System Readiness: A Look Beyond TRAs

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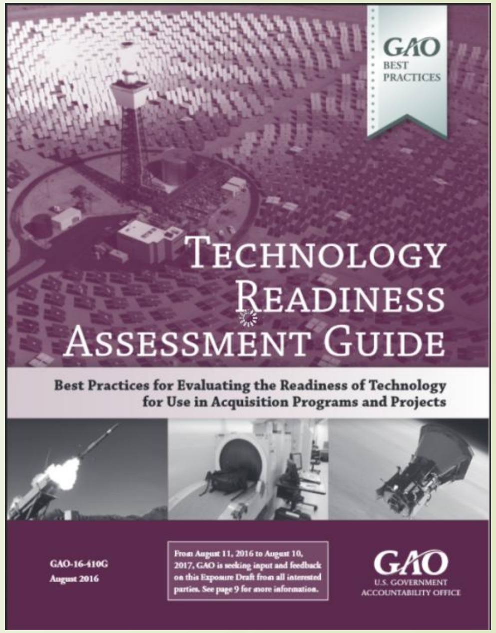
Need for Systems Engineering Transformation

- Increasingly, system design problems today are reaching insoluble levels of complexity.
- Just as important is the rate at which complexity is increasing.
  - E.g. Internet of Things (IoT)
- System Engineering needs a transformation to increase its effectiveness in this environment.
- A key element in this transformation is the need for new system metrics, metrics that
  - assess the readiness of systems for operation and use
  - help to manage risk and reduce the total cost of ownership.
- For the Department of Defense (DoD), this transformation will aid in producing more capable, interoperable, and supportable weapon systems for the warfighter.

Metrics at the Next Level

- Currently DoD uses Technology Readiness Assessments (TRAs) to determine a system’s readiness in making acquisition decisions.
- GAO has published their Exposure Draft of the *Technology Readiness Assessment Guide, Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects* (GAO-16-410G) for public review and comment.
- Both experts and practitioners have expressed concern that TRLs being abstracted from a single technology or relatively few technologies are not representative of systems with numerous and complex technologies and interfaces.
- There is an ongoing realization of a need for metrics that enhance the current TRA.



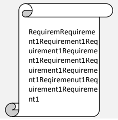
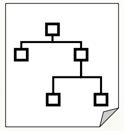
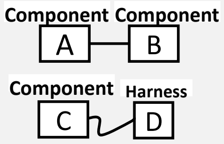
A New System-Level Metric

- Failures at the integration points are a leading cause of unsuccessful system development, making integration one of the primary areas of risk for today’s development programs.
- System-level metrics must place a greater emphasis on integration.
  - Although still experimental in practice, DoD has developed the System Readiness Assessment (SRA) methodology to address this concern.
- The SRA methodology enables traceability throughout the entire system as it measures the readiness of all system components and considers each one equally critical.
- Assessments are performed multiple times over the course of the system life cycle.

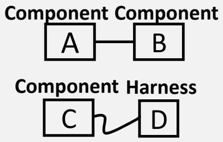
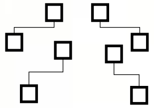
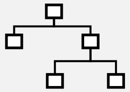
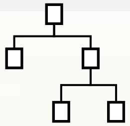
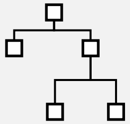
Assessing Readiness at the System Level

- The SRA uses the existing Technology Readiness Level (TRL) and introduces an evidence-based Integration Readiness Level (IRL) scale.
  - Like TRLs, IRLs are defined as a series of levels that articulate the key maturation milestones for integration activities and also present a direction for improving integration.
  - Just as TRL is used to assess the risk associated with developing technologies, IRL assesses the risk of integrating these technologies.
- The readiness of each component within the system is…..
  - assessed based on its TRL and all of its integrations (IRLs)
  - important to identify lagging or leading areas of development that may be problematic.

