International Council on Systems Engineering
A better world through a systems approach

The TRA Tool:
Modeling and Projecting Readiness Levels with MBSE

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Professional experience

- Systems engineer at Northrop Grumman Corporation working on spacecraft
  - System Architecture Lead for a space vehicle design team
  - Use MBSE and TRLs throughout work
  - Previous work on R&D programs developing MBSE tools
- Graduated from Purdue University with a B.S. in Aeronautical and Astronautical Engineering
- Currently pursuing a M.S. in Space Systems Engineering from Johns Hopkins University

Expertise

- Systems Engineering
- MBSE
- Space Systems
- Mission Engineering

Today's Agenda

- What is TRL and how to use it?
- Can SRL and IRL help better convey the maturity of a complex system?
- Can MBSE be used to efficiently track the maturity of a complex system?

Technology Readiness Levels

What do they tell you? What do they not tell you?

TRL Definitions

- First introduced in 1995 NASA paper
- Scale for assessing technology maturity
- Useful for high level assessment of risk associated with different technologies
- Does not replace good engineering review of test methods and levels
- Room for interpretation of definitions leads to under or over inflation
  - Values in sales material can be over inflated
  - Values in funding requests can be underinflated

TRL	Definition
1	Basic principles observed and reported.
2	Technology concept and/or application formulated.
3	Analytical and experimental critical function and/or characteristic proof of concept.
4	Component and/or breadboard validation in laboratory environment.
5	Component and/or breadboard validation in relevant environment.
6	System/subsystem model or prototype demonstration in a relevant environment.
7	System prototype demonstration in an operational environment.
8	Actual system completed and qualified through test and demonstration.
9	Actual system proven through successful mission operations.

Definitions per 2009 DOD TRA Deskbook

Importance of TRL

- Concise way to express system maturity to stakeholders even when non-technical
- Major systems customers often require that all components in a system be at least TRL 6 by Preliminary Design Review

USA DOD

"Title 10 United States Codes (U.S.C.) Section 2366b requires, in part, that the Milestone Decision Authority (MDA) certify that the technology in Major Defense Acquisition Pro-grams (MDAPs), including space MDAPS, has been demonstrated in a relevant environment (TRL 6) before Milestone B [PDR] approval."
- DOD TRA Deskbook, 2009

NASA

"Once TRL 6 is demonstrated, the risk associated with the new technology is roughly equivalent to the risk of a new design that employs standard engineering practice and is bounded by previously implemented ground-based systems. NASA practice recommends technology demonstrates TRL 6 prior to the Preliminary Design Review (PDR)."
- NASA TRL Best Practices Guide, 2020

ESA

"In most cases, the technologies incorporated into a system development project should already be at TRL 6-7 when the project is formally started. "
- ESA Technology Readiness Handbook for Space Applications, 2008

Higher Levels

- In major system development focus is on TRL levels between 4 and 6.
  - Anything three or below generally not to be considered
  - Anything six or above generally avoids scrutiny
- Many ways to claim progress
  - Previous versions or similar experiences can be considered breadboards or prototypes
  - Tailoring of “relevant environment”
- Once everything's at TRL 6 or above are you ready for I&T?

