Acquisition Research Program:
Creating Synergy for Informed Change

System Maturity Indices for Decision Support in the Defense Acquisition Process

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Abstract

In the National Aeronautics and Space Administration (NASA) and the Department of Defense (DoD) the Technology Readiness Level (TRL) scale is a measure of maturity of an individual technology, with a view towards operational use in a system context. **A comprehensive set of concerns becomes relevant when this metric is abstracted from an individual technology to a system context, which may involve interplay among multiple technologies that are integrated through a systems engineering process.** This research proposes the development of a system-focused approach for managing system development and making effective and efficient decisions during a systems engineering process. This research will present **a System Readiness Level (SRL) index that incorporates both the current TRL scale and the concept of an Integration Readiness Level (IRL) and provide a method for determining current and future readiness of a system to determine its potential position in the systems engineering process.**

What's Missing in TRL?

- A complete representation of the (difficulty of) integration of the subject technology or subsystems into an operational system (Dowling and Pardoe, 2005, Mankins, 2002, Meystel et al., 2003, Smith, 2005, Valerdi and Kohl, 2004),
- The uncertainty that may be expected in moving through the maturation of TRL (Shishko et al., 2003, Cundiff, 2003, Dowling and Pardoe, 2005, Mankins, 2002, Smith, 2005, Moorehouse, 2001), and
- Comparative analysis techniques for alternative TRLs (Cundiff, 2003, Dowling and Pardoe, 2005, Mankins, 2002, Smith, 2005, Valerdi and Kohl, 2004).

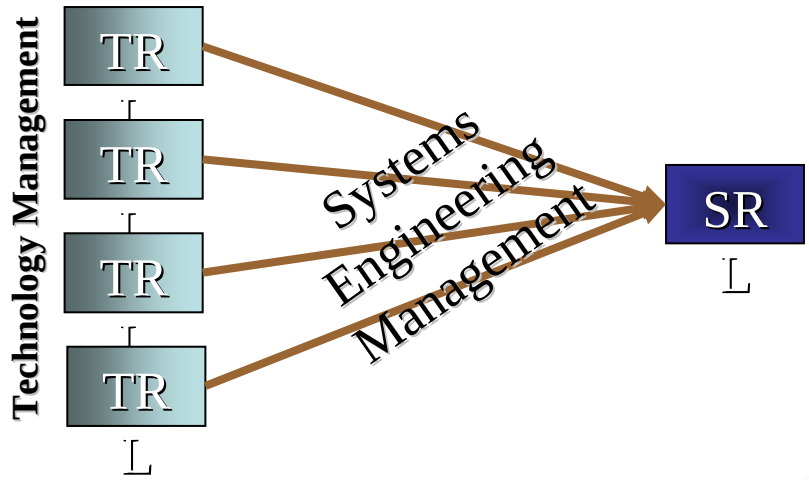
"In order to succeed over the longer term, additional methodologies are needed, including those which allow the identification of anticipated uncertainty in planned R&T programs…" (Mankins, 2002)

Other Work

- Manufacturing Readiness Level (DoD)
  - Used to assess the SE/design process and maturity of a technology's associated manufacturing processes to enable rapid, affordable transition to acquisition programs.
- Integrated Technology Analysis Methodology (ITAM) (Mankins, 2002)
  - Discipline-neutral, quantitative measure of the relative technological challenge inherent in various candidate/competing advanced systems concepts.
- Systems Integration Readiness Level (MoD)
  - System Readiness Levels (*SRLs*) were developed as a tool for projects to assess System Maturity, and to communicate this in a consistent manner.
- Capability RL, Design RL, Habitation RL, Human RL, Logistics RL, Operational RL, and Software RL

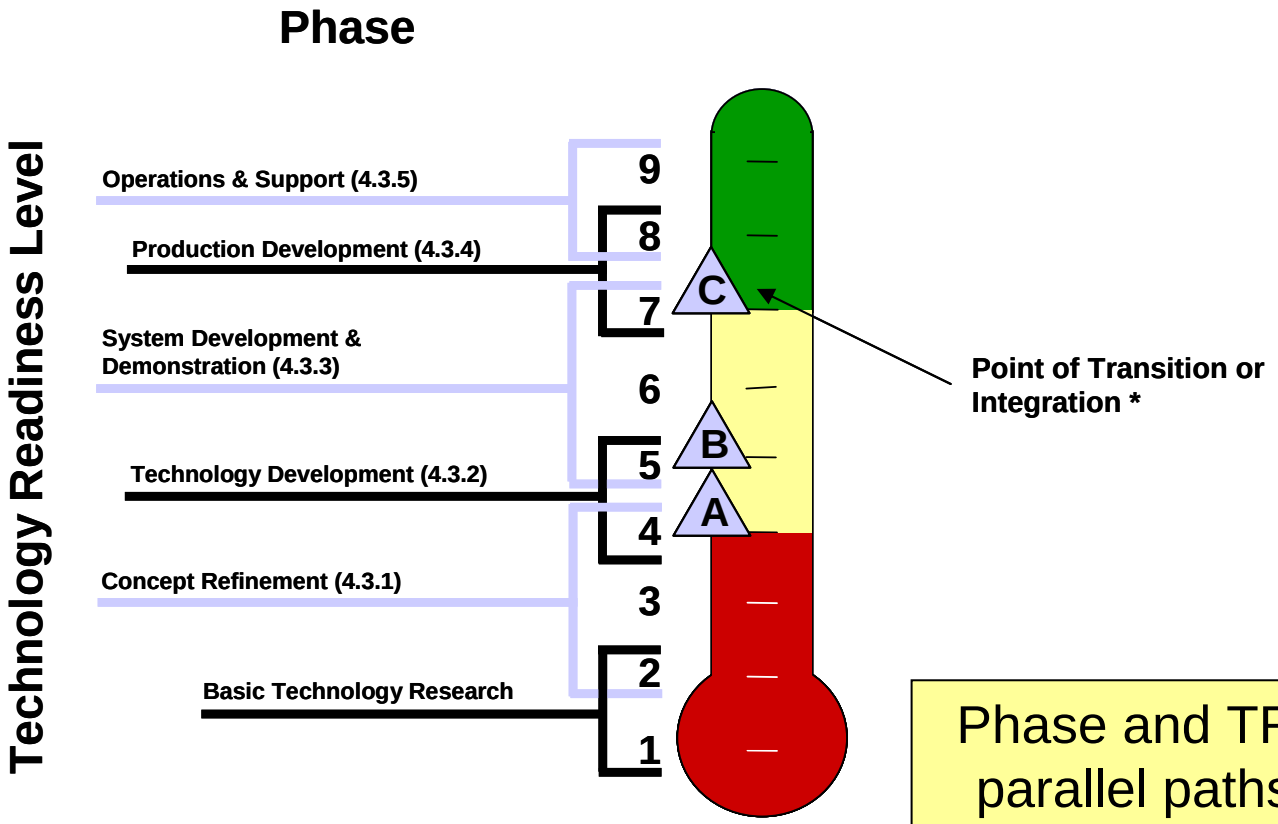
Why do we need a Systems Readiness Level (SRL)?

- TRL is only a measure of an individual technology; it gives no indication of a systems readiness.
- There is no method for integrating TRLs
- There is no systematic measure of a systems readiness.