Integration Readiness Levels

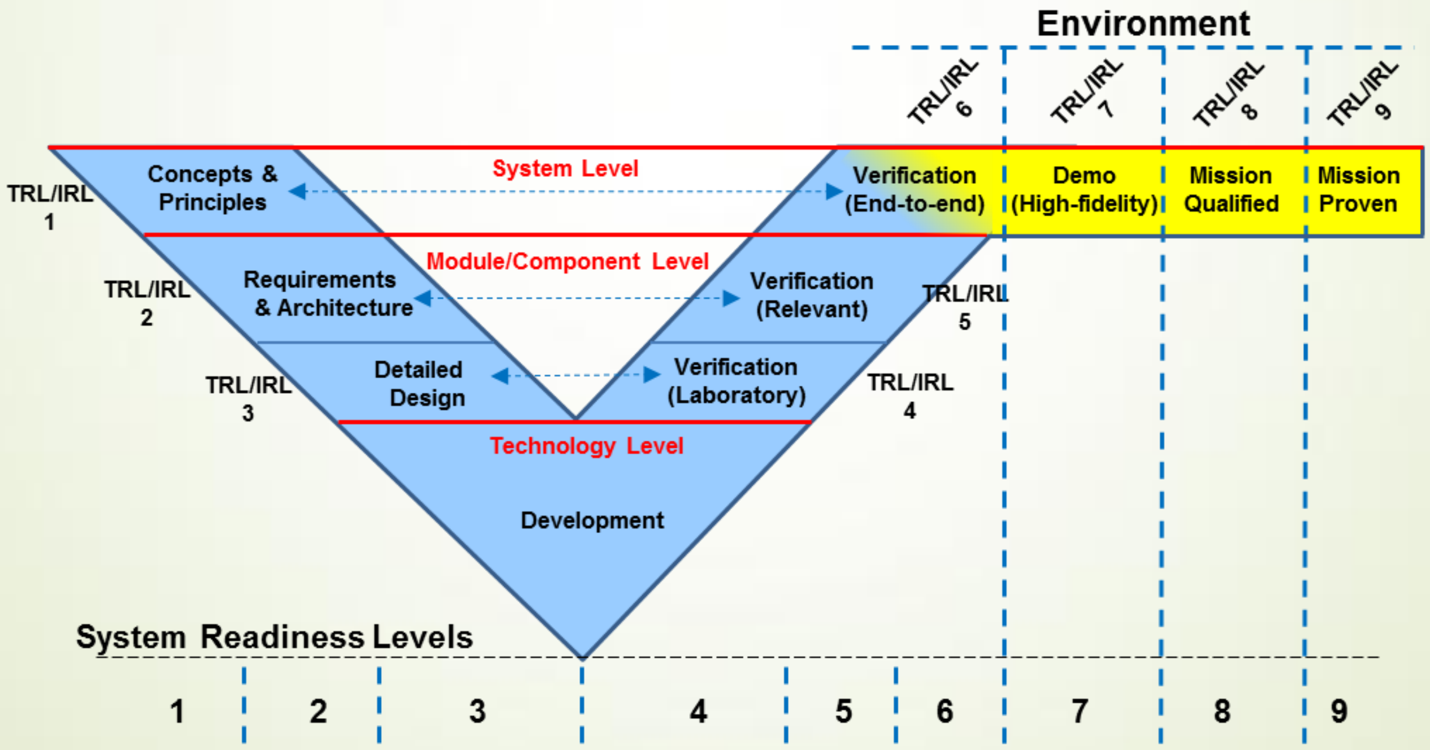
IRL	Definition	Depiction	Evidence Description
0	No Integration		**No integration between specified components has been planned or intended**
1	A high-level concept for integration has been identified	 Concept	**Principal integration technologies have been identified** Top-level functional architecture and interface points have been identified High-level concept of operations and principal use cased has been started
2	There is some level of specificity of requirements to characterize the interaction between components	 Requirements	**Inputs/outputs for principal integration technologies/mediums are known, characterized and documented** Principal interface requirements and/or specifications for integration technologies have been defined/drafted
3	The detailed integration design has been defined to include all interface details	 Design	**Detailed interface design has been documented** System interface diagrams have been completed Inventory of external interfaces is completed and data engineering units are identified and documented
4	Validation of interrelated function between integrating components in a laboratory environment	 Lab	**Functionality of integrating technologies (modules/functions/assemblies) has been successfully demonstrated in a laboratory/synthetic environment** Data transport method(s) and specifications have been defined