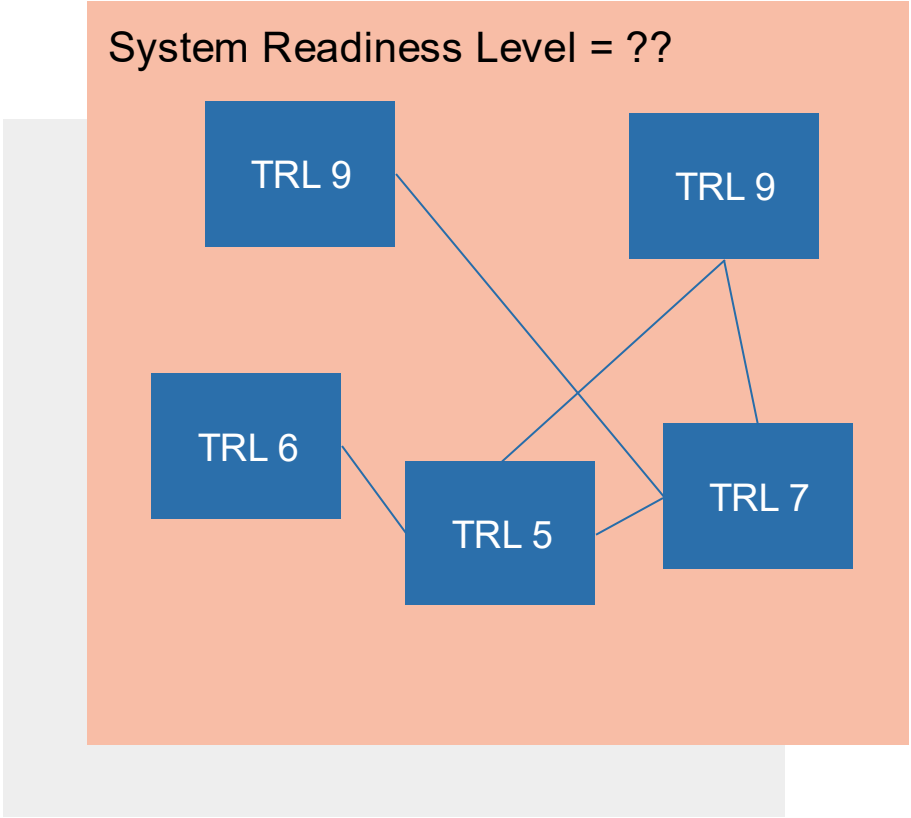
TRL	Definition	Description
4	Component and/or breadboard validation in laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively “low fidelity” compared with the eventual system. Examples include integration of “ad hoc” hardware in the laboratory.
5	Component and/or breadboard validation in relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include “high-fidelity” laboratory integration of components.
6	System/ subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology’s demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.

Definitions per 2009 DOD TRA Deskbook

Shortfalls of TRL, The use of IRL

Rolling up component TRLs to asses a system's maturity can be misleading

- Strategies such as taking the lowest TRL or averaging them oversimplify a complex problem
- No way to characterize maturity and complexity of interfaces between components
- Introduction of Integration Readiness Level and System Readiness Level intended to address this



IRL

- First proposed by Saucer in 2006
- Evolved several times with current versions pulled from Saucer's 2023 work
- First definitions based on OSI model, but latter adapted to align with the TRL levels
- Dependence on maturation in environments can be out of synch with industry norms
- Can one number represent the maturity of an interface that is multidomain?

IRL	Definition
0	No integration
1	An Interface between technologies has been identified with sufficient detail to allow characterization of the relationship.
2	There is some level of specificity to characterize the Interaction (i.e. ability to influence) between technologies through their interface.
3	There is Compatibility between technologies to orderly and efficiently integrate and interact to include all interface details.
4	Validation of interrelated functions between integrating components in a laboratory environment
5	Validation of interrelated functions between integrating components in a relevant environment
6	Validation of interrelated functions between integrating components in a relevant end-to-end environment
7	System prototype integration demonstration in an operational high-fidelity environment
8	System integration completed and mission qualified through test and demonstration in an operational environment
9	System integration is proven through successful mission proven operations capabilities

Definitions per 2009 DOD TRA Deskbook

SRL

- First introduced in Saucer's 2006 paper with levels tied to traditional system milestone reviews
- In 2011 proposed mathematical derivation from a system's IRL and TRL along with nine level scale
  - Definitions don't always match the math

SRL	Definition
1	System alternative material solutions have been considered.
2	System material solution identified.
3	System high-risk immature technologies have been identified and prototyped.
4	System performance specifications and constraints have been defined and the baseline has been allocated.
5	System high-risk component technology development has been completed; low-risk system components identified.
6	System component integrability has been validated.
7	System threshold capability has been demonstrated at operational performance level using operational interfaces.
8	System interoperability has been demonstrated in an operational environment.
9	System has achieved initial operational capability and can satisfy mission objectives.

Saucer, 2011

SRL Derivation

- Mathematical derivation allows for a more deterministic assessment of system maturity
- Each component has a Component SRL which speaks to the maturity of that component in the system
- A single composite SRL rolls up system level maturity
- How can one effectively track and visualize the SRL of a system with many components and integrations?