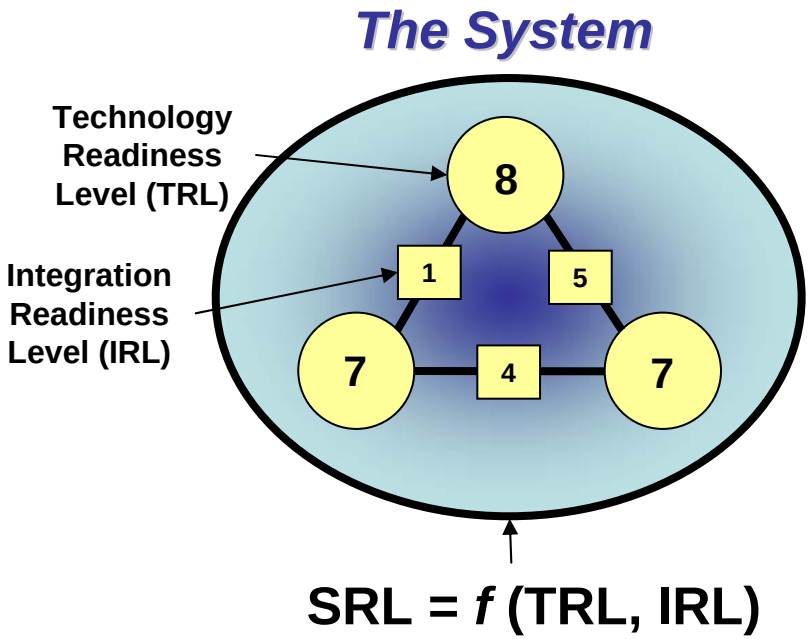
A 1999 GAO Report stated that programs started with a technology at TRL 5 or below experienced "significant cost and schedule increases." GAO also recommended that technologies should mature until the equivalent of TRL 7 before they are included in weapon system programs.

Parallel *(not integrated)* Development



Phase and TRL scales on parallel paths still do not consider integration.

Systems Readiness Level



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:**
  - Currently TRL is only a measure of an individual technology
  - There is no method for integrating TRLs
  - There is no systematic measure of a systems readiness
  - Cost and schedule reduction in strategic technology development planning
- **Deliverable:** Integration of methodologies for strategic roadmap planning that illustrate the timely implementation of capability increments.

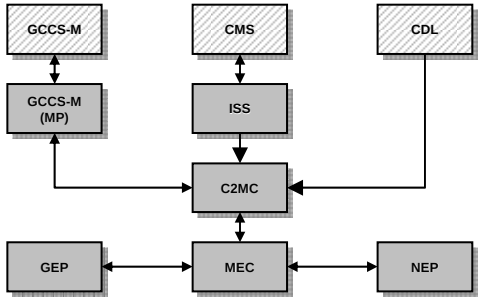
Maturity Indices

LEVEL	TRL Definition	IRL Definition	SRL Definition	SRL VALUE
9	Actual system proven through successful mission operations	Integration is mission proven through successful mission operations	Operations and Support	0.90 to 1.00
			Production	0.80 to 0.89
8	Actual system completed and qualified through test and demonstration	Actual integration completed and mission qualified through test and demonstration in the system environment	System Development and Demonstration	0.60 to 0.79
7	System prototype demonstration in relevant environment	The integration of technologies has been verified and validated with sufficient detail to be actionable		
6	System/subsystem model demonstration in relevant environment	The integrating technologies can accept, translate and structure information for its intended application	Technology Development	0.40 to 0.59
5	Component and/or breadboard validation in relevant environment	There is sufficient control between technologies necessary to establish, manage and terminate the integration		
4	Component and/or breadboard validation in laboratory environment	There is sufficient detail in the quality and assurance of the integration between technologies	Concept Refinement	0.10 to 0.39
3	Analytical & experimental critical function and/or characteristic proof-of-concept	There is compatibility between technologies to orderly and efficiently integrate and interact		
2	Technology concept and/or application formulated	There is some level of specificity to characterize the interaction between technologies through their interface		
1	Basic principles observed and reported	An interface between technologies has been identified with sufficient detail to allow characterization of the relationship		

Step 1: Identify hardware and software systems to be analyzed

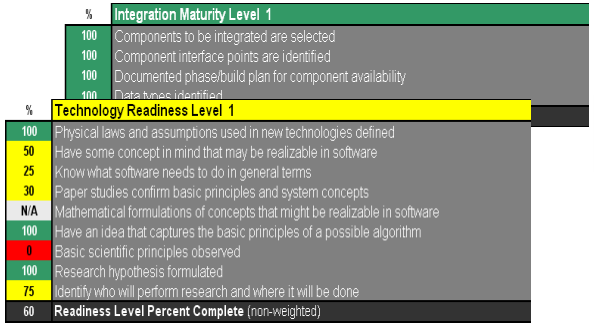
Include the major technologies and components that make-up the overall system

Step 2: Define network diagram for systems



Emphasis is on the proper depiction of hardware and software integration between systems

Step 3: Apply detailed TRL and IRL evaluation criteria to systems

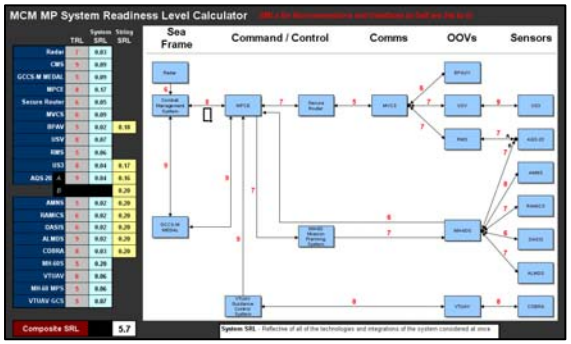


%	Integration Maturity Level 1
100	Components to be integrated are selected
100	Component interface points are identified
100	Documented phase/build plan for component availability
100	Data types identified

%	Technology Readiness Level 1
100	Physical laws and assumptions used in new technologies defined
50	Have some concept in mind that may be realizable in software
25	Know what software needs to do in general terms
30	Paper studies confirm basic principles and system concepts
N/A	Mathematical formulations of concepts that might be realizable in software
100	Have an idea that captures the basic principles of a possible algorithm
0	Basic scientific principles observed
100	Research hypothesis formulated
75	Identify who will perform research and where it will be done
60	**Readiness Level Percent Complete** (non-weighted)

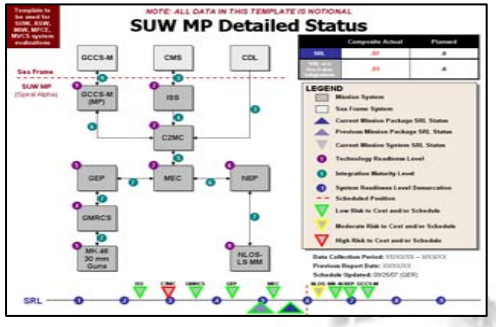
Utilize detailed evaluation criteria to determine the TRL of identified systems and the IRL of defined connections

Step 4: Calculate individual and composite SRLs



Leverage TRL and IRL evaluations to compute an assessment of overall system status via SRLs

