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Wholistic Sustainment Maturity: The Extension of System Readiness Methodology across all Phases of the Lifecycle of a Complex System

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Abstract

The purpose of this paper is to investigate the applicability of the Stevens Institute of Technology (hereinafter Stevens) Systems Development & Maturity Laboratory (SysDML) System Readiness Level (SRL) Model and methodology for analysis of 'wholistic' maturity of a complex system measured by other metrics beyond Technology Readiness Level (TRL). This paper proposes a 'wholistic' Systems Maturity model that includes a Manufacturing Maturity measured by a Manufacturing Readiness Level (MRL) analysis and Sustainment Maturity measured by a Sustainability Maturity Level (SML) analysis based on the Stevens SRL methodology [1]. In addition, the contextual relational metrics needed for the SRL model will be defined for sustainment maturity in order to determine 'wholistic' sustainment maturity of large scale, complex systems. The general purpose of this 'wholistic' sustainment maturity is to facilitate effective decision-making by Program Managers and Systems Engineering Leads and provide a composite evidence-based maturity assessment for large scale, complex systems for Department of Defense (DoD) milestones and reviews.

This paper will address the 'wholistic' system view where a system's object can be defined as a technology starting from a capability/component up to a system within a System of Systems (SoS). As long as there is parity for all objects under analysis and the appropriate interface/integration/interoperability readiness level (IRL) point of view is maintained the SRL model can provide the relative maturity of a complex system and the contextual maturity of each object within that system providing insight into potential areas needing further analysis and focus by Program Managers and Systems Engineering Leads. Note that this method will not provide a definitive composite value for maturity. The data this methodology provides can assist the Program Manager in determining where additional focus

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and/or resources may be needed as well as a relative “value” for the maturity of the ‘wholistic’ system to determine if progress is being made along the development timeline.

This paper will describe how the SRL Model can be used for ‘wholistic’ Sustainability maturity and will define the relational connections between objects with respect to technology and manufacturing that can be used for the model. Additionally, the paper will define the ordinal scales, aligned to the TRL MRL and SML scales as well as the key milestones and reviews of the various phases of a development program. Finally, the paper will recommend methods for displaying the aforementioned system maturity, based on Human Factors, in order for an analyst to easily determine what is of highest and lowest importance within the results of the new ‘wholistic’ readiness model.

Keywords: Sustainment Maturity, System Readiness Assessment, Technology Readiness

1. Introduction

As United States Department of Defense (DoD) systems development activities grow in complexity it becomes increasingly paramount to have effective and efficient methods and processes to examine ‘wholistic’ systems maturity in order to make systems engineering and programmatic decisions. Given the trends toward on-going system readiness assessments and affordability initiatives in the development, acquisition and sustainment of complex systems, there is a need for a ‘wholistic’ approach to measure the maturity of a complex system throughout its lifecycle. Complex systems are of a particular challenge with relational maturity effects amongst the many components that make up the whole of the system. It is extremely important to have the ability to see the relational impacts of varying development rates, obsolescence and even the cascading effects of adding enhancements at various points in a systems cycle. The challenge is to understand the dependence or sensitivity of the changing maturity for a component within a complex system in terms of the impacts on the overall system readiness, performance, cost and sustainment of the system at large. Brian Sauser et al. of the Systems Development & Maturity Laboratory (SysDML) at Stevens Institute of Technology formulated a method to define contextual technical readiness of complex systems termed System Readiness Level (SRL) [2]. This model introduces the concept of a contextual relational Integration/Interface Readiness Level (IRL) between objects of a system as a means to calculate the relative system technological maturity [2] which uses an object’s Technology Readiness Level (TRL) [3]. Figure 1 depicts the Stevens SRL Model with buttons representing objects and TRL level; and lines, integration points and IRL levels. Figure 1 also depicts the formula for calculating Component Maturities with respect to a system and the overall System Technical Maturity.

