SYSTEMS
Development &
Maturity Laboratory

System (of Systems) Acquisition Maturity Models and Management Tools

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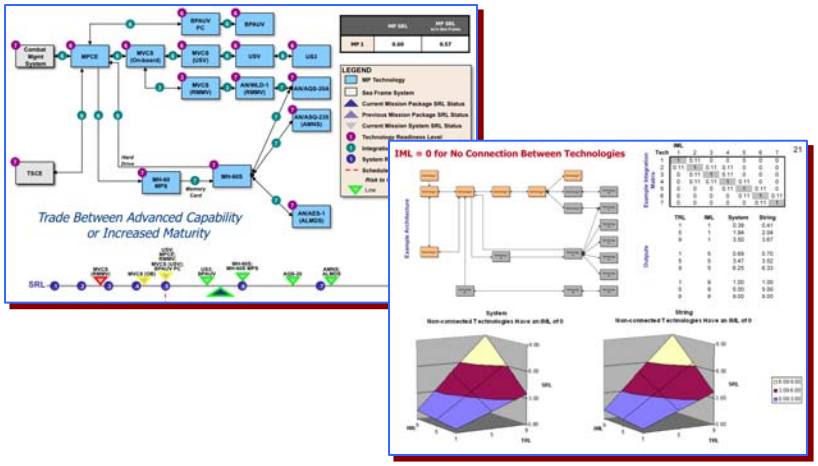
School of Systems and Enterprise



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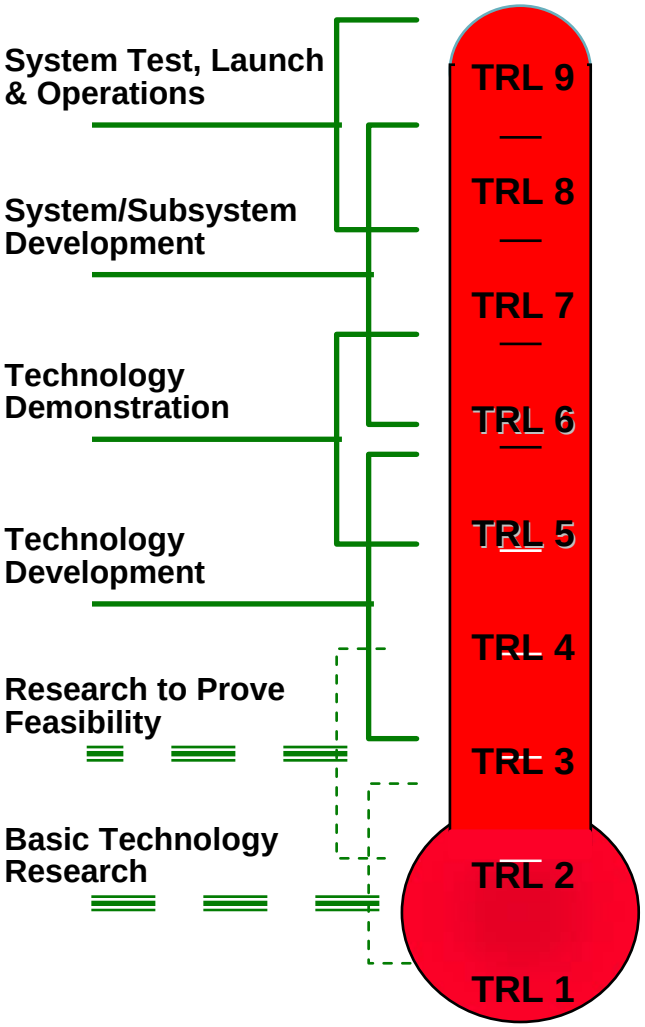
Technology Readiness Level (TRL)



Actual system proven through successful mission operations

Actual system completed and qualified through test and demonstration

System prototype demonstration in a relevant environment

System/subsystem model or prototype demonstration in a relevant environment

Component and/or breadboard validation in relevant environment

Component and/or breadboard validation in laboratory environment

Analytical and experimental critical function and/or characteristic proof-of-concept