Step 5: Document status via roll-up charts

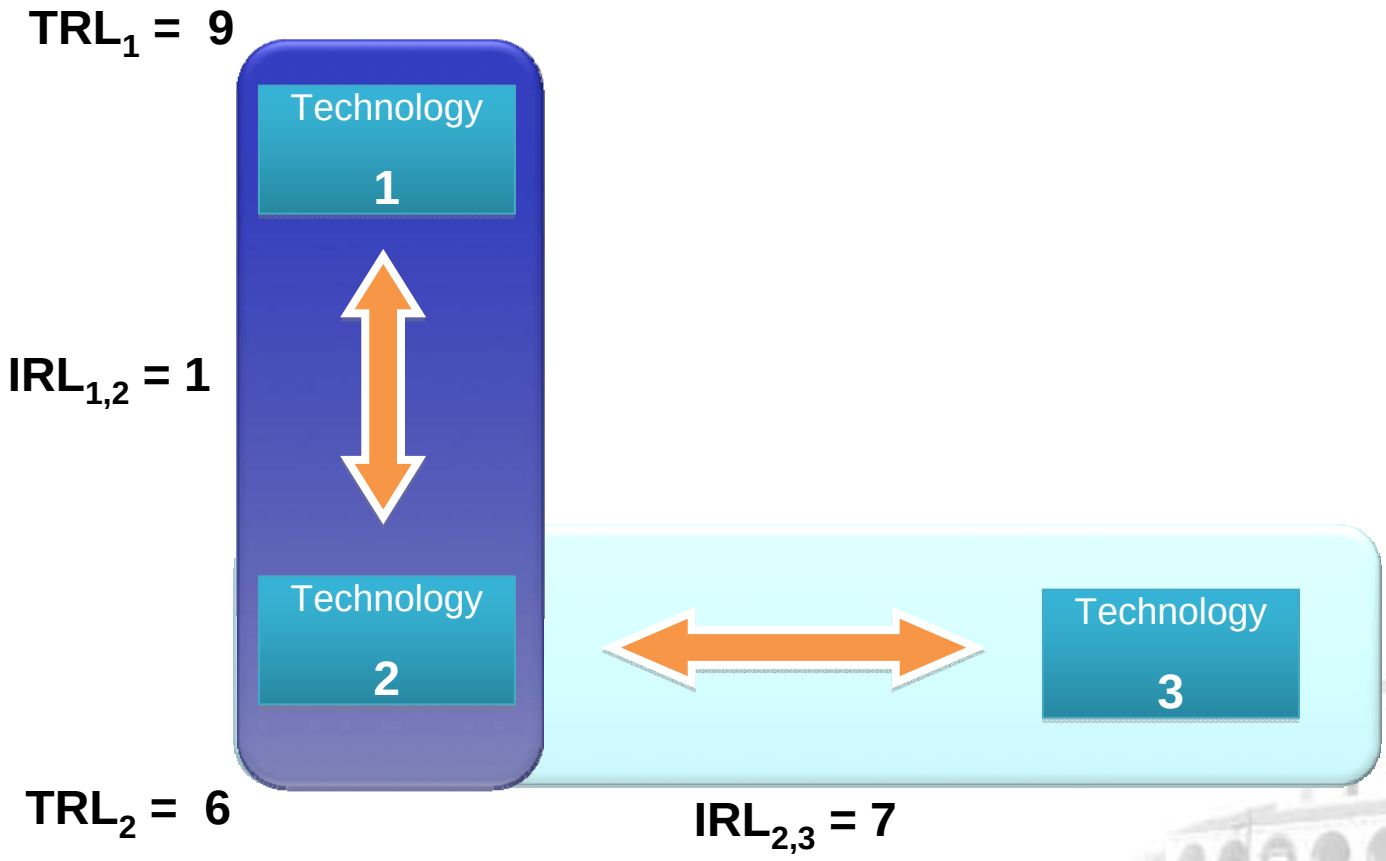


Populate reporting chart templates with evaluation and calculation outcomes to highlight both current status and performance over time