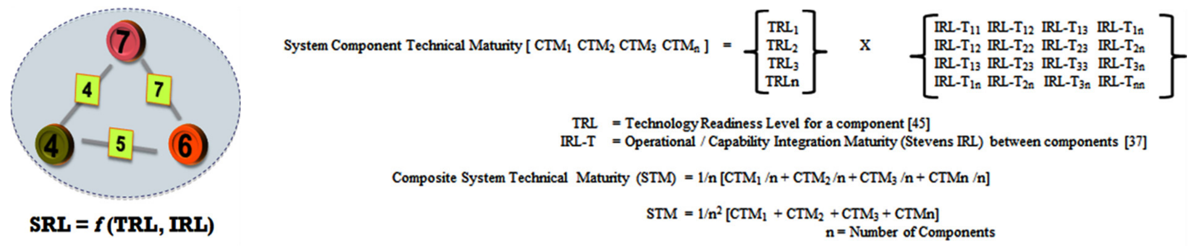

Figure 1: Stevens System Readiness Level (SRL) Model

Entering the data from the example system in Figure 1 into the formula to calculate and plot the three Component technical maturities (as they relate to the example system) and the composite relative system maturity of the example system a System Maturity of 0.46. Interpreting the data in Figure 2 the example system is at a relative technology maturity of TRL 6.

$$\text{System Component Technical Maturity } [\text{ CTM } \text{CTM}_2 \text{ CTM}_3 \text{ }] = \begin{bmatrix} 7 \\ 4 \\ 6 \end{bmatrix} \text{ X } \begin{bmatrix} 9 & 4 & 7 \\ 4 & 9 & 5 \\ 7 & 5 & 9 \end{bmatrix}$$

$$= [\text{CTM}_{red} = 0.50, \quad \text{CTM}_{brown} = 0.39, \quad \text{CTM}_{orange} = 0.51]$$

$$\text{Composite System Technical Maturity } (\text{STM}) = 1/3\ [\text{CTM}_{red}/3 + \text{CTM}_{brown}/3 + \text{CTM}_{orange}/3]$$

$$= 1/9\ [\ [0.50 + 0.39 + 0.51\ ] = 0.46$$

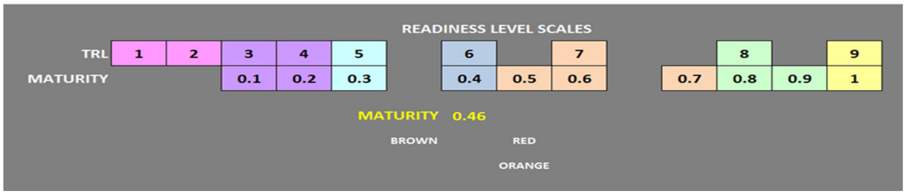

Figure 2: SRL Model Example Maturity Calculation

The value of SRL is in the determination of the relative, not absolute, maturity of the complex system. In the case of this simple example the developer could show their Customer that they are at the desired Maturity Level even though the complex systems components are maturing at varying rates and are currently at differing levels of maturity.

The Stevens SRL model has been validated by NAVSEA PMS 420, Littoral Combat Ship Mission Module Program Office which used SRL to monitor development and integration progress. The authors have researched the Stevens SRL methodology and have concluded it to be a promising mechanism for determining relative maturity of a complex system for decision support. The authors contend that using SRL results as a definitive level of maturity for the 'wholistic' system is inaccurate and that the important information is in the relational contextual maturity of the systems components. Through pilot investigations it has been found that components that lag the systems SRL relative maturity by 2 or more levels require in-depth review to determine if they contain areas of risk necessitating additional focus. Likewise, components that lead the relative system maturity by 2 or more levels have been found to have potential integration issues largely due to rigid inflexible interfaces that are incompatible with newly maturing components and warrant close scrutiny to ensure the integration of these mature components is not being presumed.