Integration Readiness Levels, cont'd

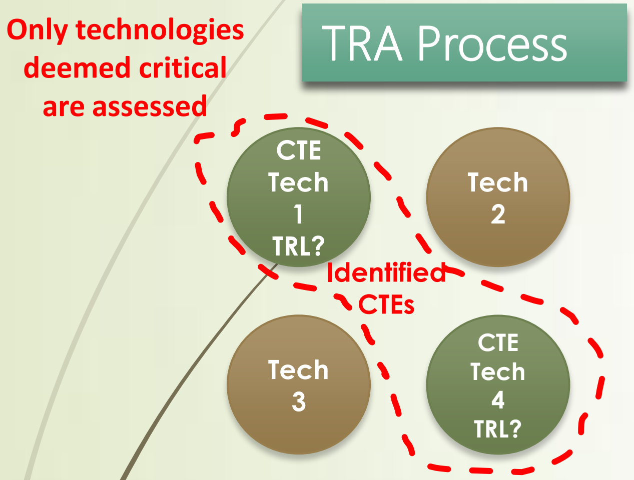
IRL	Definition	Depiction	Evidence Description
5	**Validation of interrelated functions between integrating components in a relevant environment**	 **Relevant**	**Individual modules tested to verify that the module components (functions) work together** External interfaces are well defined (e.g., source, data formats, structure, content, method of support, etc.)
6	**Validation of interrelated functions between integrating components in a relevant end-to-end environment**	 **End-to-end**	**End-to-end Functionality of Systems Integration has been validated** Data transmission tests completed successfully
7	**System prototype integration demonstration in an operational high-fidelity environment**	 **Demonstrated**	**Fully integrated prototype has been successfully demonstrated in actual or simulated operational environment** Each system/software interface tested individually under stressed and anomalous conditions Interface, Data, and Functional Verification complete
8	**System integration completed and mission qualified through test and demonstration in an operational environment**	 **Qualified**	**Fully integrated system able to meet overall mission requirements in an operational environment** System interfaces qualified and functioning correctly in an operational environment
9	**System Integration is proven through successful mission-proven operations capabilities**	 **Proven**	**Fully integrated system has demonstrated operational effectiveness and suitability in its intended or a representative operational environment** Integration performance has been fully characterized and is consistent with user requirement

Assessing Readiness at the System Level, cont'd

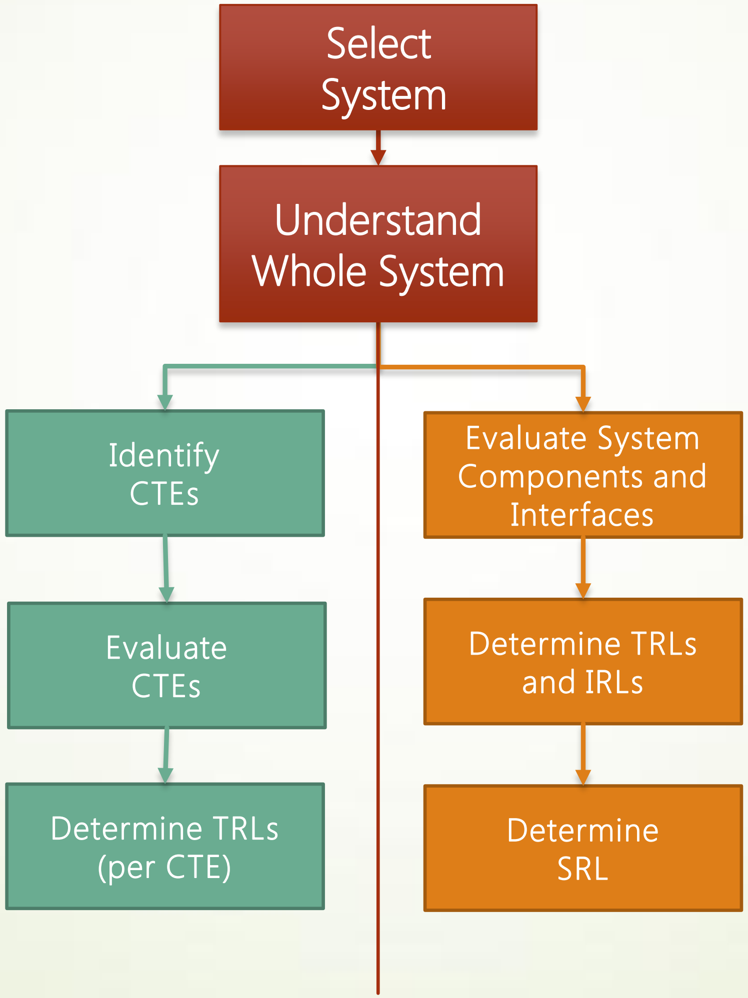
- The SRA methodology combines the component readiness levels and calculates the System Readiness Level (SRL) of the entire system.
- The SRL is designed to give a holistic picture of the readiness of complex systems by characterizing the effects of both technology and integration maturity on the systems development effort.

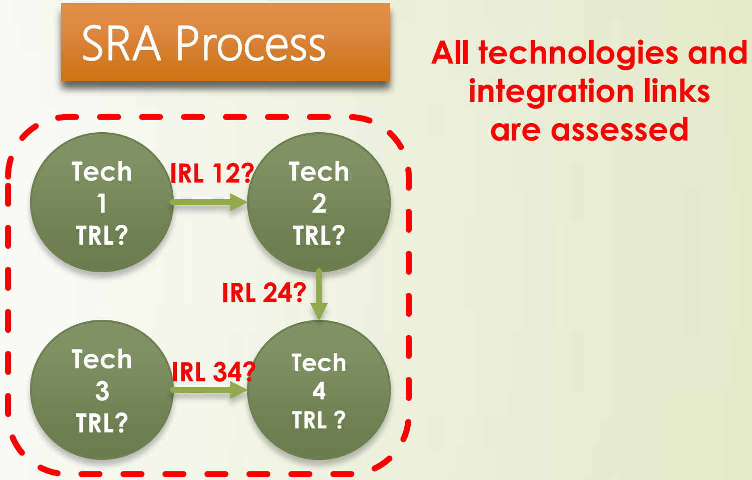


TRA and SRA, a Quick Comparison



- Identifies CTEs, those technology elements that have a significant impact on operation requirements, cost, or schedule.
- Uses DoD accepted TRL metrics for individual technology maturity assessment