Technology concept and/or application formulated

Basic principles observed and reported

TRL Shortcomings

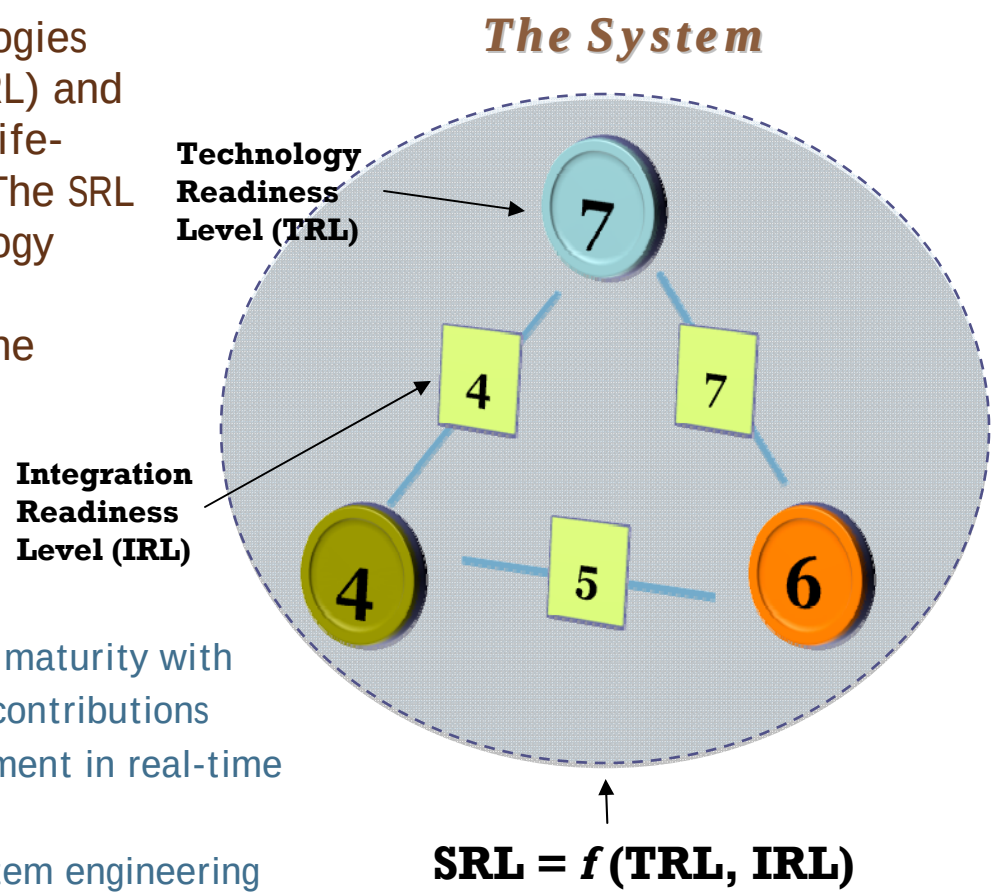
- Application of TRL to systems of technologies is not sufficient to give a holistic picture of complex system of systems readiness
  - TRL is only a measure of an individual technology
- Assessments of several technologies rapidly becomes very complex without a systematic method of comparison
- Multiple 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

Integration Readiness Level

	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.

What we are doing?

Development of metrics, tool, and methodologies for determining a systems readiness level (SRL) and potential for making efficient and effective life-cycle acquisition and operational decisions. The SRL Model is a function of the individual Technology Readiness Levels (TRL) and their subsequent integration points with other technologies, the Integration Readiness Level (IRL).



- **Value Proposition:**
  - 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

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

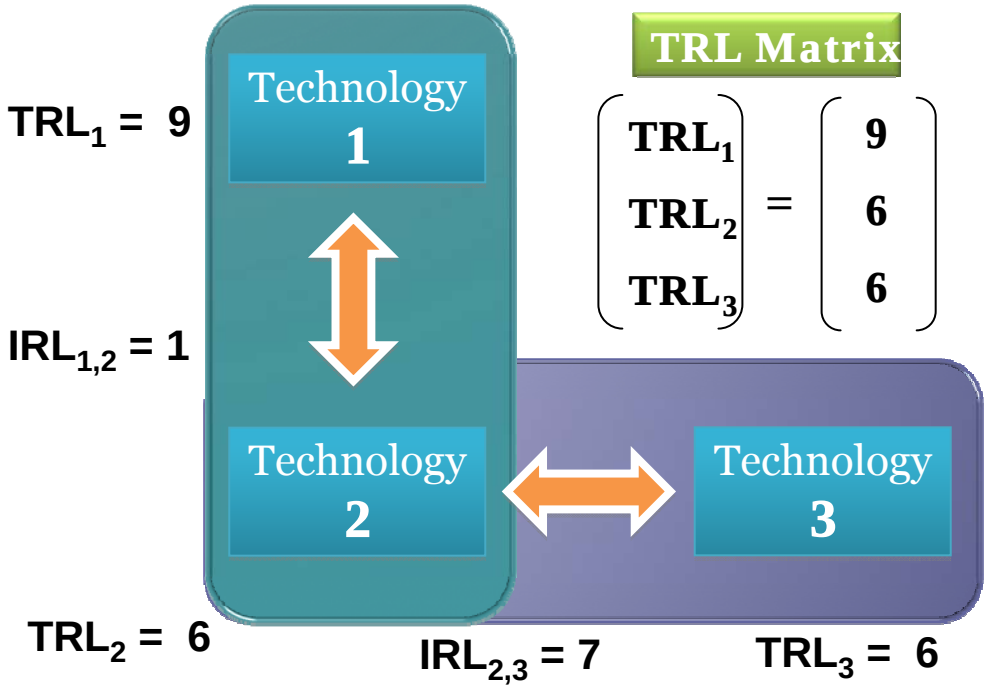
$$\begin{pmatrix} SRL_1 & SRL_2 & SRL_3 \end{pmatrix} = \begin{pmatrix} IRL_{11} & IRL_{12} & IRL_{13} \\ IRL_{12} & IRL_{22} & IRL_{23} \\ IRL_{13} & IRL_{23} & IRL_{33} \end{pmatrix} \times \begin{pmatrix} TRL_1 \\ TRL_2 \\ TRL_3 \end{pmatrix}$$

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

$$= 1/n^2\left(SRL_1 + SRL_2 + SRL_3\right)$$

- 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

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)

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

Component SRL_x represents Technology "X" and its IRLs considered

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

The Composite SRL provides an overall assessment of the system readiness

Sauser, B., J. Ramirez-Marquez, R. Magnaye, and W. Tan. (2008). "A Systems Approach to Expanding the Technology Readiness Level within Defense Acquisition." *International Journal of Defense Acquisition Management*. 1:39-58