1.1. Background – Technology and System Readiness Assessment

A number of frameworks and methodologies have been proposed to address the transition of emerging technologies into complex systems. Sauser et al [4] have developed and apply systems maturity assessment tools to technology maturity and associated cost. Verma et al [5,6] address the importance of front-end requirements to system concept design. Valerdi and Kohl [7] propose a method for assessing technology risk through the introduction of a technology risk driver. DeLaurentis has applied and developed a conceptual model [8] of the DoD SoS technical management and systems engineering processes, which depicts the processes in a hierarchical fashion and represents the flow of control between the processes throughout the acquisition lifecycle. However, the proposed models do not depict the system performance or sustainability of that performance through the lifecycle of the system.

Mavris et al have introduced a framework called Virtual Stochastic Life-Cycle Design (VSLCD) [9] in which the development uncertainty within the lifecycle of a system is represented through optimization models. Kirby and Mavris suggest the use of the Technology Identification, Evaluation, and Selection (TIES) method [10] for evaluating and prioritizing technologies. Ramirez-Marquez and Sauser postulate an optimization model [11] for system readiness. Although these sources seek to quantitatively assess the maturity of the system or complex system of interest, there is no single methodology for associating this technology maturity with the performance and sustainment of the system or constituent systems.

Sauser et al [12] investigate the impact of cost and earned value in assessing technology maturity. Mandelbaum [13] makes the case for the selection of critical technology elements based on systems supportability cost and time. Azizian et al.

[14] conducted a comprehensive review of maturity assessment approaches which analyse and decompose these assessments into three groups; i.e., qualitative, quantitative, and automated readiness assessment, and must be explored to determine what significance each adds and how they interrelate. Gove and Uzdzinski [15] propose a performance-based system maturity assessment framework in which system maturity is characterized as a function of system-level performance measures while retaining the critical assessment data provided by other system maturity metrics. The general structure of the framework sets the stage for the follow-up top-down development for specific sub-processes leading to the evaluation of system maturity and mitigation plans to address areas of high risk or concern. The DoD has developed Sustainability Readiness Levels to identify and measure "quantifiable best value outcome based product support strategies that optimize life cycle costs and readiness [16]."

1.2. Problem Definition

Given the trends in the development of Defense systems, tending toward firmer up-front requirements and more cost-effective solutions [17], the DoD has sought to place greater emphasis on affordability and agility [18,19] earlier in the development of systems. Thus, given these competing forces, there is a need for a systematic understanding and assessment of the performance and readiness of emerging technologies within complex systems as they develop and evolve over time through the procurement and acquisition process. There is a commensurate need for a model in support of the aforementioned framework for assessing front-end technology maturity, cost, and system performance that may predict the impact of a technology's development, obsolescence and enhancement on system effectiveness and overall cost as the system matures. Any model to be considered for 'wholistic' sustainment maturity needs to be easy to use, easy to understand and have results based on objective evidence.

1.3. Applicability of System Readiness Level Model to Wholistic System Maturity

For the SRL Model a 'wholistic' technical readiness can be calculated where an object can be a technology within a capability/component, a component within a module or software configuration item, or a module within a subsystem or system and a system within a System of Systems (SoS). As long as parity is maintained for all objects under analysis the SRL methodology can be used to calculate the 'wholistic' relative maturity and the contextual relational maturity levels for the individual objects that constitute the system for analysis. Figure 3 depicts these successive levels of system composition applicable to the SRL model.