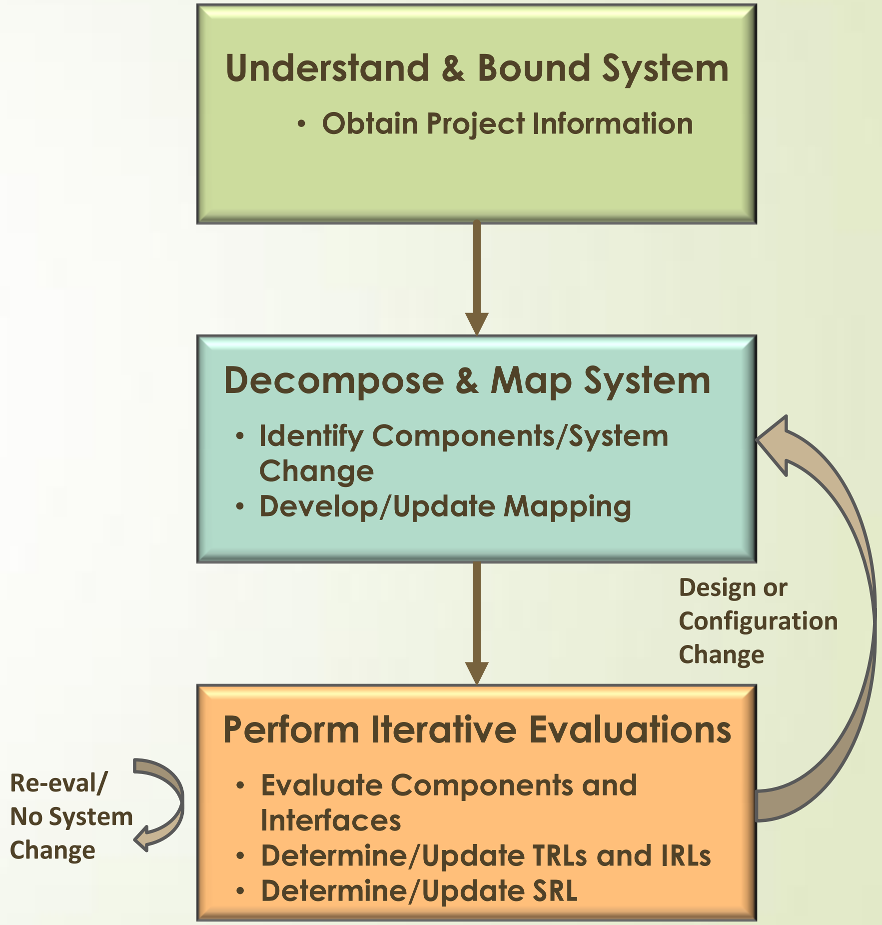




- Comprehensive system development metric based on assessment of system's individual technologies and their integration
- Measures very early in the development and as often as deemed reasonable by the PM/SE
- SRA process scalable to support different size programs