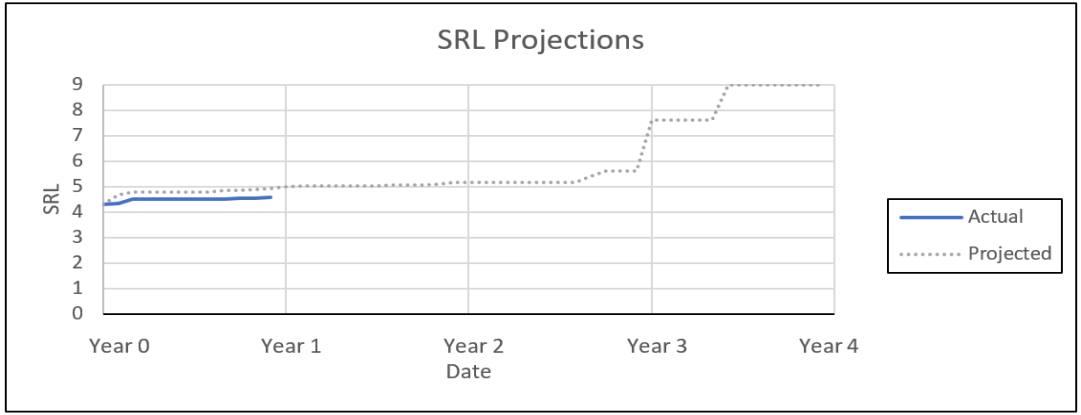
$$SRL_{Component} = \begin{bmatrix} SRL_1 \\ SRL_2 \\ SRL_3 \\ \vdots \\ SRL_n \end{bmatrix} = \begin{bmatrix} 1 & IRL_{1,2} & IRL_{1,3} & \cdots & IRL_{1,n} \\ IRL_{2,1} & 1 & IRL_{2,3} & \cdots & IRL_{1,n} \\ IRL_{3,1} & IRL_{3,2} & 1 & \cdots & IRL_{1,n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ IRL_{n,1} & IRL_{n,2} & IRL_{n,3} & \cdots & 1 \end{bmatrix} \begin{bmatrix} TRL_1 \\ TRL_2 \\ TRL_3 \\ \vdots \\ TRL_n \end{bmatrix}$$

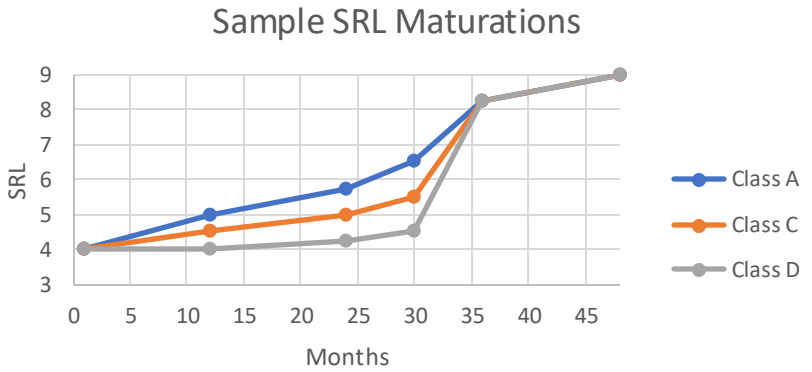
$$SRL_{Composite} = \frac{\left(\frac{SRL_1}{m_1}\right)+\left(\frac{SRL_2}{m_2}\right)+\left(\frac{SRL_3}{m_3}\right)+\cdots+\left(\frac{SRL_n}{m_n}\right)}{n}$$

Saucer, 2011

SRL Projections

- With projected dates of when TRLs and IRLs on discrete components will be achieved an SRL can be projected
- Sharp rate of maturation when system I&T starts
  - Components can get from TRL 6 to 8
  - IRLs can get from 4 to 8
- What is a normal SRL projection?
  - Dependent on mission class?