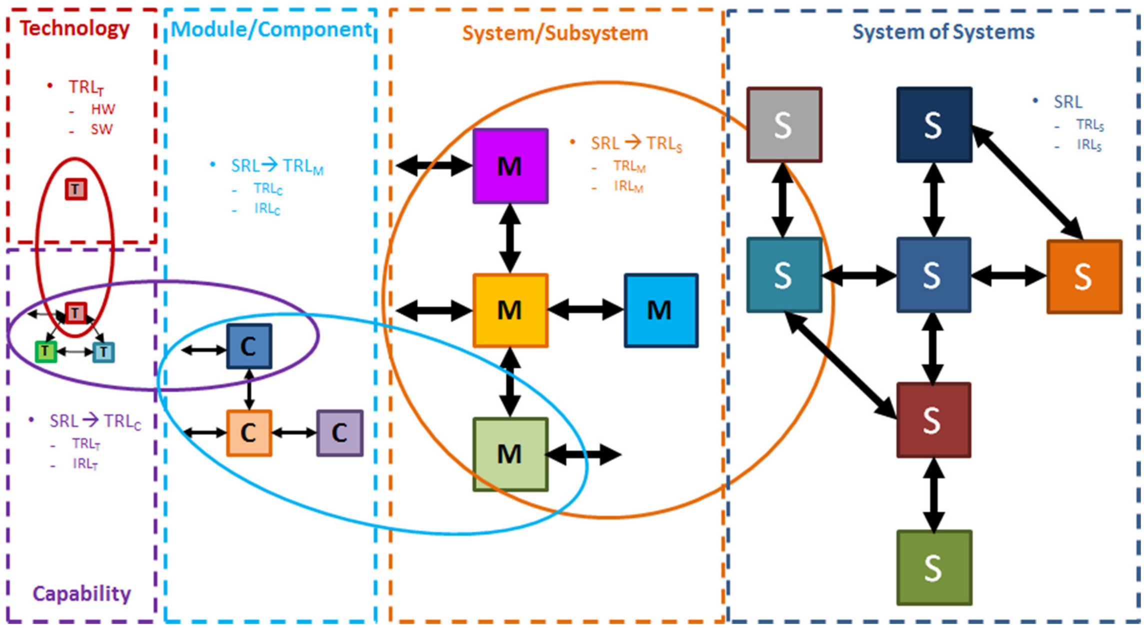

Figure 3: 'Wholistic' View of Technology Maturity

It is the authors' contention that the key to the SRL model is IRL. Whether the parity analysis defines IRL as Interface Readiness (module/Component view) or Integration Readiness (System view) or Interoperability Readiness (System of Systems view) the SRL Model can provide the relative contextual maturity of each component and the relative maturity of the 'Wholistic' System. To date, no issues or risk areas have been identified within pilot system components that are at the same or lag /lead the pilot system's relative maturity level by a single step/value. Thus, it is proposed that the SRL model can be considered for a 'wholistic' way of viewing a system's relative technology, manufacturing and sustainment maturity providing a guide to what areas to focus for decision-making by Program Managers and Systems Engineering Leads to mitigate impacts to cost, schedule, performance and sustainment.

Tetley and John [20] address the importance of the terms readiness and maturity within systems engineering. There is a difference between system technological maturity and system readiness maturity with the latter needing greater insight into manufacturing readiness and sustainment maturity. Focusing on sustainability, a 'wholistic' Sustainment Maturity model for complex systems, based on the Stevens SRL model, is proposed. In order for this model to provide qualifiable results, a contextual relational metric between system components with respect to sustainability must be identified and quantitatively defined with objective evidence-based artifacts to attain a specific level of maturity. It is posited that this metric is the relationship sustainment has with both technology and manufacturability.

For manufacturing each component has a Manufacturing Readiness level (MRL) [21] that can be defined similar to TRL maturity. In addition, when manufacturing components, 'the how' a part must interface with other parts to make the system must be considered. These interface considerations are the manufacturing IRL equivalent to the technological IRL of the Steven's SRL model. Thus it is proposed that the SRL model fits the need to calculate a complex system's relative manufacturing readiness by replacing TRL with a component's maturity on the MRL scale and by considering IRL as it relates to how well-defined (or mature) a component's interfacing with each other is.

In the same way, sustainability can use the SRL model as a means to determine a complex system's relative sustainability maturity. Though, for sustainability maturity of a complex system, both the technology and manufacturing linkage (interface and integration points) between components needs to be analysed to obtain a clearer picture of the overall system's sustainability. As a real world example there might be a functional equivalent component for an obsolete part of a system; however, the form factor of the replacement may be vastly different and incompatible with the physical constraints of the system. Thus the technological sustainability of the system is still high but the manufacturability sustainability of the system has been lowered. In order to use the SRL model for sustainability, TRL must be replaced with a component's sustainability maturity level (SML) [2] and then use the SRL model to calculate a relative sustainability maturity considering both the technological and manufacturing IRL.