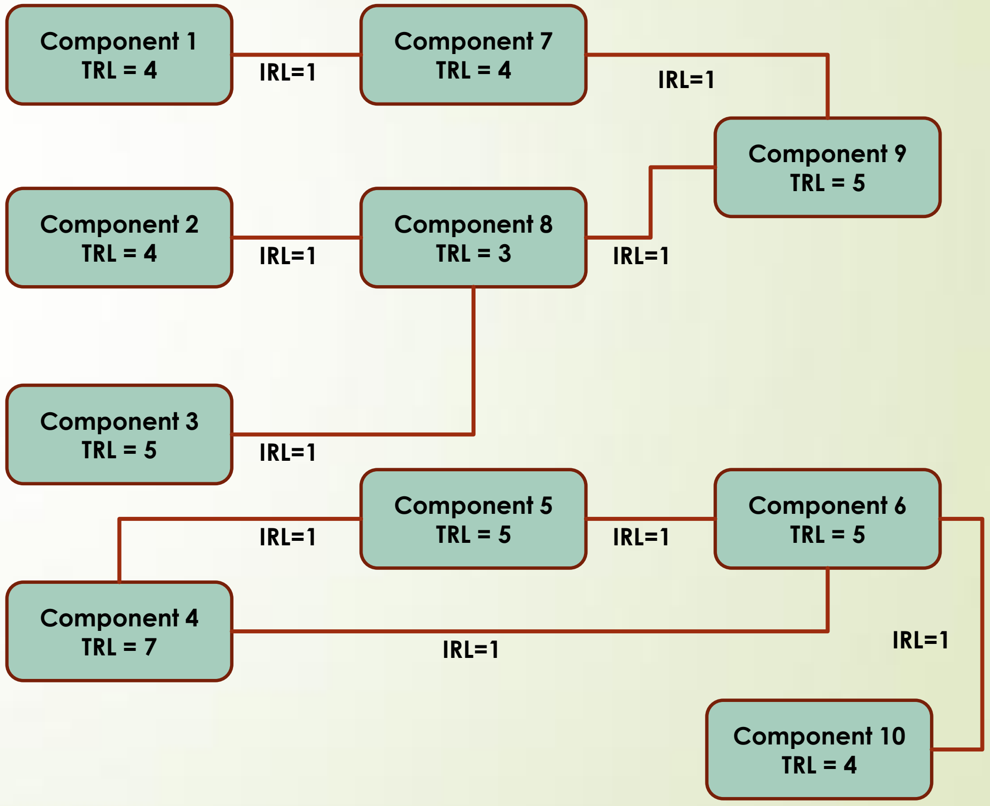
System Readiness Assessment, the Methodology

- Understand the System
  - Obtain Project Information
    - Functional/System Block Diagrams, Architecture, Project Data, etc.
- System Decomposition & Mapping
  - Identify H/W and S/W technologies
  - Develop system mapping
- Iterative Evaluation Throughout Development Cycle
  - Apply TRL and IRL decision criteria
  - Calculate SRL values
  - Document status



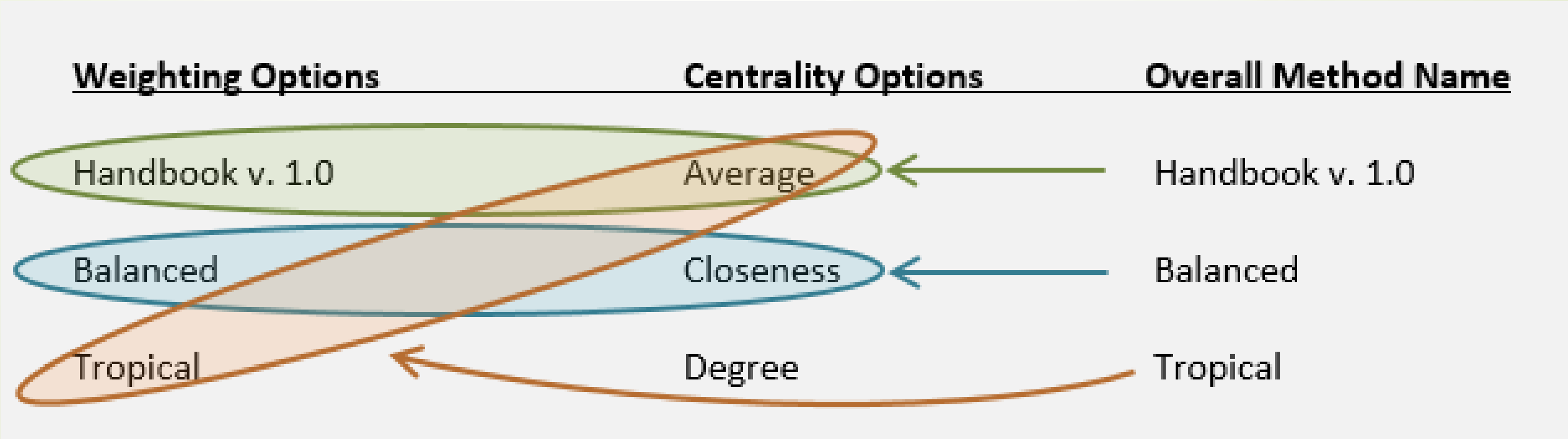
Three techniques for measuring System Readiness

- These three approaches were selected after extensive research of system readiness methods across the spectrum of literature and practice.
- Each technique results in an indicator of readiness by mathematically combining the TRLs and associated IRLs of the system
- Similar to the use of predictive models, it is possible to analyze the system's readiness by selecting one technique or using all three.