Definitions per 2009 DOD TRA Deskbook

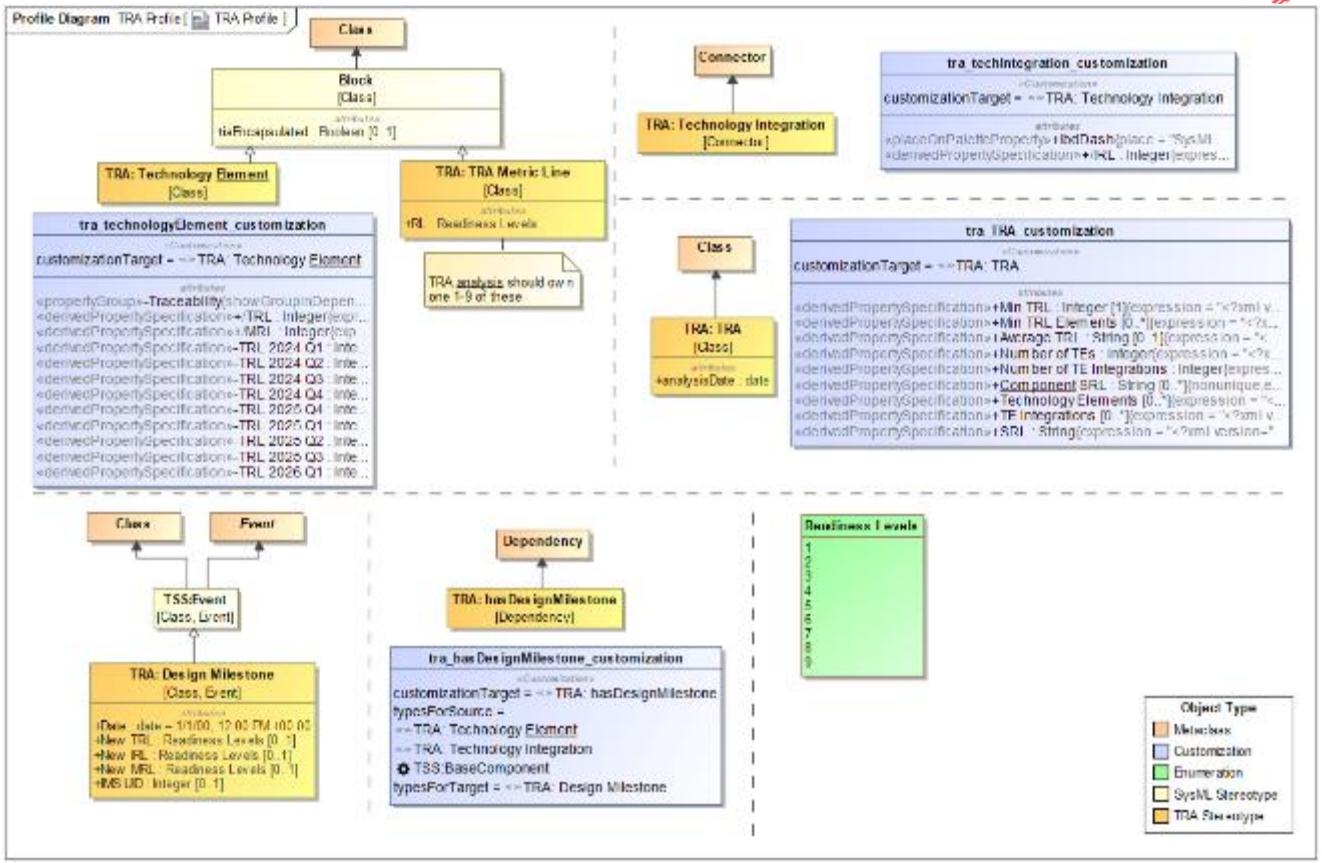
Tracking Readiness Levels in MBSE

What makes a good MBSE tool?

- It must be usable on real world applications!
  - Do not prioritize ontological exactness over the end users needs
  - It should not be too onerous to set up new model with tool. Allow for automatic imports
  - Tool must be maintainable, allowing for updates to data as designs progress
  - Include automation to allow visualizations and data generation with a minimal set of user inputs
- It should be tailorable. Every program's needs are different
- Automatically interface to other tools
  - Use the Digital Thread!