Figure 4 depicts pictorial views of an example system's 'wholistic' maturity based on the above proposal. The diagram to the left depicts the complex systems component map with buttons representing component with technical maturity (TRL) and technological IRLs indicated by squares on the relational interfaces between these components. The next diagram going left to right depicts the same complex system from a manufacturability perspective. Gears represent a component's manufacturing maturity (MRL) and the physical IRL between components as triangles on the relational interfaces. The final two diagrams depict a complex systems 'wholistic' sustainment using the lifecycle symbol to represent a component's sustainability maturity (SML). As indicated above in order to use the SRL model for sustainability, sustainment maturity must be looked at from a technological and manufacturability perspective. The technological IRLs are used for the first and the manufacturability IRLs for the latter. The need for this dual view for sustainability has been verified by an actual issue for a Lockheed Martin product. Due to an obsolescence issue a new component was needed for a fielded product. A technological equivalent was found that had no impact on the systems functional maturity. However, this component physically could not fit within the allocated space and therefore the manufacturability IRL maturity was heavily impacted which impacted the products sustainability.

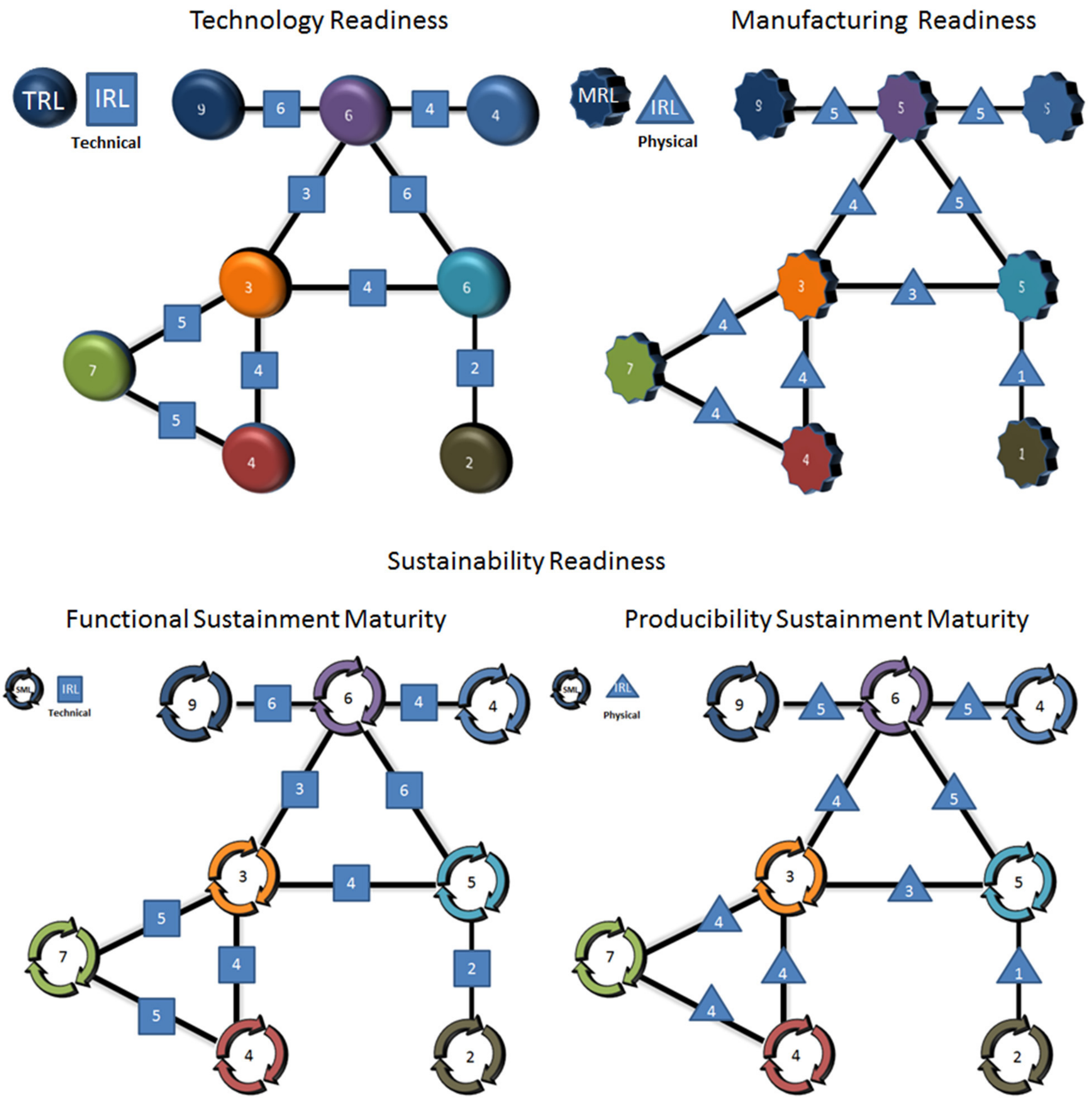

Figure 4: 'Wholistic' View of System Maturity

1.4. Proposed Use of System Readiness Level Model to Wholistic System Maturity

Applying the Stevens Model to the diagrams in Figure 4 would allow an analyst to calculate the relative maturity of the complex system, with regards technological, manufacturability and sustainment, As stated previously within this paper the real "value" of the model is the contextual relational maturity of the components of the complex system. As long as evidence based parody definitions are used for the components relationships to other components within the Complex system the SRL Model will highlight those components needing additional insight to determine if focussed attention is warranted. The Model does not highlight where an issue exists just where an issue may exist.

Figures 5 and 6 show the results of the Stevens Model for a theoretical complex 'wholistic' system for the Technological and Manufacturability points of view.

