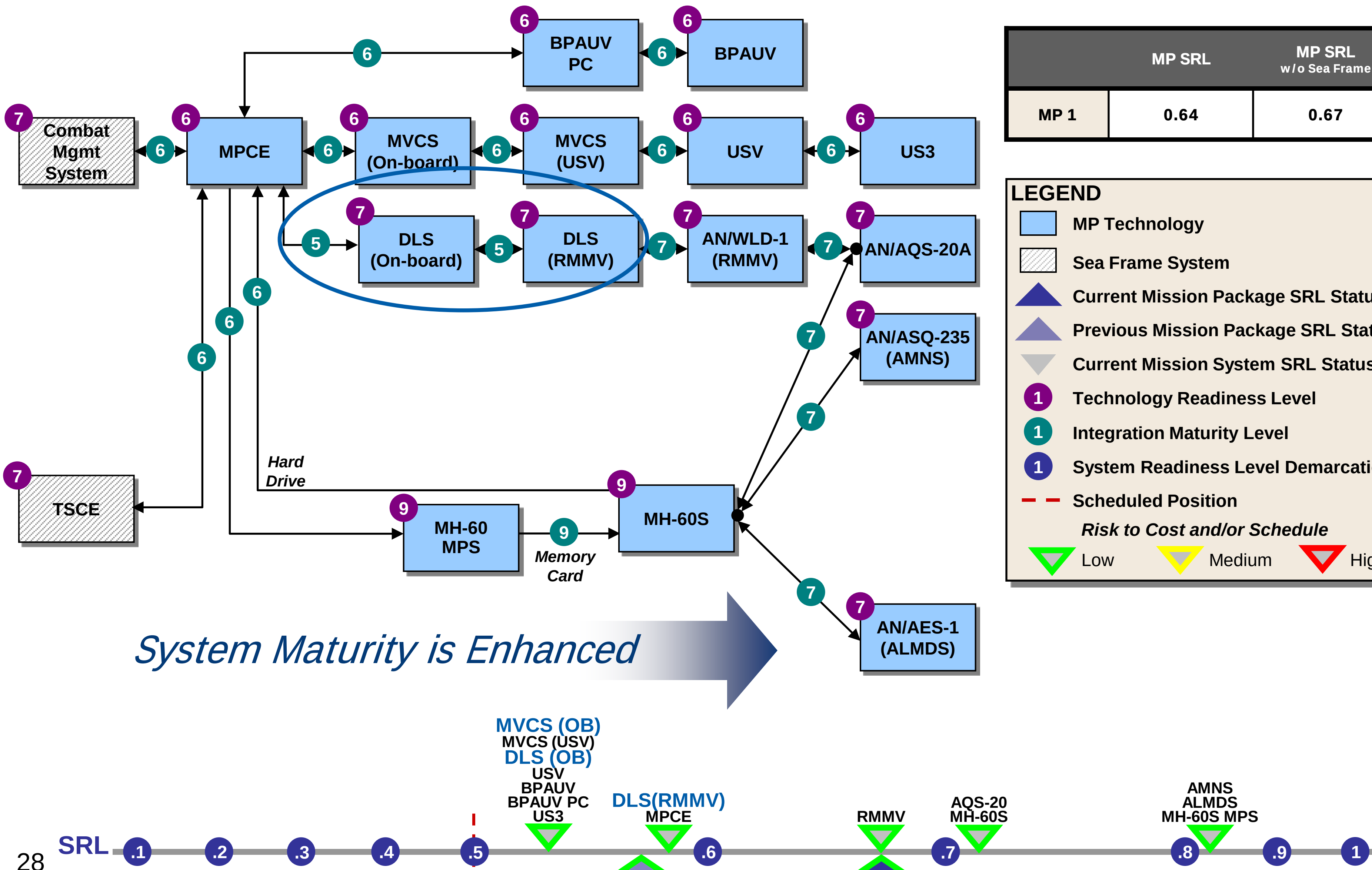
	MP SRL	MP SRL w/o Sea Frame
MP 1	0.60	0.57