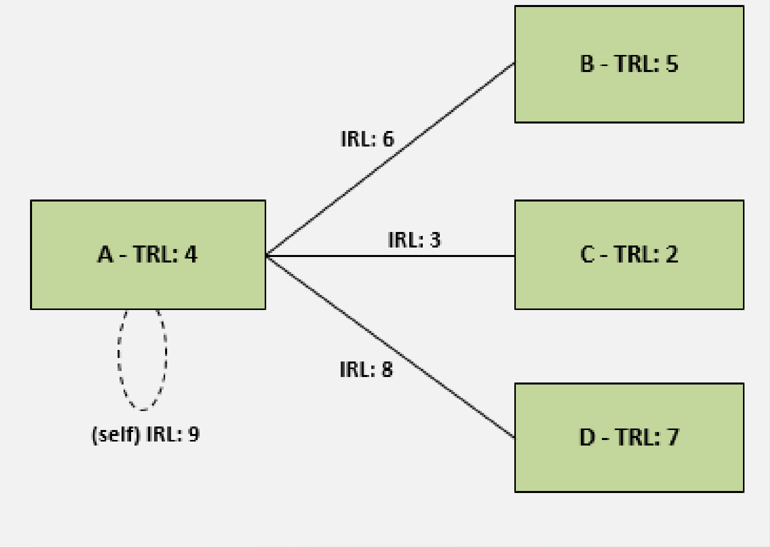
SRL Calculation Methods

- Each calculation method is comprised of both a specific
  - weighting method
  - centrality method
- The weighting methods are used to calculate component SRL values
- The centrality methods combine the component SRLs into a system or composite SRL
  - k is the number of integrations for a component



The 1st technique, the Handbook method

- After normalizing, the TRL of each neighboring component is multiplied with the associated IRL (the IRL for self-integration = 9)
- These terms are summed then divided by the total number of integrations for that component
- The result is a readiness measure, the Component SRL, which takes into account all of the component's integration links
- A Composite SRL for the system is then obtained by applying one of the centrality options.

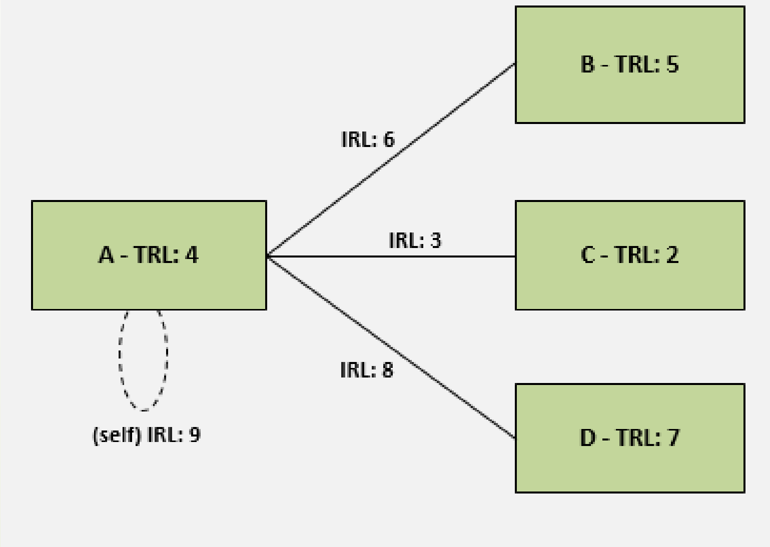


$$SRL_A = \frac{\frac{TRL_A}{9} * \frac{IRL_{A-A}}{9} + \frac{TRL_B}{9} * \frac{IRL_{A-B}}{9} + \frac{TRL_C}{9} * \frac{IRL_{A-C}}{9} + \frac{TRL_D}{9} * \frac{IRL_{A-D}}{9}}{k+1}$$

The Balanced Method

- The 2nd technique, termed the Balanced Method, is similar to the first except the individual component readiness is weighted separately from the contribution of the neighboring components.
- This technique is well suited for highly connected components and enables the influence of neighboring components to be consistently balanced with the individual component.

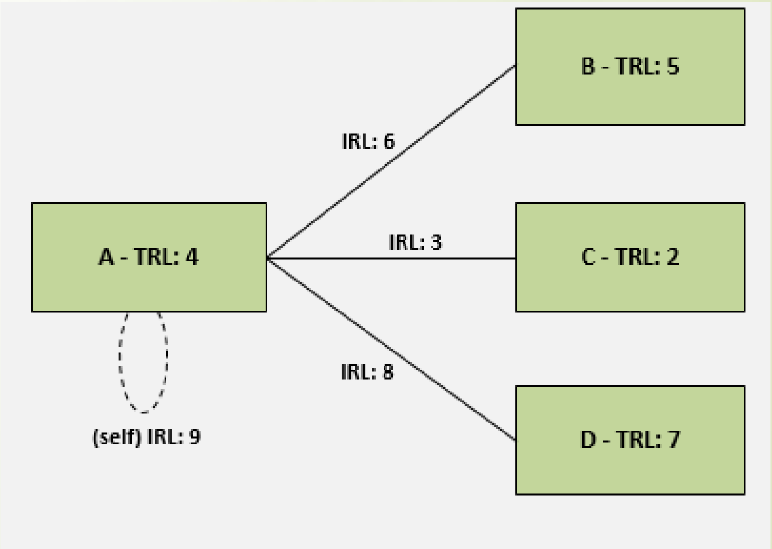
$$\boldsymbol{SRL_A} = \frac{1}{9}\left(\frac{\boldsymbol{TRL_A * IRL_{A-A}}}{2} + \frac{\boldsymbol{TRL_B * IRL_{A-B} + TRL_C * IRL_{A-C} + TRL_D * IRL_{A-D}}}{2k}\right)$$