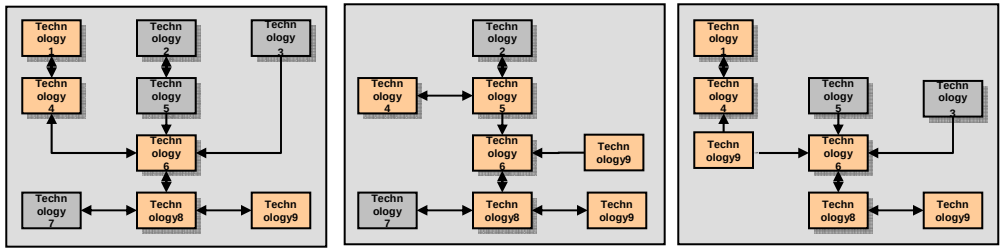
Key Assumptions and Limitations

- Ordinal data is given numeric value in order to assess overall progression or performance.
  - Grade Point Average (GPA), Failure Modes and Effects Analysis (FMEA)
- One system cannot be compared to the SRL of another system unless they are the same system.
  - You cannot a student with a 3.2 GPA in physics with a student that has a 3.8 GPA in biology. These students belong to different systems of education, but they are evaluated with the same system of metrics.
- Analysis is limited by the experience of previous assessments and experience of the assessors

Key Assumptions and Limitations

- Analysis may result in rank reversals, where a less mature SRL receives a higher rating than a more mature SRL.
  - The reason for this is that the rankings are ordinal scale numbers, and multiplication is not a valid operation on them. The ordinal rankings only say that one ranking is better or worse than another, but not by how much.
- If used as a top-down tool, SRL may only identify major maturity deficiencies in a system.
  - When used as a "bottom-up" tool SRL can augment or complement other (systems) engineering management activities and identify many more maturity deficiencies resulting in top-level symptoms.

1.0 SoS Architectures Defined



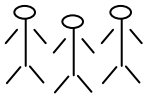
Functional *Capability* | **Physical** *Hardware* | **Logical** *Software / Data Flow*

System architectures are defined along with identification of operational threads and the critical technology elements and interfaces

2.0 Assessment Framework Developed

MP SE

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



SEIPT

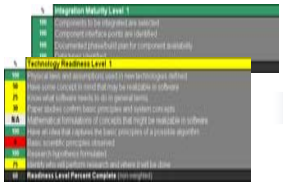
- Review proposed criteria, schedule, and milestones