Iterative SME Evaluation Throughout Development Cycle

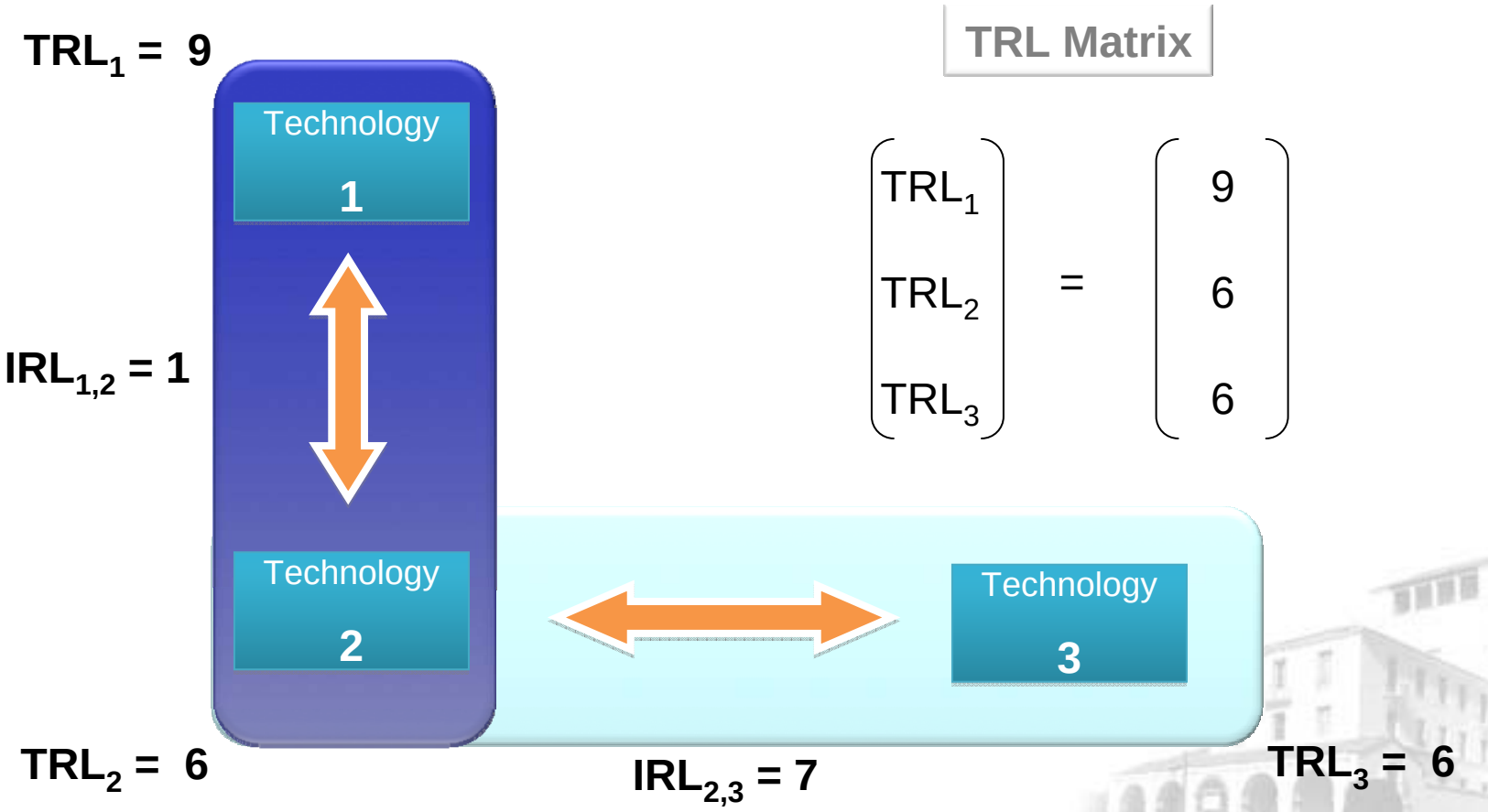
System Alpha

Determining the TRL and IRL



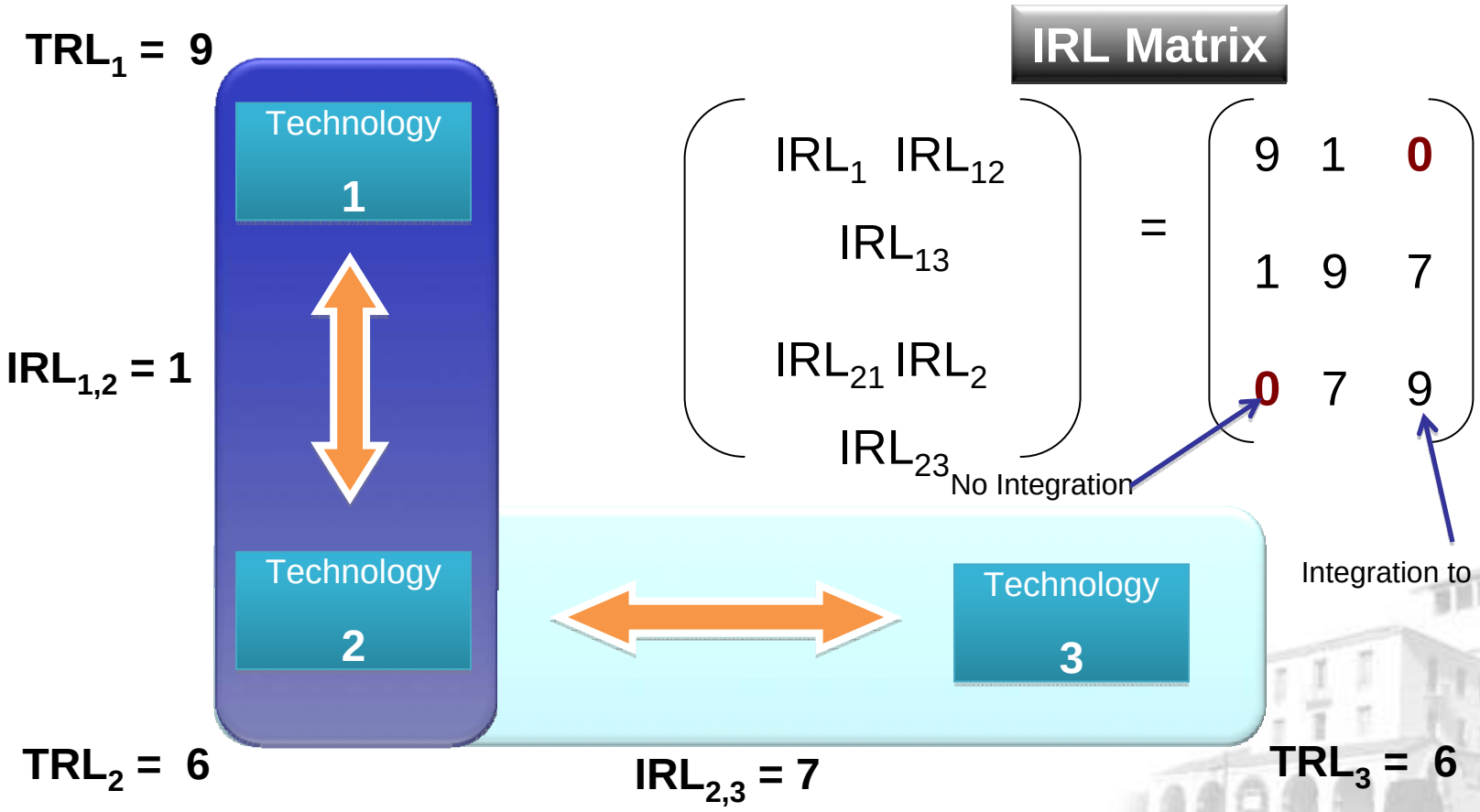
System Alpha – TRL

Creating the TRL Matrix



System Alpha – IRL

Creating the IRL Matrix



SRL for System Alpha

Normalizing the TRLs and IRLs

$$\begin{pmatrix} IRL_1 & IRL_{12} & IRL_{13} \\ IRL_{21} & IRL_2 & IRL_{23} \\ IRL_{31} & IRL_{32} & IRL_3 \end{pmatrix} \begin{pmatrix} TRL_1 \\ TRL_2 \\ TRL_3 \end{pmatrix} \Rightarrow \begin{pmatrix} 9 & 1 & 0 \\ 1 & 9 & 7 \\ 0 & 7 & 9 \end{pmatrix} \begin{pmatrix} 9 \\ 6 \\ 6 \end{pmatrix}$$

Non-Normalized [(0,9) scale]

$$\begin{pmatrix} 1.0 & 0.11 & 0.0 \\ 0.11 & 1.0 & .78 \\ 0.0 & .78 & 1.0 \end{pmatrix} \begin{pmatrix} 1.0 \\ 0.67 \\ 0.67 \end{pmatrix}$$

Normalized [(0,1) scale]

SRL Calculation of System Alpha

Calculating the SRLx

$$SRL = IRL \times TRL$$

$$\begin{pmatrix} SRL_1 \\ SRL_2 \\ SRL_3 \end{pmatrix} = \begin{pmatrix} IRL_1 & IRL_{12} & IRL_{13} \\ IRL_{21} & IRL_2 & IRL_{23} \\ IRL_{31} & IRL_{32} & IRL_3 \end{pmatrix} \begin{pmatrix} TRL_1 \\ TRL_2 \\ TRL_3 \end{pmatrix}$$

$$\begin{pmatrix} SRL_1 \\ SRL_2 \\ SRL_3 \end{pmatrix} = \begin{pmatrix} 1.07 \\ 1.30 \\ 1.19 \end{pmatrix}$$

$(0,n_x)$ scale

Note: SRL_x represents Technology X and its IRLs

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). (forthcoming)

SRL for System Alpha

Calculating the Composite SRL

$$\begin{pmatrix} SRL_1 & SRL_2 & SRL_3 \end{pmatrix} = \begin{pmatrix} 1.07 & 1.30 & 1.19 \end{pmatrix}$$ **$(0,n_x)$ scale**

$$\begin{pmatrix} SRL_1 & SRL_2 & SRL_3 \end{pmatrix} = \begin{pmatrix} 0.54 & 0.43 & 0.60 \end{pmatrix}$$ **(0,1) scale**

Composite SRL = 1/3 (0.54 + 0.43 + 0.60)

= 0.52

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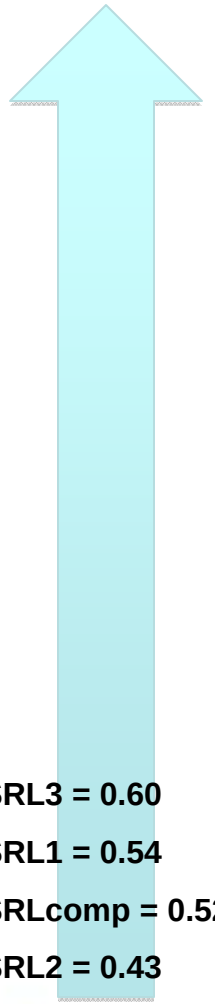
SRL Mapping



0.77 to 1.00	*Operations & Support*	Execute a support program that meets operational support performance requirements and sustains the system in the most cost-effective manner over its total life cycle.
0.68 to 0.76	*Production*	Achieve operational capability that satisfies mission needs.
0.60 to 0.67	*System Development & Demonstration*	Develop system capability or (increments thereof); reduce integration and manufacturing risk; ensure operational supportability; reduce logistics footprint; implement human systems integration; design for production; ensure affordability and protection of critical program information; and demonstrate system integration, interoperability, safety and utility.
0.40 to 0.59	*Technology Development*	Reduce technology risks and determine appropriate set
0.10 to 0.39	*Concept Development*	Refine initial concept; Develop system/technology strategy.