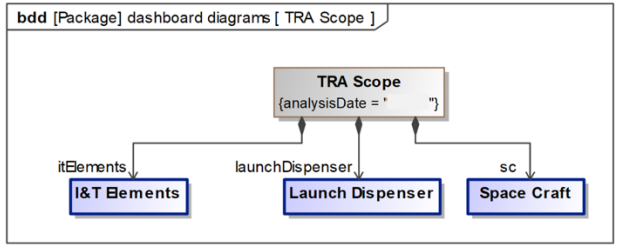
TRA Tool Profile

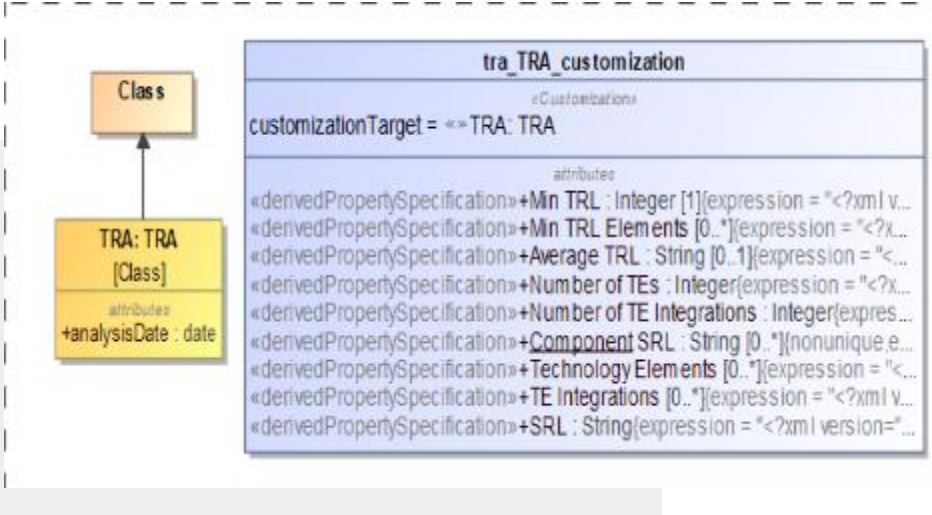
- Technology Element and Technology Integration stereotypes used to tag blocks and connectors to be included in assessment
- TRA stereotype owns the analysis and automatically calculates most metrics
- Design Milestones used to record events that would increment a readiness level of technology elements or integrations linked with the hasDesignMilestoneDependency



TRA Analysis Object

- Bulk of automation in the TRA stereotype's customization
- An instance of a TRA is given a directed composition relationship to a system block and recursively searches the architecture for all Technology Elements and Integrations
- Find min TRL in system and return array of technologies at minimum
- Find average TRL
- Metrics on quantity of technologies and integrations
- Component SRLs stored in array owned by the analysis
  - They are not owned by the technologies themselves
  - Component SRL has no meaning in the context of a technology alone. It must be in the context of a system
- Composite SRL returned as well
- Values are dependent on the analysisDate attribute
  - By varying it a user can see results projected into future or past dates