TD / PM

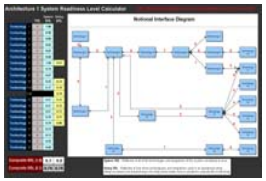
- Approves assessment framework

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

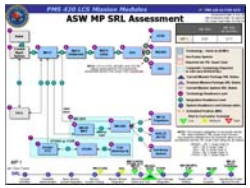
3.0 Quarterly SRL Assessment



TRLs / IRLs Evaluated and Justified



SRL Calculated

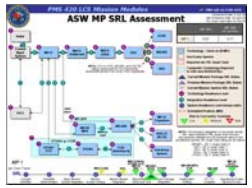


Reports Built

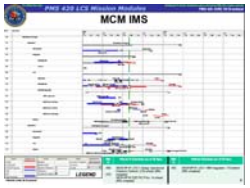
Risks Identified Against Schedule

- *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*

4.0 Cost Evaluated

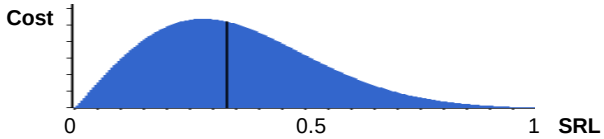


SRL Assessment

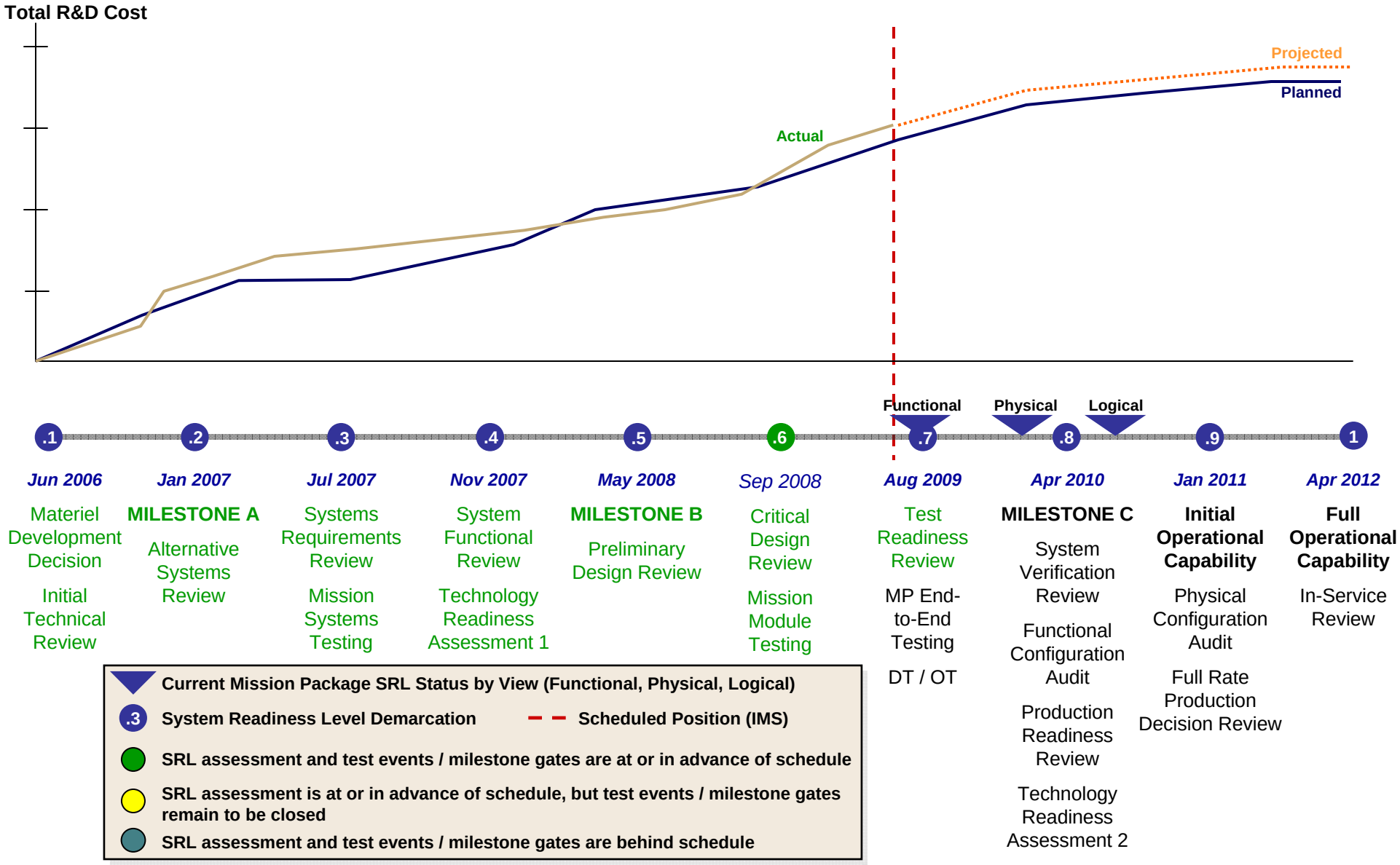


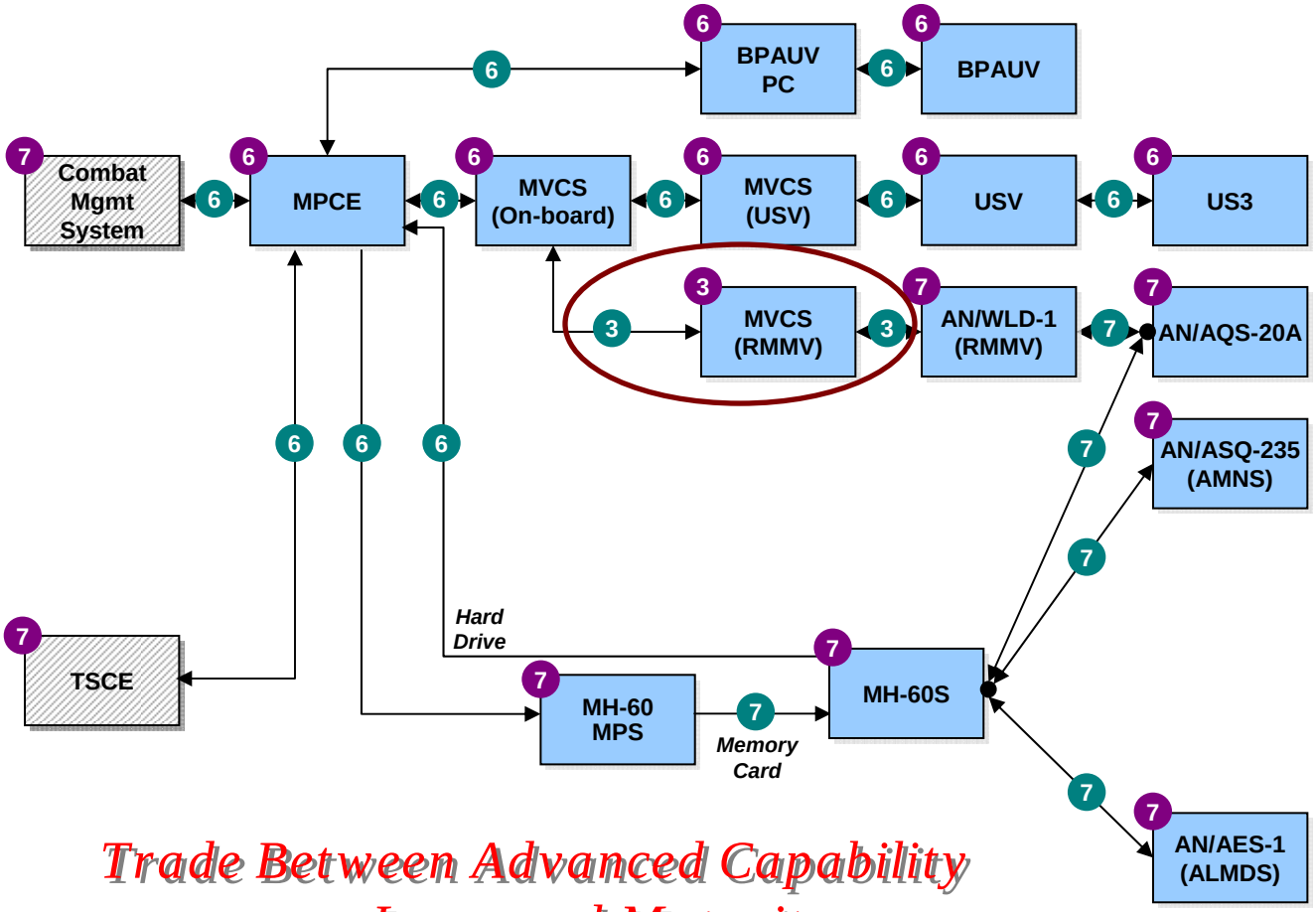
IMS

Cost required to meet each SRL increment can be calculated from the test events / milestone gates scheduled to be achieved each increment, which are hours loaded in the IMS