A Modified Tropical Algebra Approach

- Using the principles of Tropical Algebra, addition is replaced with the min function and multiplication is replaced with addition.
- This technique assigns each component's SRL based on the minimum combination of the neighboring IRLs and TRLs.

$$SRL_A = \frac{\min(\mathrm{TRL_A} + \mathrm{IRL}_{\mathrm{A}-A}, \mathrm{TRL_B} + \mathrm{IRL_{A-B}}, \mathrm{TRL_C} + \mathrm{IRL_{A-C}}, \mathrm{TRL_D} + \mathrm{IRL_{A-D}})}{2}$$



Centrality Methods (to determine Composite SRL)

- **Average:** The composite SRL is obtained by simply averaging the component SRLs for a system.

  Closeness: Each component receives a weight equal to the reciprocal of the sum of its distance to each other node (where each connection gets length 1) divided by the sum of all reciprocal distance sums. The Composite SRL is the sum product of these weights with each component SRL. *Closeness centrality biases towards components which are "close" to many other components.*

  $DistanceSum(A) = 1 \text{ (A to B)} + 1 \text{ (A to C)} + 1 \text{ (A to D)} = 3$

  Similarly, *DistanceSum(B) = 5, DistanceSum(C) = 5, and DistanceSum(D) = 5.* So,

  $$\boldsymbol{ClosenessCentrality(A)} = \frac{\frac{1}{3}}{\frac{1}{3}+\frac{1}{5}+\frac{1}{5}+\frac{1}{5}} = \mathbf{0.357}$$

  Degree: Each node gets a weight equal to the number of neighbors of that node, divided by the total number of neighbors for all nodes. The composite SRL is the sum product of these weights with each component SRL. Degree centrality biases towards components which are connected to many other components.

  $Neighbors(A) = 3, \quad Neighbors(B) = Neighbors(C) = Neighbors(D) = 1$

  so, $$\boldsymbol{DegreeCentrality(A)} = \frac{3}{3+1+1+1} = \mathbf{0.50}$$

Combining Weighting and Centrality to Obtain Composite SRLs

- Using the example four node system, the following values are obtained:

Component	SRLs *(Handbook, Balanced, Tropical)*	Average Centrality	Closeness Centrality	Degree Centrality
A	0.395, 3.704 , 2.5	0.25	0.357	0.50
B	0.426, 3.833 , 5.0	0.25	0.214	0.17
C	0.185, 1.667 , 3.5	0.25	0.214	0.17
D	0.586, 5.278 , 6.0	0.25	0.214	0.17