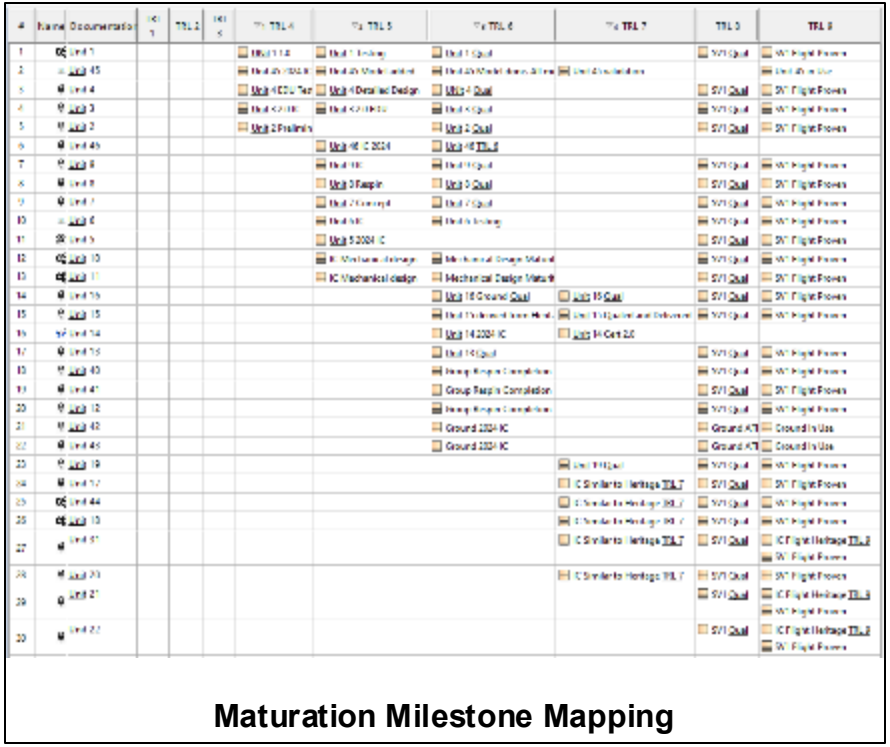




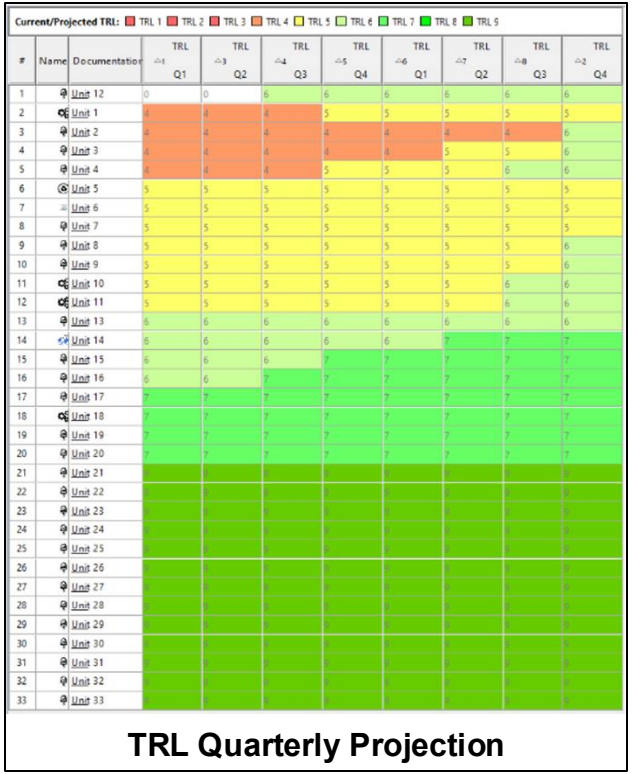
Readiness Level Visualizations

#	Analysis Date	SRL	Average TRL	Min TRL	Min TRL Elements	Number of T Es	Number of TE Integrations
1	MM/DD/YYYY	4.69	6.2	4	868 Flight Software Sim 749 Converter Unit 739 Flight Computer 751 Drive Module	40	110