SRL3 = 0.60

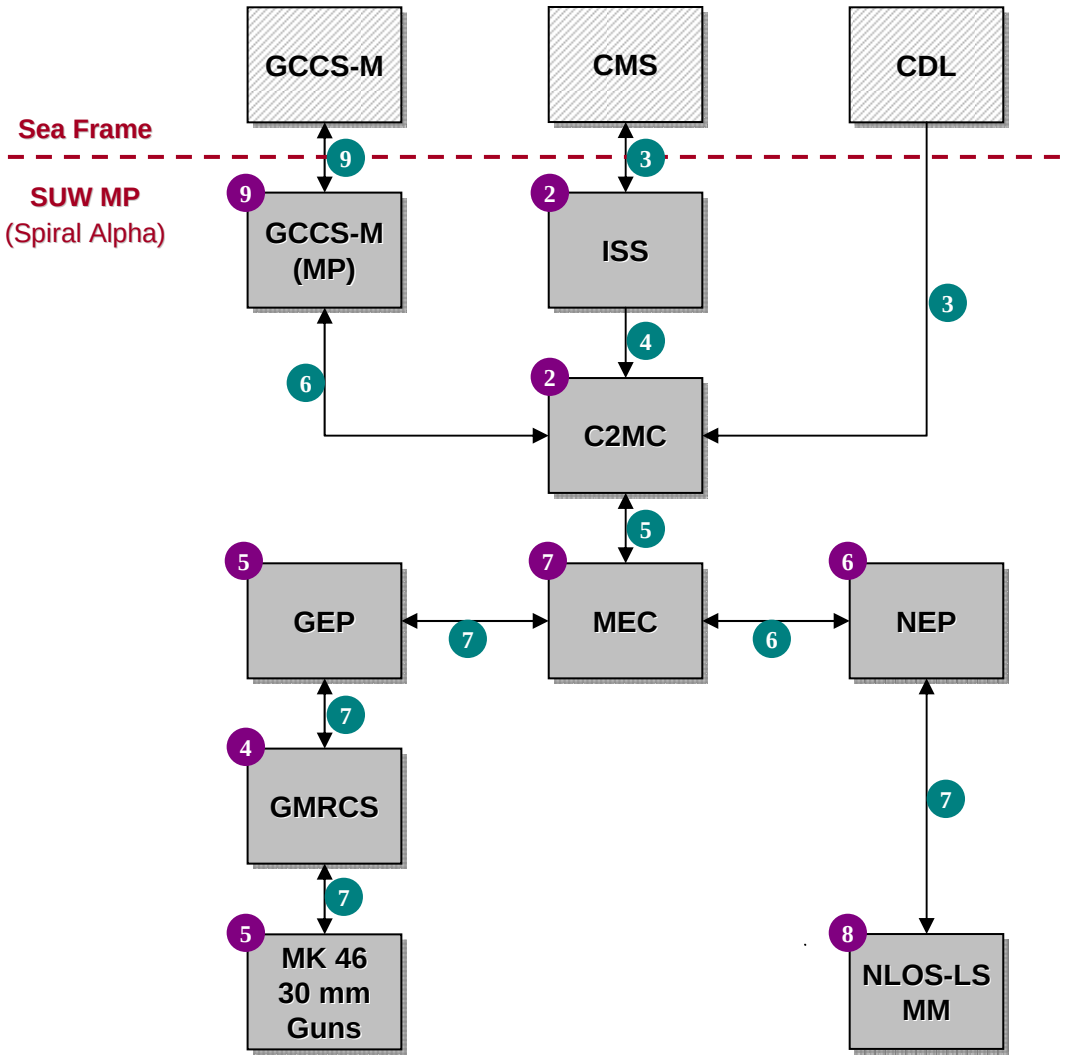
SRL1 = 0.54

SRLcomp = 0.52

SRL2 = 0.43

NOTE: ALL DATA IN THIS TEMPLATE IS NOTIONAL

Detailed Status



	Composite Actual	Planned
SRL	.57	.6
SRL w/o Sea Frame Integrations	.53	.6

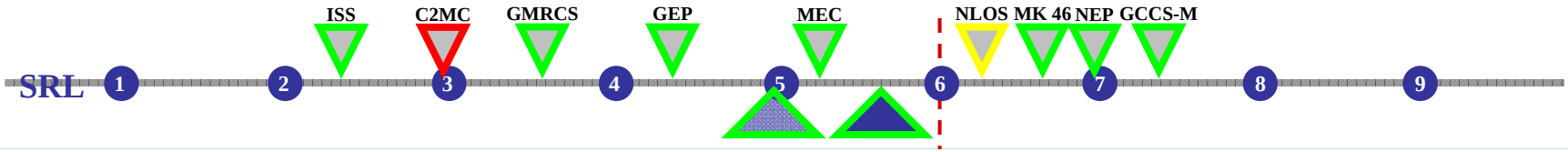
LEGEND

- Mission System
- 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
- Low Risk to Cost and/or Schedule
- Moderate Risk to Cost and/or Schedule
- High Risk to Cost and/or Schedule

Data Collection Period: XX/XX/XX – X/XX/XX

Previous Report Date: XX/XX/XX

Schedule Updated: 09/25/07 (QER)



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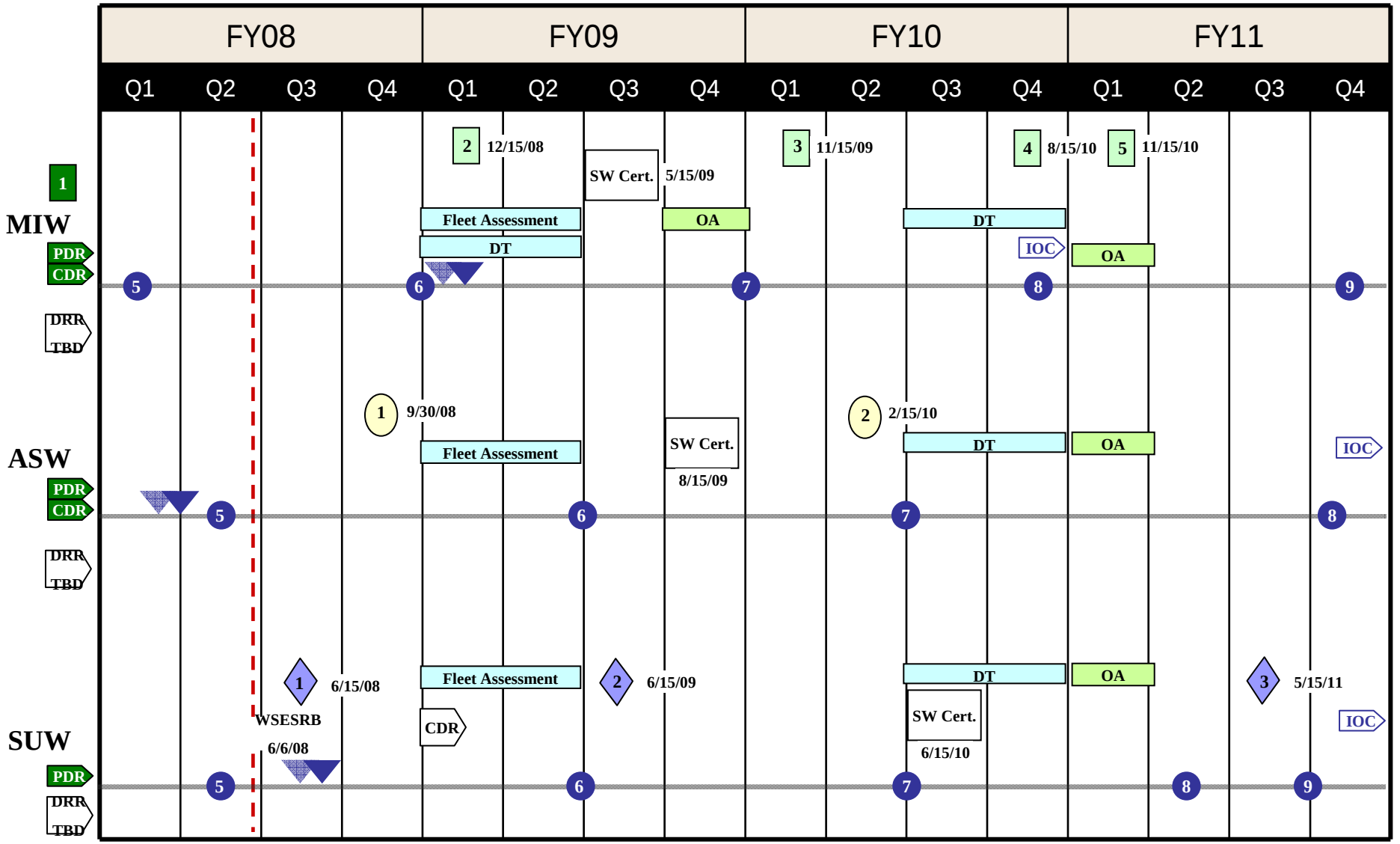
System Status Roll-up