Trade Between Advanced Capability or Increased Maturity



Taking Action to Mitigate Risk



	MP SRL	MP SRL w/o Sea Frame
MP 1	0.64	0.67

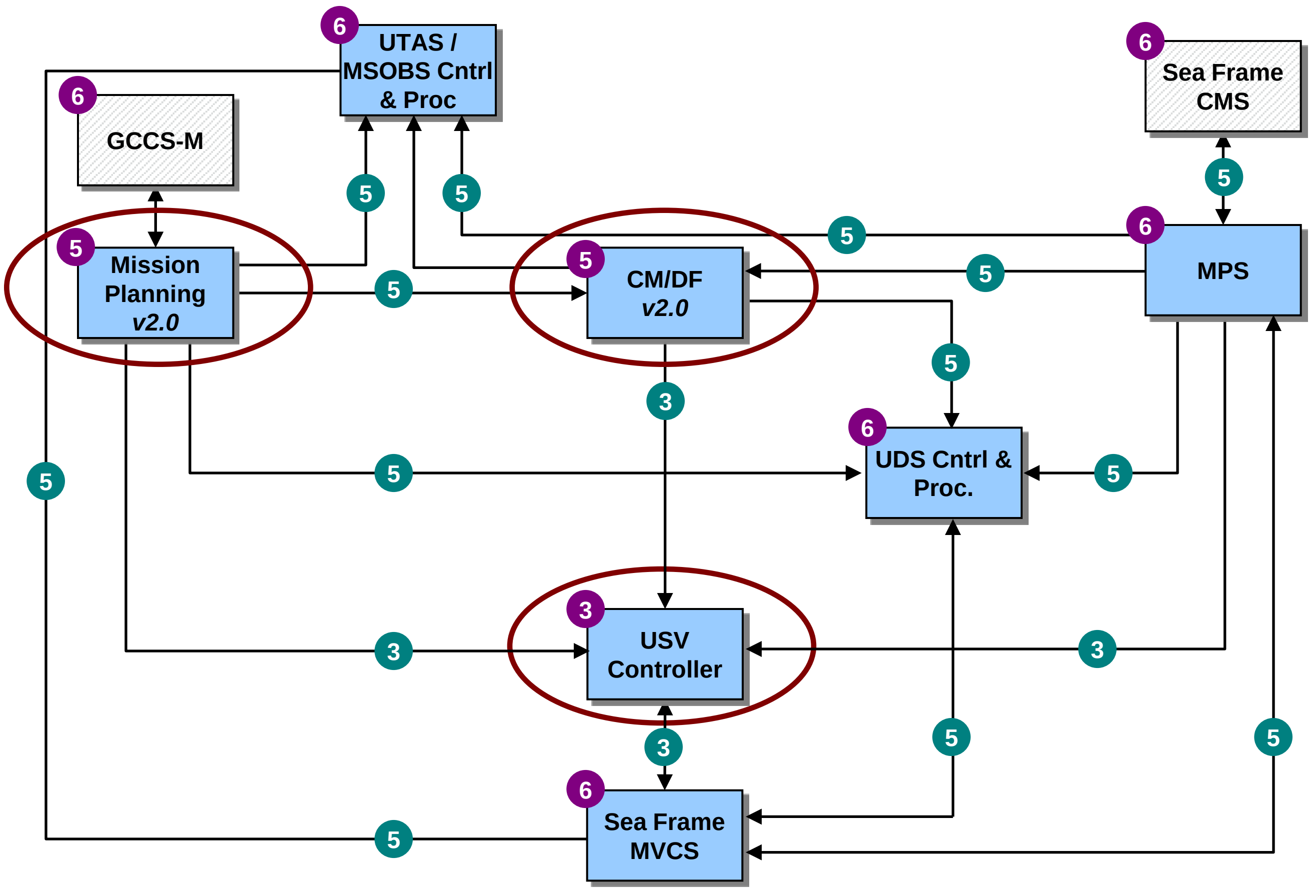
LEGEND

- MP Technology
- Sea Frame System
- Current Mission Package SRL Status
- Previous Mission Package SRL Status
- Current Mission System SRL Status
- 1 Technology Readiness Level
- 1 Integration Maturity Level
- 1 System Readiness Level Demarcation
- Scheduled Position