Example Reporting Format





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

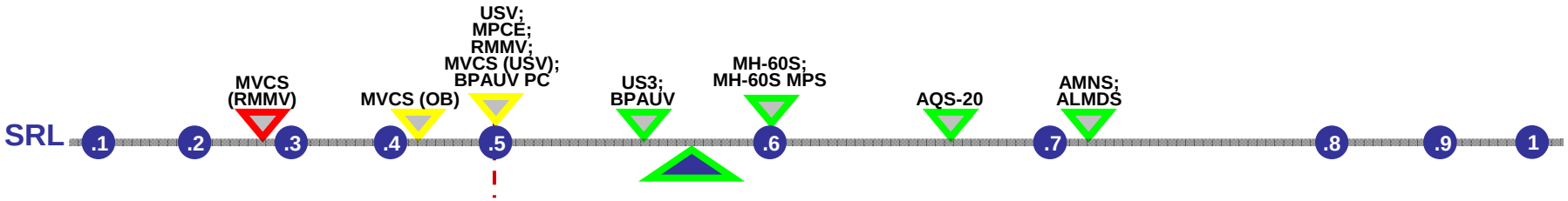
LEGEND

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

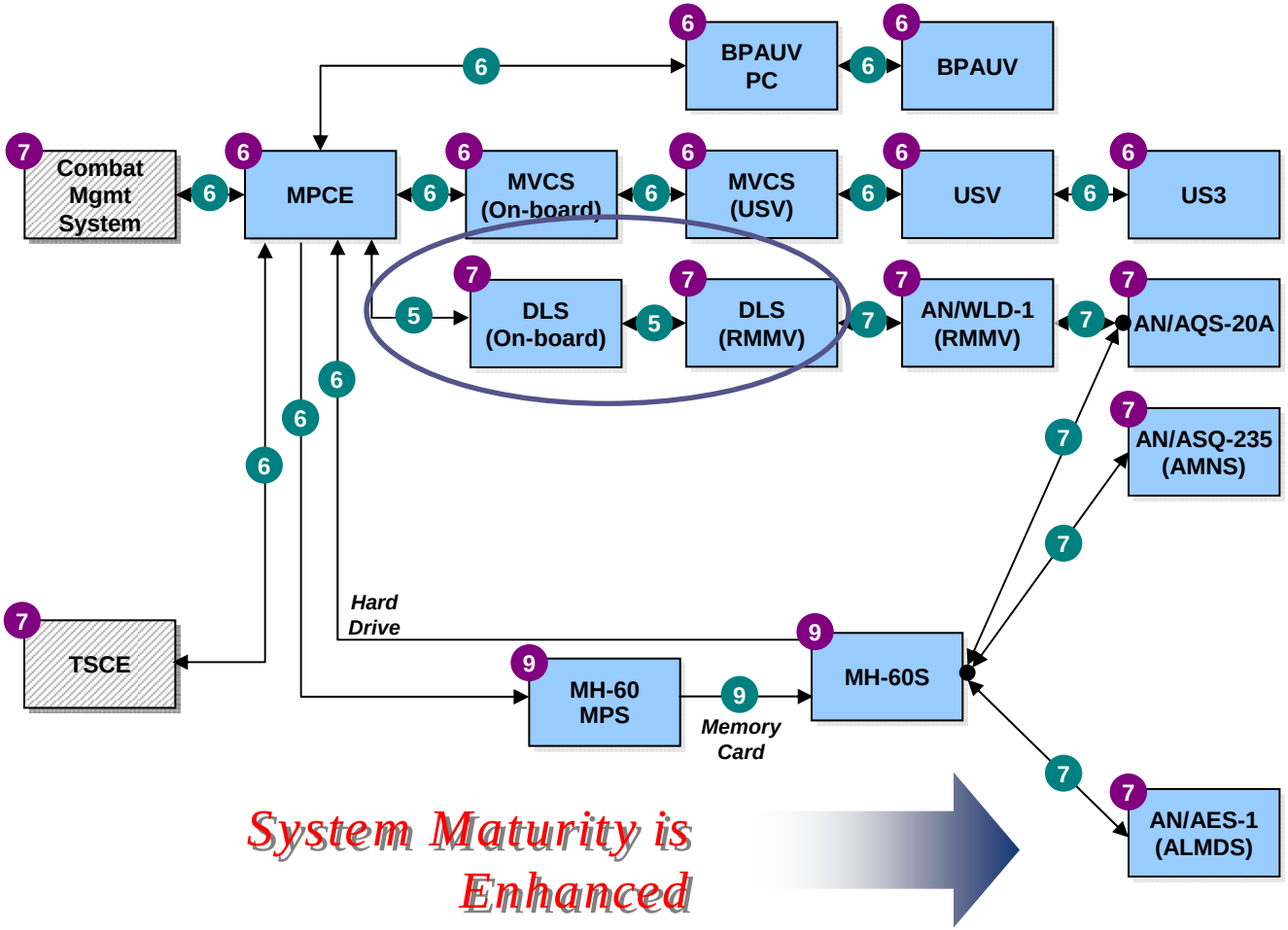
Risk to Cost and/or Schedule

Low Medium High

Trade Between Advanced Capability or Increased Maturity