LEGEND

- Current Reporting Period Status
- Previous Reporting Period Status
- Scheduled Position
- .7 System Readiness Level

Data Collection Period: XX/XX/XX – X/XX/XX

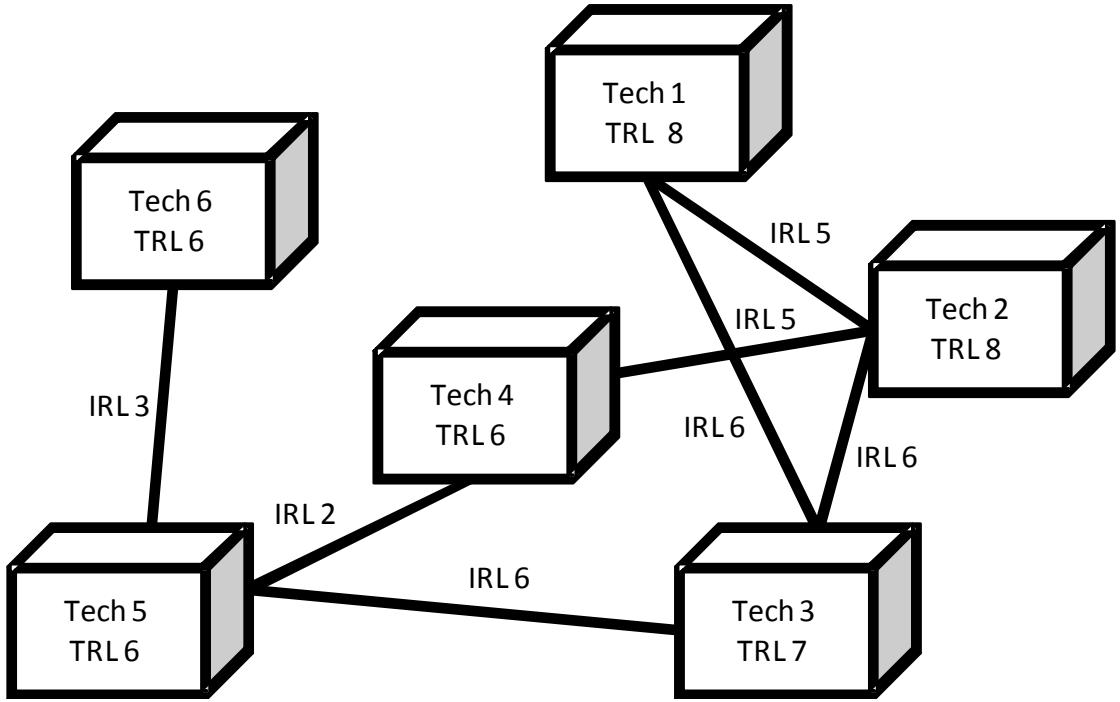
Previous Report Date: XX/XX/XX

Schedule Updated: 09/25/07 (QER)

Current Research

- SRL Resource Optimization
- System Earned Readiness Management (SERM)
- SRL Confidence
- SRL String (“Theory”)

Resource Optimization Models and System Earned Readiness Management (SERM)



ROBOTIC SERVICING MISSION FOR THE HUBBLE SPACE TELESCOPE

Tech 1- Remote Manipulator System (RMS);

Tech 2 - Special Purpose Dexterous Manipulator (SPDM);

Tech 3 - Electronic Control Unit (ECU);

Tech 4 - Autonomous Grappling (AG);

Tech 5 - Autonomous Proximity Operations (APO);

Tech 6 - Laser Image Detection and Radar (LIDAR).

CURRENT SRL = 0.48 (still in Technology Development)

SRL Resource Optimization

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

Case	SRL1	SRL2	SRL3	SRL4	SRL5	SRL6	SRL	COST, $million	TIME, man-hours
100%	1.00	1.00	1.00	1.00	1.00	1.00	1.00	26.574	19,122
75%	0.96	0.94	0.96	0.89	0.86	1.00	0.93	19.892	14,044
60%	0.96	0.92	0.94	0.78	0.78	0.89	0.90	15.870	10,254
45%	0.93	0.84	0.89	0.67	0.71	0.83	0.81	11.930	7,283
30%	0.89	0.73	0.84	0.52	0.64	0.78	0.73	7.727	4,961
15%	0.76	0.66	0.76	0.46	0.56	0.67	0.64	3.991	2,733
						Current Status	0.48		

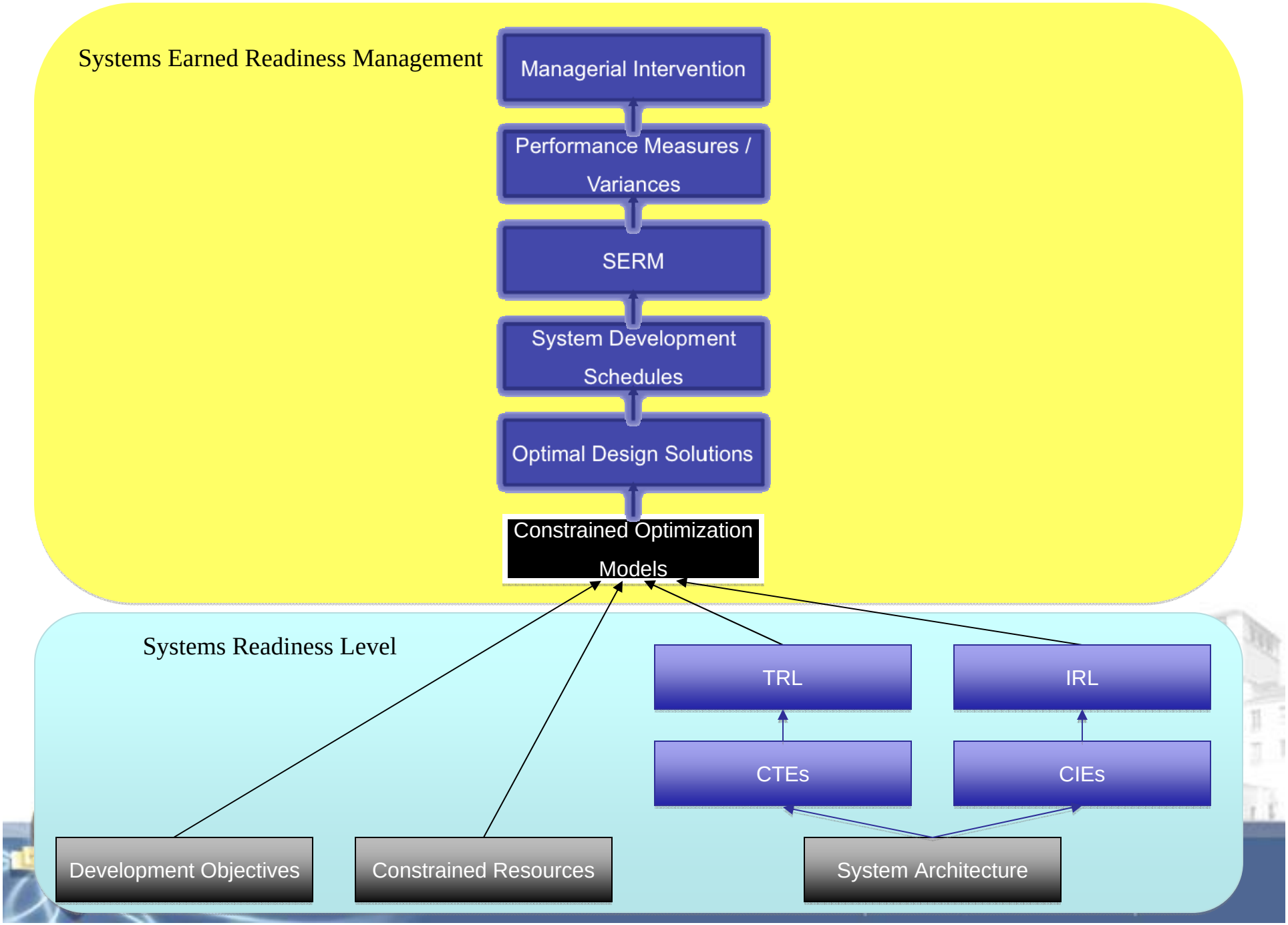
SRL Resource Optimization

Model $SCOD_{min}$ = 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.