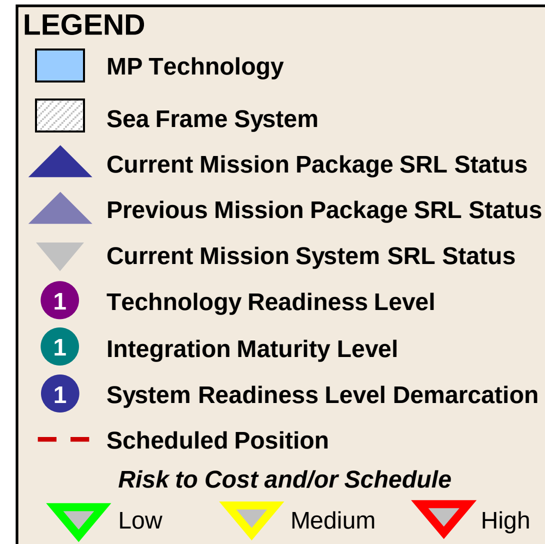
Risk to Cost and/or Schedule

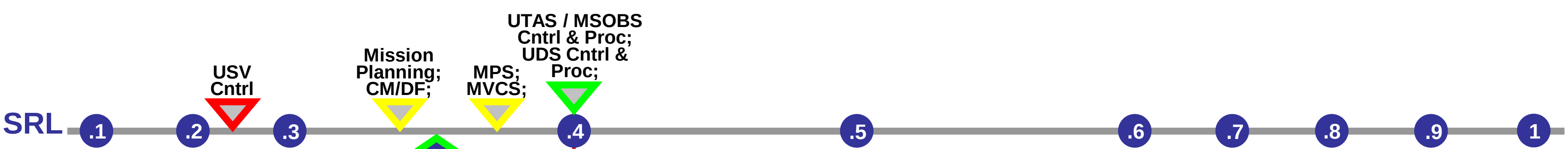
Low Medium High

Planning for the Unexpected

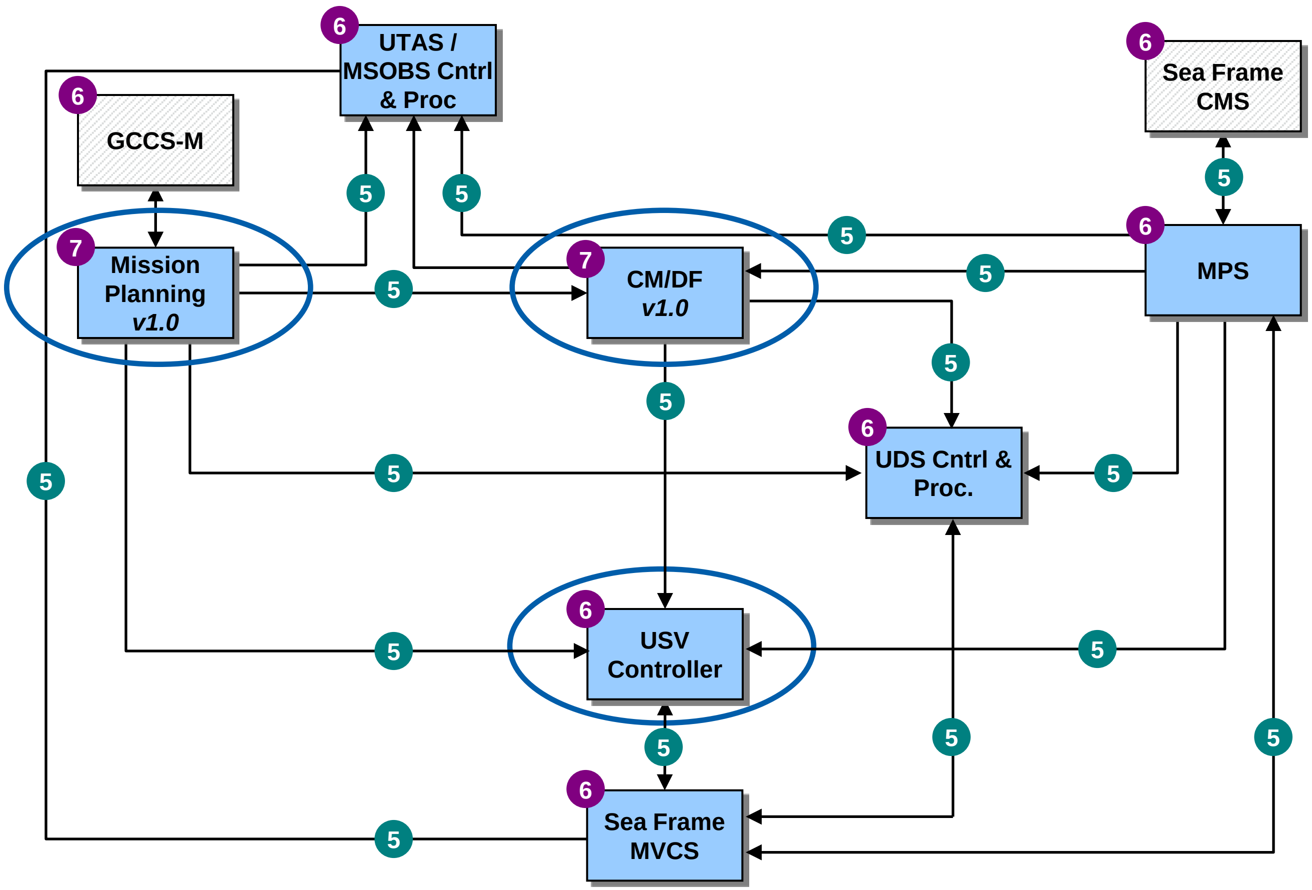


	MP SRL	MP SRL w/o Sea Frame
MP SW	0.39	0.35





Effectively Channeling Resources



	MP SRL	MP SRL w/o Sea Frame
MP SW	0.46	0.45

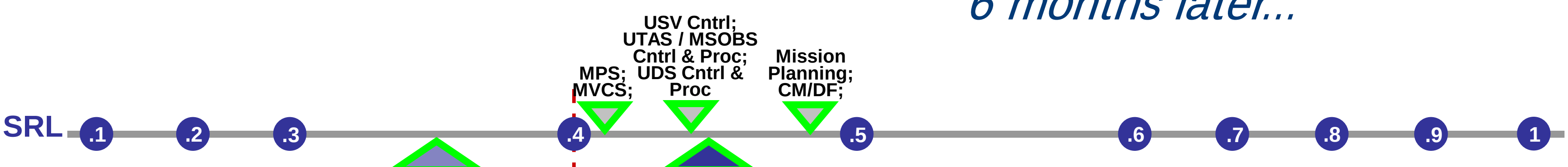
LEGEND

- MP Technology
- Sea Frame System
- Current Mission Package SRL Status
- Previous Mission Package SRL Status
- Current Mission System SRL Status
- 1 Technology Readiness Level
- 1 Integration Maturity Level
- 1 System Readiness Level Demarcation
- Scheduled Position