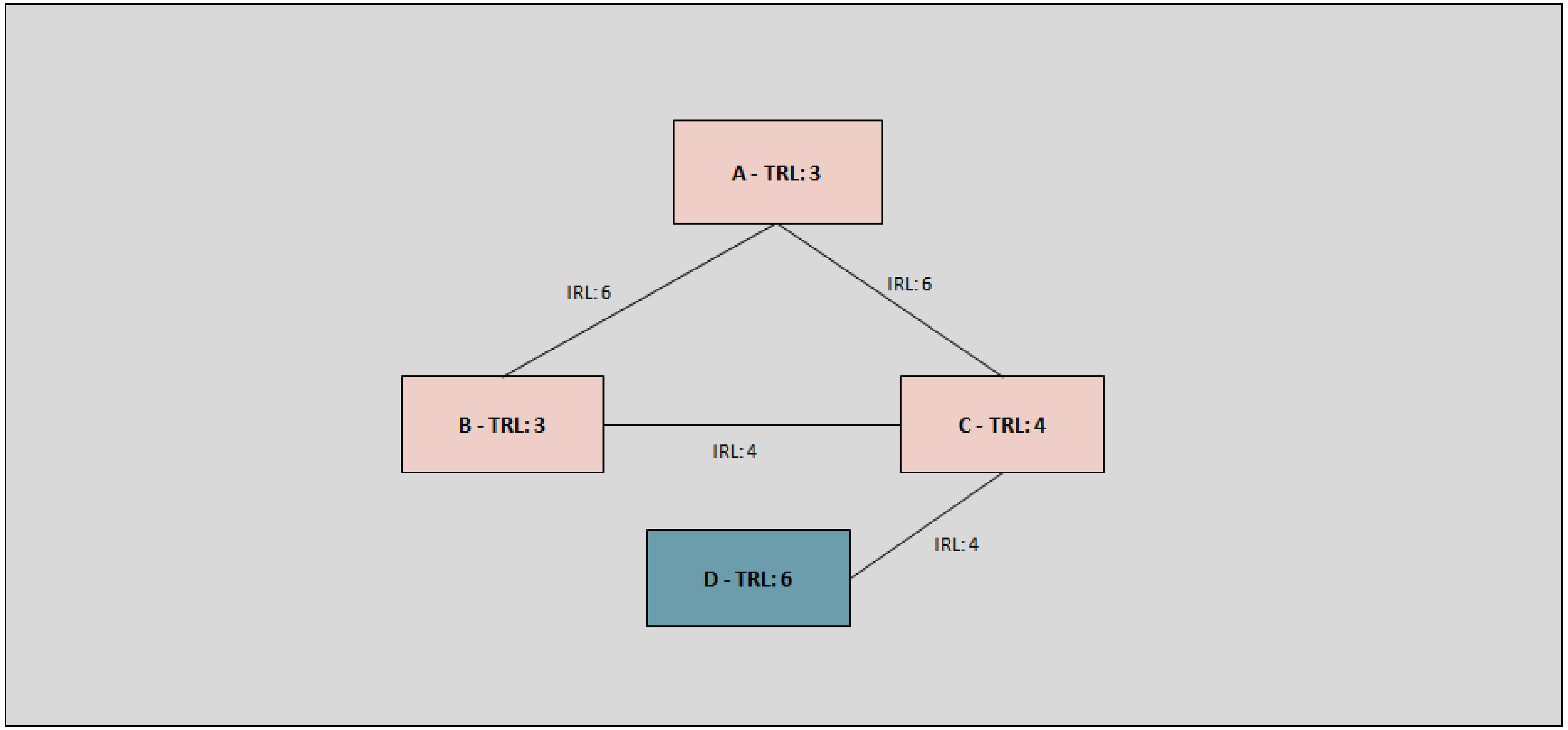
As an example, to calculate the overall *Balanced* composite SRL using *Closeness Centrality*, we take:

$$Balanced\ Composite\ SRL = Balanced\ SRLs \times Closeness\ Centrality\ Weights$$
$$= 3.704 * 0.357 + 3.833 * 0.214 + 1.667 * 0.214 + 5.278 * 0.214 = \mathbf{3.63}$$

Moving Forward…….SRA User Environment

- DoD continues to pilot the SRA methodology and investigate other techniques.
- A **User Environment (UE)** has been developed and deployed that provides an interactive environment to model the system integration and architecture and calculate system readiness using the different methods.

The SRA User Environment



** Components can be changed stylistically (e.g., color, location) but please do not modify labels (TRLs, IRLs, or component names) or system layout without using buttons below*

**SD = Standard Deviation*

Color Key	-2 SD		-1 SD		Avg		+1 SD		+2 SD
	0.169		0.240		0.311		0.382		0.453

Edit/Update System | Save System Snapshot | New Thread

System Summary

Min TRL	3
Max TRL	6

Min IRL	4
Max IRL	6

Handbook v. 1.0	0.311
Balanced	2.96

Specify SRL Calculation Methods

Calculation Method	Handbook v. 1.0
Show Details	No

Results

Composite SRL	0.311
System SRL*	4

**SRA Handbook v. 1.0 Method Only*

Component	Component_SRL
A	0.284
C	0.278
B	0.251
D	0.432

Moving forward……ISRACOI

- To advance this new, emerging systems engineering methodology, a worldwide collaborative community, the **International Systems Readiness Assessment Community of Interest (ISRACOI)**, has been formed.
  - Website: http://www.isracoi.org
- ISRACOI's purpose is "*to study, inform, and promote insight and lessons learned for system readiness assessment and system metrics in order to reduce acquisition risk and improve the performance of modern day complex systems*".


ISRACOI

The ISRACOI Website is the primary knowledge sharing hub for SRL analysis.

Learn. Contribute. Advance.

Welcome to the International Systems Readiness Assessment Community of Interest

The International Systems Readiness Assessment (SRA) Community Of Interest (ISRACOI) is a worldwide collaborative community of individuals from industry, academia, and government who have an interest in integration planning and measurement, system readiness metrics, and reducing program risk through comprehensive system thinking. ISRACOI strives to create and maintain a collaborative environment for systems readiness information and relevant research. Our goal is to share, disseminate, and maintain relevant artifacts such as an SRA Engineering Handbook, a Glossary of Terms, and relevant published papers.

Contact Information

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