TRA Metrics Table

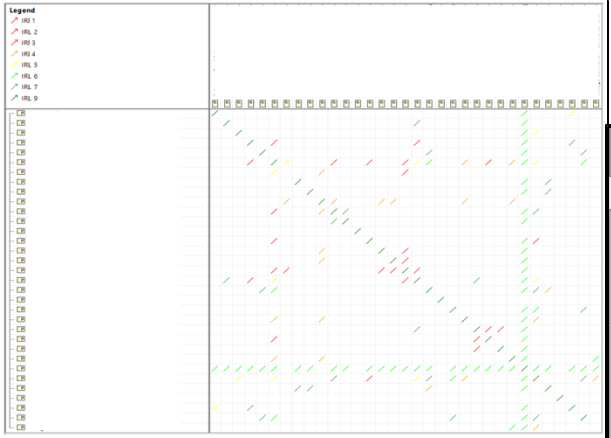


Maturation Milestone Mapping

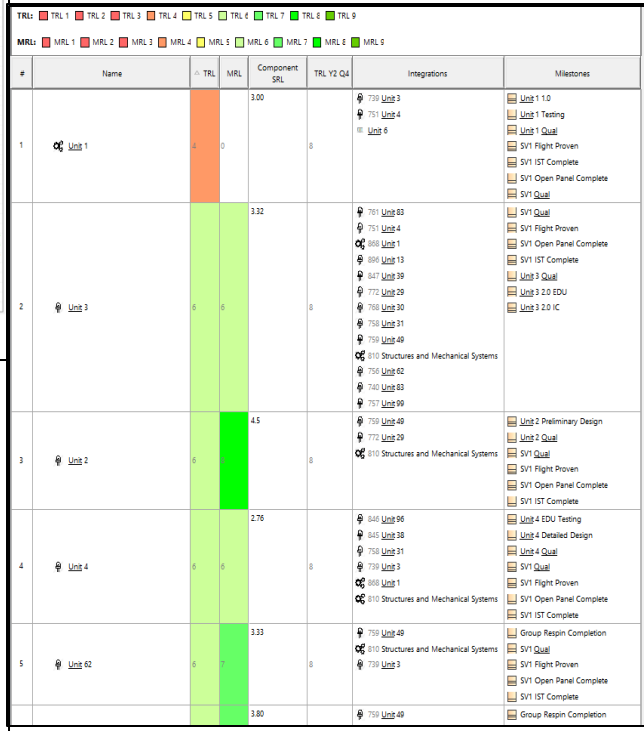


TRL Quarterly Projection

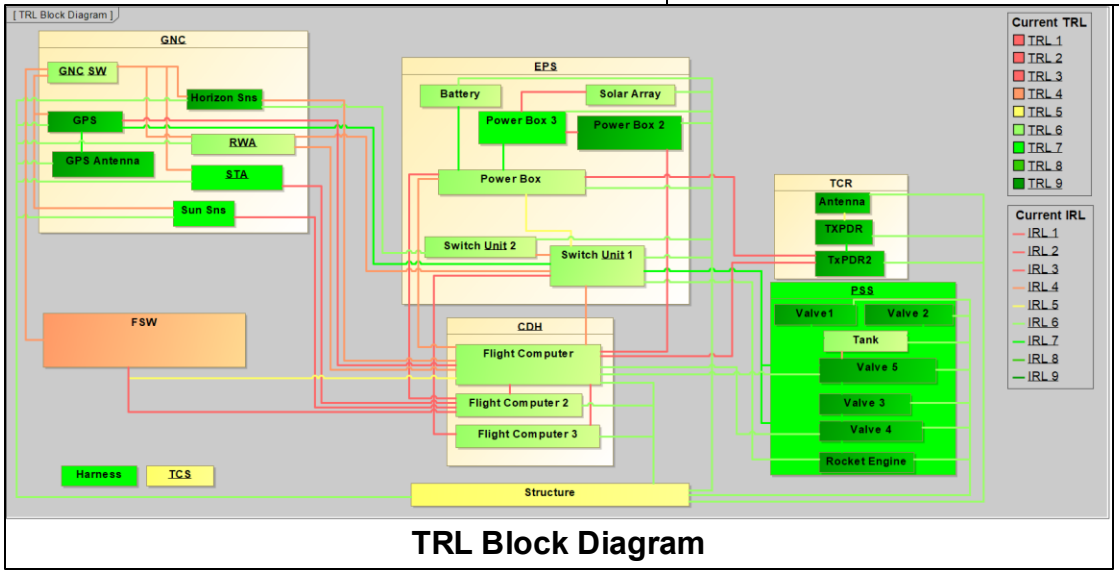
Readiness Level Visualizations



IRL Matrix



Technology Element Table



TRL Block Diagram

Conclusion

- Detailed survey of literature on readiness levels
- Discussion on applying levels to complex system development efforts (specifically spacecraft)
  - Areas of improvement
- Role of IRL and SRL
- Applying concepts to an MBSE tool

Future Work
Develop SRL projections for historic programs of various mission class to understand “normal trends”
Expand linkages to external tools for automatic data synch (ie. Microsoft Projects)
Incorporate MRL
Risk Weighting. Adjustment factor to TRL for level of effort to mature
Complexity weighting. Weigh value of component in SRL calc by its importance to system
Better IRL definitions

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