Example provided by Northrop Grumman Integrated Systems



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

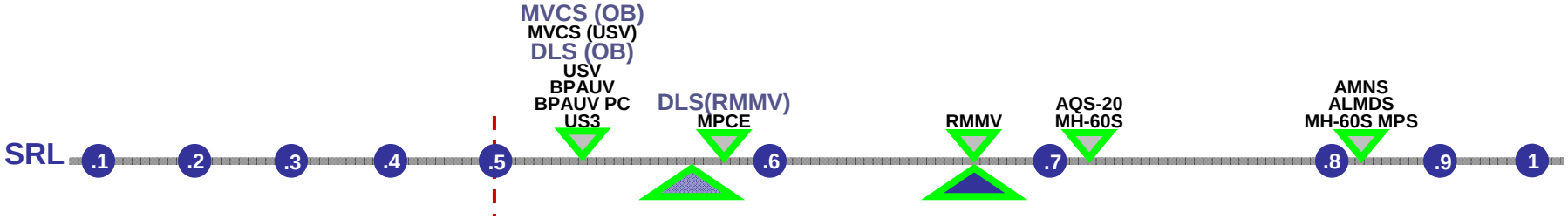
LEGEND

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

Risk to Cost and/or Schedule

Low Medium High

System Maturity is Enhanced



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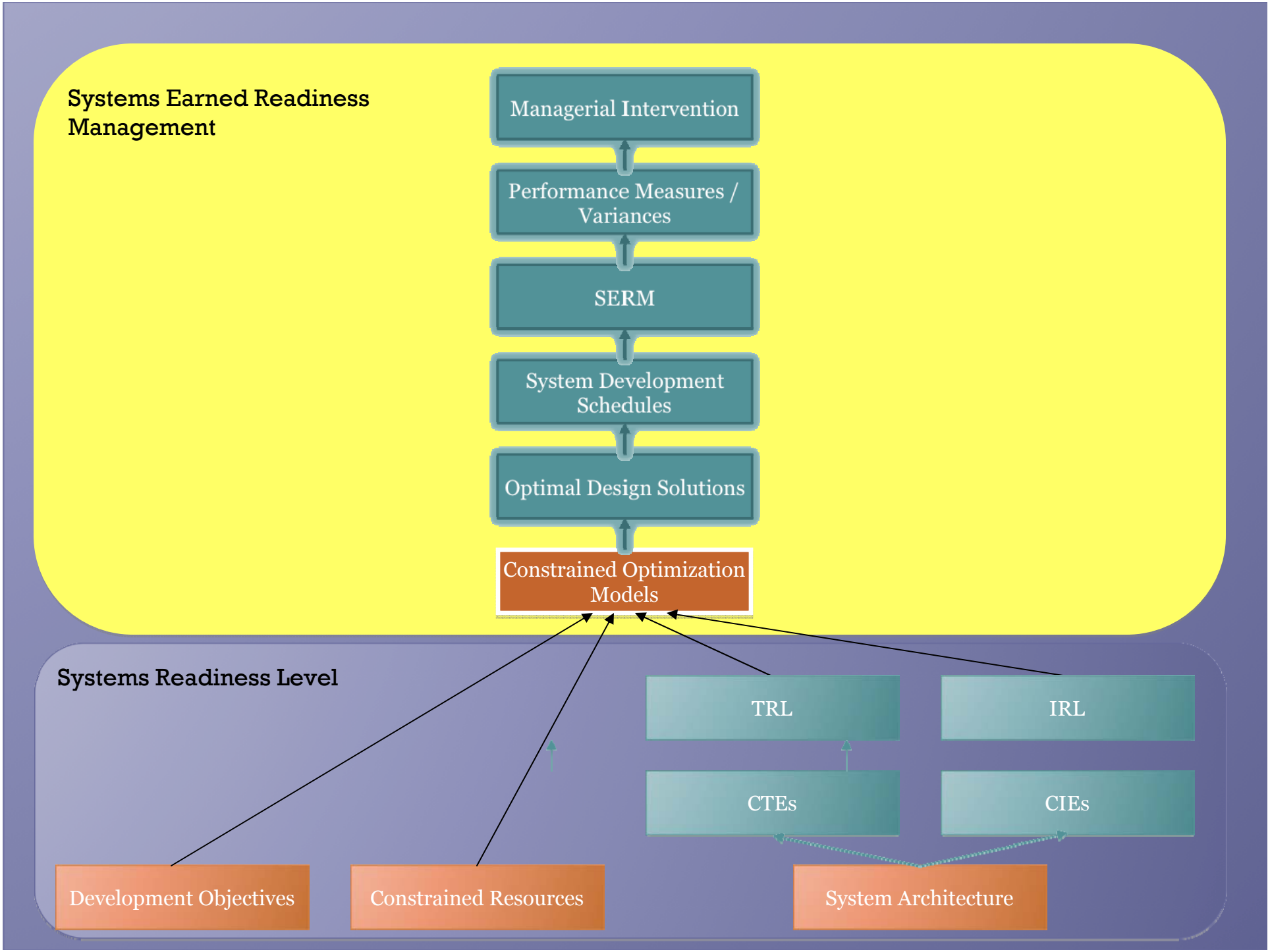