Desired Improvements in SRL (%)	SRL		Time (man-hrs)		Computed Minimum Cost ($ x1000)
	Targeted	Computed	Targeted	Computed	
0	0.480	0.480	n.a	n.a	n.a
20	0.584	0.587	3,824	1,654	2,203
40	0.688	0.692	7,649	3,797	5,914
60	0.792	0.794	11,473	7,667	11,065
80	0.896	0.896	15,298	11,309	16,888

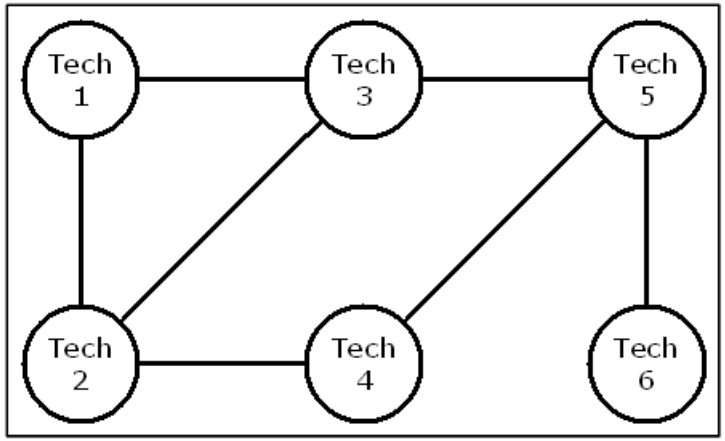
Design Solution from SCODmin Model

Target SRL	TRL						IRL						
	1	2	3	4	5	6	1,2	1,3	2,3	2,4	3,5	4,5	5,6
1 (Year 5)	9	9	9	9	9	9	9	9	9	9	9	9	9
0.896 (Year 4)	9	9	9	8	9	9	9	9	9	8	8	5	7
0.792 (Year 3)	8	9	9	6	9	9	9	9	9	5	8	4	6
0.688 (Year 2)	8	8	9	6	9	9	8	8	7	5	7	2	4
0.584 (Year 1)	8	8	8	6	7	6	7	7	7	5	6	2	4
0.48 (Year 0)	8	8	7	6	6	6	5	6	6	5	6	2	2


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

SRL Confidence

SRL Confidence

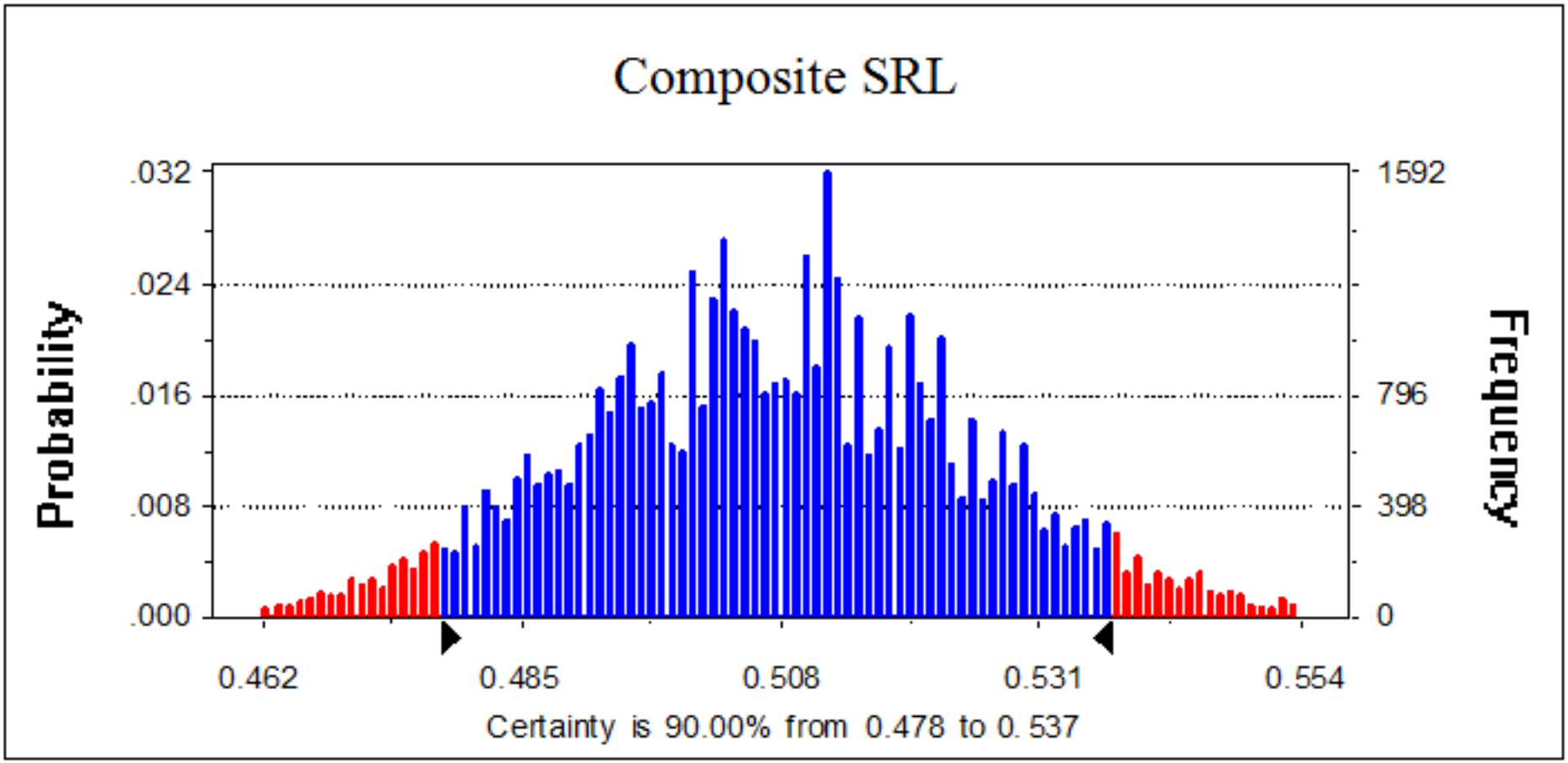


Context Diagram

TRL & IRL States Table

Technology(i)	TRL(k)			Probability ($p_{i0,k}$)			Integration(i,j)	IRL(k)			Probability ($p_{ji,k}$)		
1	7	8	9	0.15	0.80	0.05	1,2	4	5	6	0.05	0.60	0.35
2	7	8	9	0.05	0.80	0.15	1,3	5	6	7	0.20	0.70	0.10
3	6	7	8	0.10	0.80	0.10	2,3	5	6	7	0.05	0.80	0.15
4	5	6	7	0.15	0.80	0.05	2,4	4	5	6	0.10	0.80	0.10
5	5	6	7	0.25	0.70	0.05	3,5	5	6	7	0.20	0.70	0.10
6	5	6	7	0.20	0.70	0.10	4,5	1	2	3	0.15	0.60	0.25
							5,6	2	3		0.40	0.60	