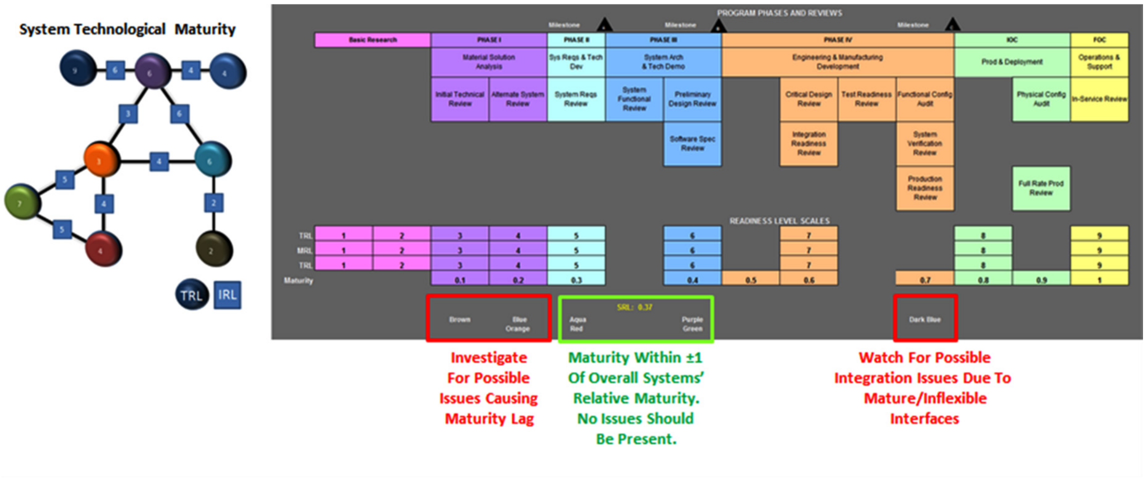

Figure 5: Relative System Technical Maturity

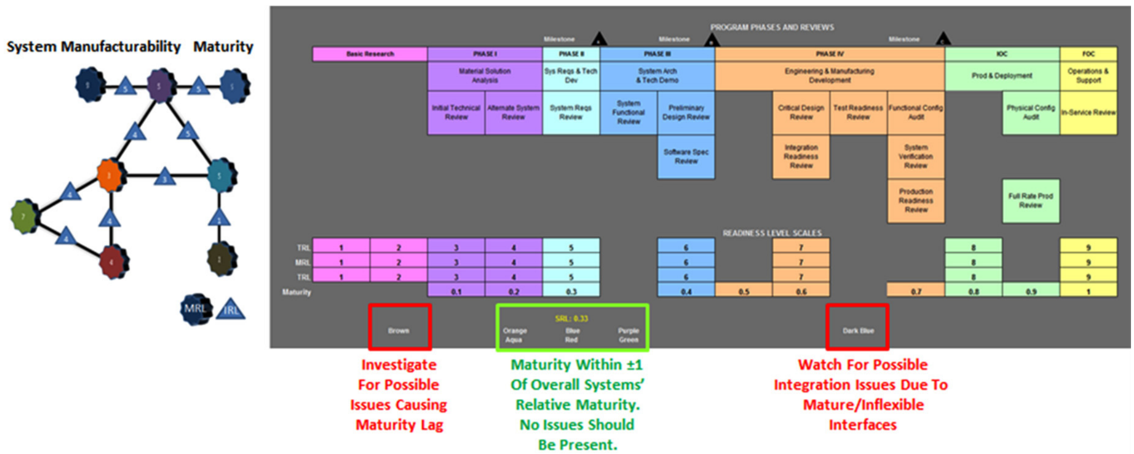

Figure 6: Relative System Manufacturing Maturity

Reviewing the data in these Figures, the brown component is highlighted needing review for the root cause of lagging the system's relative maturity in both categories. There may be a perfectly good explanation (e.g., new emerging capability being added, programmatic decision to leave for later) but nonetheless a deep-dive review is warranted. The data also shows that the blue and orange components lag the system's maturity by more than 1 for Technical Maturity but not manufacturing and therefore a technical deep-dive review by Program Management or Systems Engineering Lead is all that is necessary to determine if issues are present that require addressing. Note: The Stevens Model results do not indicate the definitive presence of an issue, but merely highlight areas where an issue may be a concern. Dark blue represents a re-use item in the example, and the diagram highlights the need for diligence to make sure the potentially older inflexible interfaces of the component are being considered by the component interfacing with the item (represented by purple).

Figure 7 depicts the two Sustainment views (Technological & Manufacturability). Reading the Sustainment Maturity plots one can easily see the impacts of the 'wholistic' system immaturity on the dark blue component's sustainability. In addition, the data highlights the need to determine if there are capability (technical) sustainability issues with the blue, orange and aqua components that are not present from a Producibility (manufacturing) sustainability perspective. And as with the Technical and Manufacturing Maturity plots the brown component is lagging the system's relative sustainment maturity and needs Program focus.