Systems Earned Readiness Management
Managerial Intervention
Performance Measures / Variances
SERM
System Development Schedules
Optimal Design Solutions
Constrained Optimization Models
Systems Readiness Level
TRL
IRL
CTEs
CIEs
Development Objectives
Constrained Resources
System Architecture

Resource Optimization Models and System Earned Readiness Management (SERM)

SRL Resource Optimization

$$\text{Max} \quad SRL(\mathbf{TRL},\mathbf{IRL})$$

$$s.t.$$

$$R_1(\mathbf{TRL},\mathbf{IRL}) \le r_1$$

$$\vdots$$

$$R_H(\mathbf{TRL},\mathbf{IRL}) \le r_H$$

Model SRL$_{max}$ = an optimization model with the objective to maximize the SRL (a function of TRL and IRL) under constraints associated with resources.

Resources Available	TRL						IRL						
	1	2	3	4	5	6	1,2	1,3	2,3	2,4	3,5	4,5	5,6
100%	9	9	9	9	9	9	9	9	9	9	9	9	9
75%	9	9	9	9	9	9	9	9	8	9	8	6	8
60%	9	9	9	9	9	9	9	8	8	7	8	5	7
45%	9	9	9	8	9	9	8	8	8	6	8	4	6
30%	8	9	9	6	9	9	8	8	8	5	7	2	5
15%	8	8	8	6	9	6	8	8	7	5	7	2	4
0%	8	8	7	6	6	6	5	6	6	5	6	2	2

Sauser, B.J. and J.E. Ramirez-Marquez. (2009). "System Development Planning via System Maturity Optimization." *IEEE Transactions on Engineering Management.* (in press; available at http://ieeexplore.ieee.org)

SRL Resource Optimization

$$\text{Min} \quad Cost(\mathbf{TRL},\mathbf{IRL})$$

$$s.t.$$

$$SRL(\mathbf{TRL},\mathbf{IRL}) \geq \lambda$$

$$R_1(\mathbf{TRL},\mathbf{IRL}) \leq r_1$$

$$\vdots$$

$$R_n(\mathbf{TRL},\mathbf{IRL}) \leq r_n$$

Model SCOD$_{\mathbf{min}}$ = an optimization model whose objective is to minimize development cost (a function of TRL and IRL development) under constraints associated with schedule and the required SRL value.

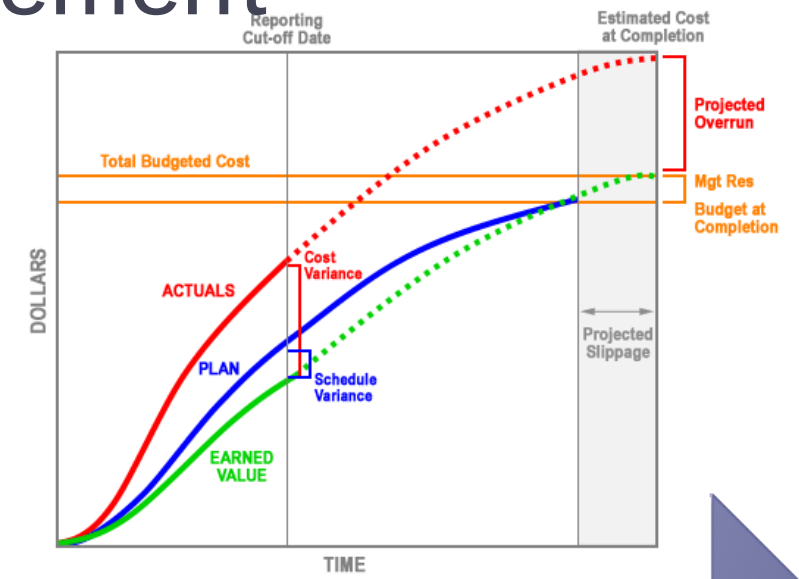
Year	Target SRL	TRL						IRL						
		1	2	3	4	5	6	1,2	1,3	2,3	2,4	3,5	4,5	5,6
6	1.000	9	9	9	9	9	9	9	9	9	9	9	9	9
5	0.896	9	9	9	8	9	9	9	9	9	8	8	5	7
4	0.792	8	9	9	6	9	9	9	9	9	5	8	4	6
3	0.688	8	8	9	6	9	9	8	8	7	5	7	2	4
2	0.584	8	8	8	6	7	6	7	7	7	5	6	2	4
1	0.480	8	8	7	6	6	6	5	6	6	5	6	2	2

Magnaye, R., B. Sauser, and J. Ramirez-Marquez. (2010). "System Development Planning Using Readiness Levels in a Cost of Development Minimization Model." *Systems Engineering*. 13(4) (in press)

Systems Earned Readiness Management

Earned value analysis

- Is a performance monitoring tool
- Provides a measure of performance that is:
  - Realistic?
  - Based on actual data?
- Provides answers to these questions:
  - What WORK is scheduled to have been completed?
  - What was the cost estimate for the WORK scheduled?
  - What WORK has been accomplished?
  - What was the cost estimated of the completed WORK?
  - What have our actual costs been?
  - What are the variances?