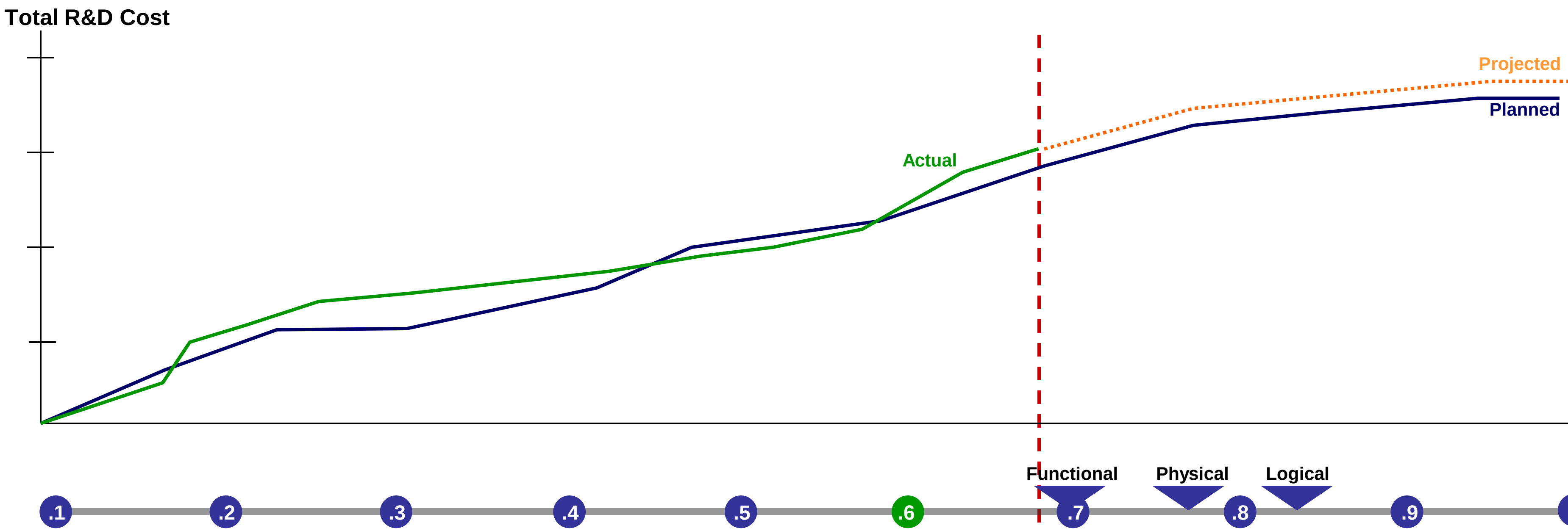
Risk to Cost and/or Schedule

Low Medium High

6 months later...



Linking Cost to Maturity via Milestones



Jun 2006	Jan 2007	Jul 2007	Nov 2007	May 2008	Sep 2008	Aug 2009	Apr 2010	Jan 2011	Apr 2012
Materiel Development Decision	**MILESTONE A**	Systems Requirements Review	System Functional Review	**MILESTONE B**	Critical Design Review	Test Readiness Review	**MILESTONE C**	**Initial Operational Capability**	**Full Operational Capability**
Initial Technical Review	Alternative Systems Review	Mission Systems Testing	Technology Readiness Assessment 1	Preliminary Design Review	Mission Module Testing	MP End-to-End Testing	System Verification Review	Physical Configuration Audit	In-Service Review
						DT / OT	Functional Configuration Audit	Full Rate Production Decision Review	
							Production Readiness Review		
							Technology Readiness Assessment 2		

- Current Mission Package SRL Status by View (Functional, Physical, Logical)
- .3 System Readiness Level Demarcation
- Scheduled Position (IMS)
- SRL assessment and test events / milestone gates are at or in advance of schedule
- SRL assessment is at or in advance of schedule, but test events / milestone gates remain to be closed
- SRL assessment and test events / milestone gates are behind schedule

Lessons Learned

- Methodology is highly adaptable and can be quickly applied to a wide variety of development efforts
- Programs tend to minimize the importance of system and subsystem integration and thus overestimate the maturity of their development
- Widespread familiarity with TRL makes acceptance and utilization of TRL and IRL easier
- Formulating the system architecture early in development is a key step and leads to an enhancement of the overall systems engineering effort
- System architecture formulation also provides the opportunity to bring together SMEs from both the physical and logical realms and necessitates insightful discussions across the team
- The decision maker is afforded the ability to asses program status from a system of systems perspective

The SRL methodology delivers a holistic evaluation of complex system readiness that is robust, repeatable, and agile