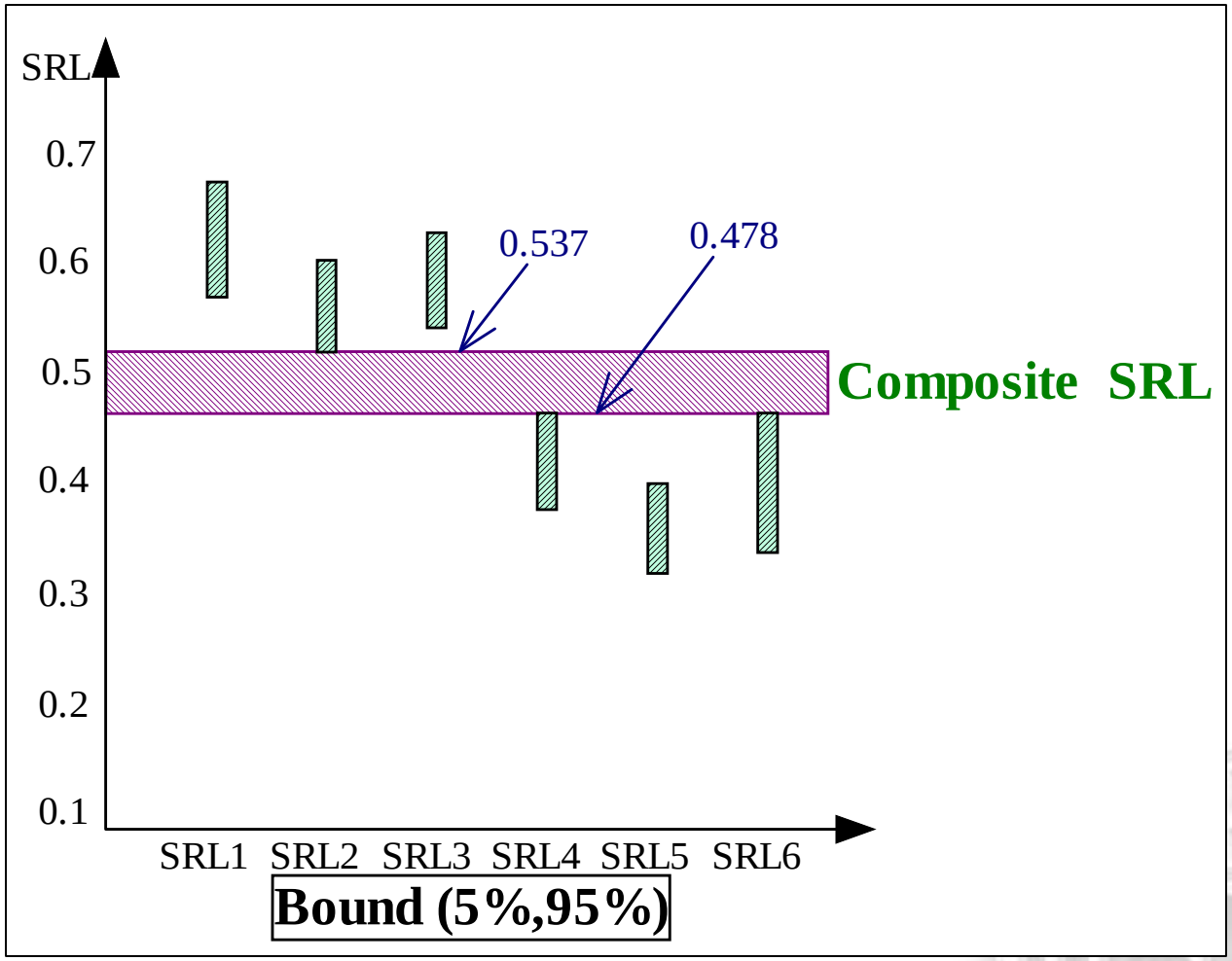
SRL Confidence Simulation



SRL Confidence Simulation Results

Percentile	SRL	SRL1	SRL2	SRL3	SRL4	SRL5	SRL6
0%	**0.435**	0.514	0.448	0.475	0.325	0.278	0.340
5%	**0.478**	0.584	0.534	0.556	0.391	0.333	0.352
25%	**0.495**	0.617	0.562	0.577	0.416	0.358	0.395
50%	**0.507**	0.634	0.574	0.602	0.436	0.370	0.426
75%	**0.519**	0.667	0.593	0.617	0.457	0.389	0.444
95%	**0.537**	0.691	0.620	0.645	0.481	0.417	0.481
100%	**0.587**	0.786	0.682	0.719	0.556	0.488	0.519

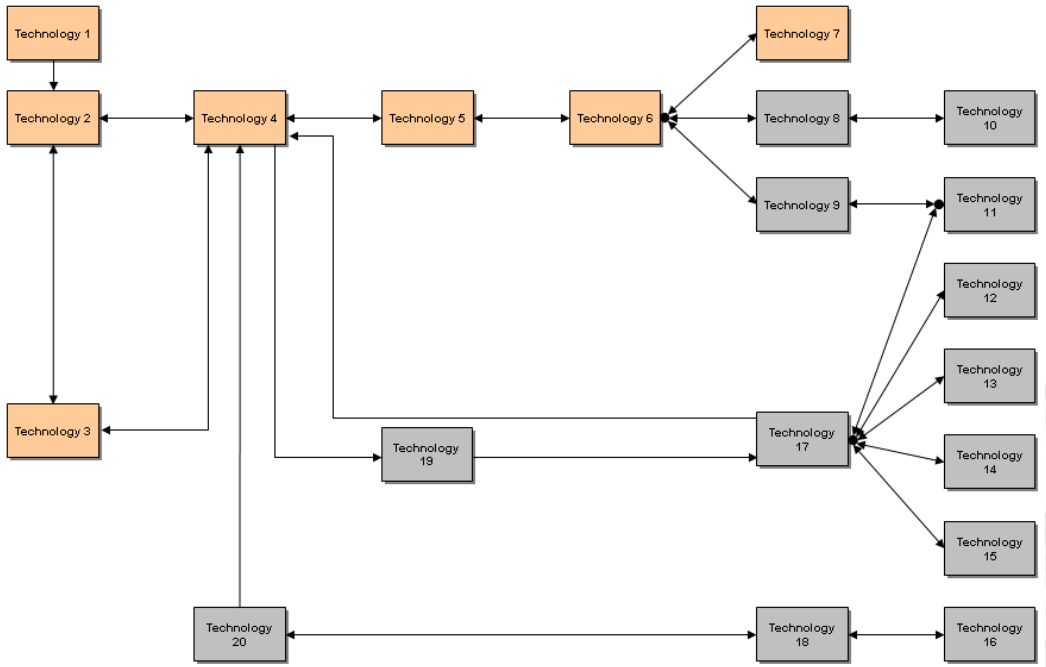
SRL Confidence Analysis



SRL String (“Theory”)

SRL String ("Theory")

- SRL Evaluations per Mission Thread
- Automatically weights those technologies most important to the system



Future Research Plans

- Case studies for SRL Mapping to Life Cycles
  - New projects. Moving forward
  - Historical data. Failed projects. Completed projects
- SERM Toolset
  - Identify SERM Toolset, i.e: algorithms, applications
  - Evaluate toolset with case studies

- Forecasting and Road mapping
  - Applications for predictive cost and risk forecasting with business case analysis
  - SRL calculator with architecture formation
  - Technology tradeoff environment
  - Disruptive Technologies in Systems Maturity Forecasting
  - Vendor Selection in System Maturity Assessment