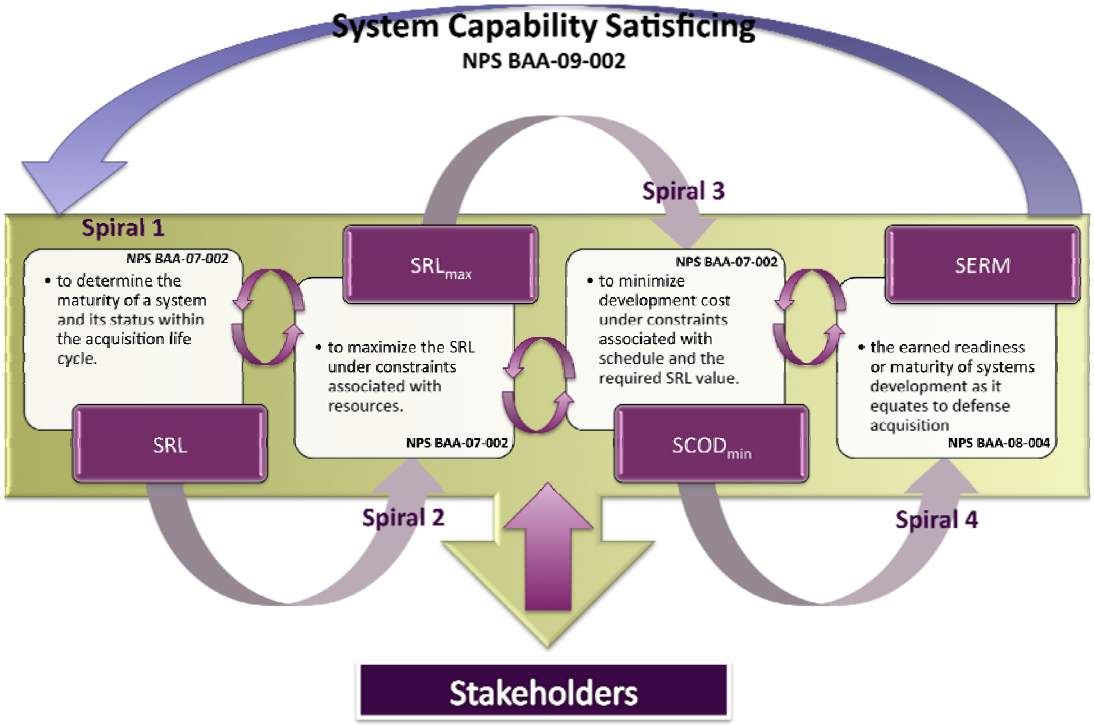
SERM

Replaces WORK with MATURITY
Using SRL_{max} and $SCOD_{min}$
makes it predictive

Model Based Systems Engineering

- Utilizing Model Based Systems Engineering (MBSE):
  - Setup an environment to model the current SRL approach;
  - Review other 'metrics' need to be included and determine their relationships to TRL, IRL, and the System Architecture;
  - Provide a process for determining SRL within MBSE.
  - Determine a set of 'views' or diagrams on the model creation which enables a way to communicate (e.g. a System Maturity Diagram)
  - MBSE allows for the functional decomposition of models which would allow for a recursive SRL assessment whereby an SRL at one level transforms to a TRL at another.

System Capability Satisficing



"*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?*"

http://www.Systems-Development-Maturity.com

http://www.SystemReadinessLevel.com

Welcome Publications Research Tools Who We Are SMA Roundtable

As part of the School of Systems and Enterprises, the Systems Development & Maturity Laboratory (SD&ML) resides in the S.C. Williams Library on the Stevens Institute of Technology campus. The SD&ML is dedicated to:

1) advancing the state of knowledge and practice in systems development and maturity, and
2) acting as a collaborative catalyst for a national community interested in systems development and maturity.

FACULTY

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Welcome Publications Research Tools Who We Are SMA Roundtable

There is a need for "...research in developing more formal metrics and models for determining systems engineering effectiveness for enabling continuous improvement."

Kelly Miller, Chief Systems Engineer, NSA
Conference on Systems Engineering Research

SYSTEMS Development & Maturity Laboratory

Welcome...

The **Systems Development & Maturity Laboratory (SD&ML)** has been pursuing the development of system-focused methodologies, processes, and tools for managing system development and making effective and efficient decisions during the acquisition lifecycle.

This has included development of indices in order to assess developmental and earned systems maturity and the formulation of optimization models that allow for effective trade-offs in functionality, capability, cost, schedule, and maturity, that will allow for the deployment of systems that can still satisfy a customer's needs.

In the spirit of an Open-Academic Model, on this web site, we share our research ideas, visions, and results in order to inform a greater community of what we are doing so they may also expand the state of knowledge in this area.

SSE School of Systems&Enterprises

STEVENS Institute of Technology

Customers…

- U.S. Navy – NAVSEA PMS 420
- U.S. Army – Armament Research, Engineering, and Development Center
- Northrop Grumman – Integrated Systems
- Lockheed Martin – MS2
- Office of the Secretary of Defense Acquisition Research Program – Naval Postgraduate School