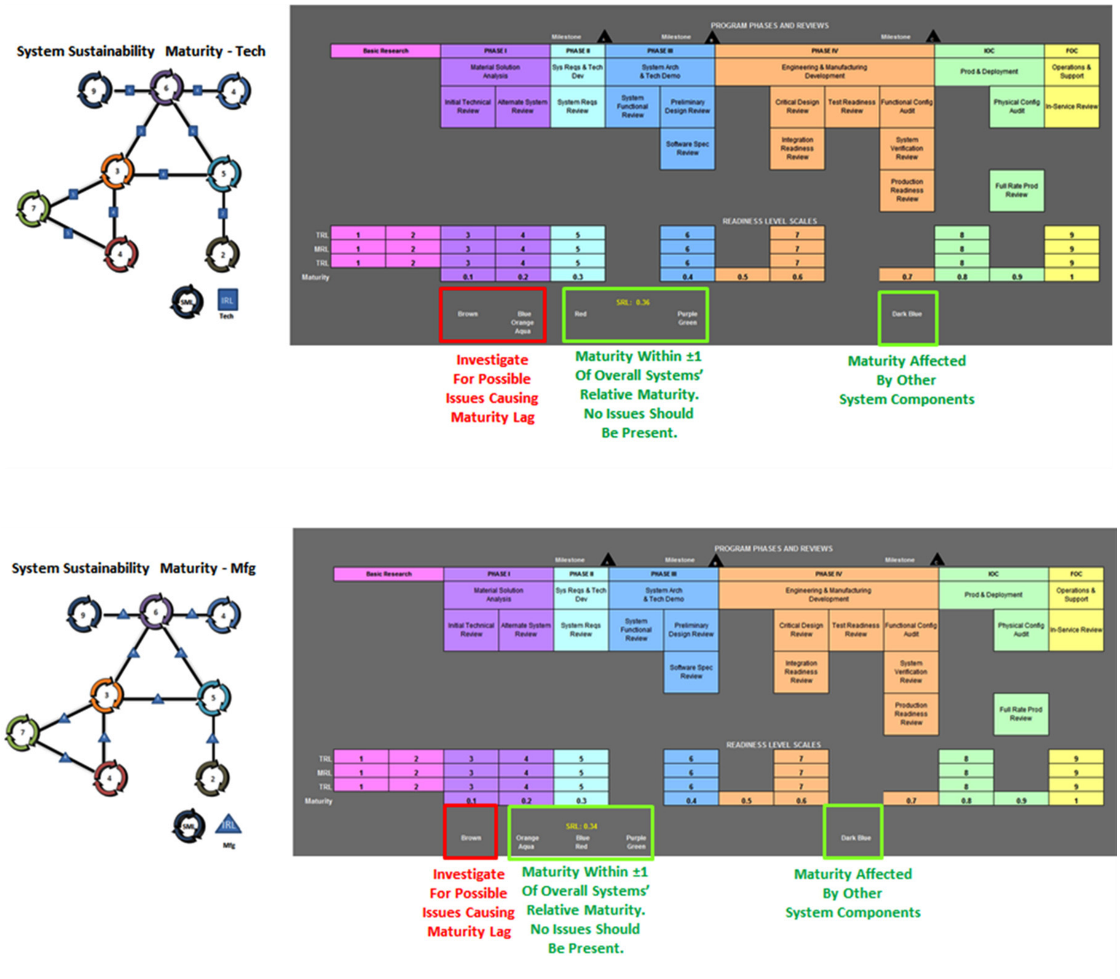

Figure 7: Relative System Sustainment Maturity

1.5. Conclusions and Future Work

As this paper has shown the SRL Model can be used to provide a 'Wholistic' technical maturity view of a complex system under development. Pilot evidence has shown that components lagging or leading the overall System maturity may contain potential issues. The authors have found no evidence to date (that they are aware of) that components with contextual relational maturities close to the overall systems' relative maturity have had hidden issues. Since a complex systems components can have a Manufacturability Maturity as well as physical relational connections with other components of the system the Authors' propose the use of the SRL Model replacing component TRL with MRL and using contextual evidence based definitions for manufacturability IRLs. For sustainability the SRL Model can provide a view of the system's Technological and Producibility sustainment maturity. This would substitute SML for component TRL or MRL and would use the Technological and Manufacturing IRLs. However, this view needs to be qualified, quantified and analyzed to determine what actionable information can be taken from the variant SRL calculation with respect to sustainability areas of issue and/or concern. The authors plan additional complex system pilots where manufacturability and sustainability analysis using the SRL Model will be employed. These efforts need to take place to collect the metric data to confirm that the Steven's Model is applicable to the 'wholistic' systems proposed in this paper. In addition, the creation of Model based design tools is needed to simplify the collection of the objective evidence metrics required to calculate a System's 'wholistic' maturity so that this methodology is automatic resulting in minimal impacting to a program's cost and schedule.

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