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System Capability Satisficing in Defense Acquisition via Element Importance Measures

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Abstract

Under the direction of the Principal Investigators and support from the Naval Postgraduate School and government/industry partnerships, the Systems Development & Maturity Laboratory at Stevens Institute of Technology has successfully developed a system maturity measure (i.e. System Readiness Level [SRL]) and supporting optimization models for inclusion in a System Earned Readiness Management methodology. At this point in the research program, it is necessary to spiral back to the beginning of the original development of the SRL to enhance fundamental capabilities of assessing system maturity in order to address some recurring issues to its application - as described to the research team in our many interactions with industry, government and academia. That is, a system has variants in its physical architecture that realize certain functionality and capability by which trade-off decisions are made to find a satisficing solution for a deployable system. This report summarizes the results of these efforts to enhance the previously developed methodologies by addressing this fundamental question, "**What are the effects of necessary trade-offs in functionality, capability, cost, schedule, and maturity, that will allow the acquisition of a system that can still satisfy a warfighter's needs?"** The end product is an enhanced SRL and a supporting methodology that will facilitate more informed acquisition decisions that can reduce risk in acquiring immature systems.

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1. Introduction

Under the direction of the Principal Investigators (PIs) and support from the Naval Postgraduate School (NPS) and government/industry partnerships, the Systems Development & Maturity Laboratory (SysDML) at Stevens Institute of Technology has successfully:

a) Developed a methodology for determining a system's maturity (i.e. System Readiness Level [SRL]) (Sauser, Ramirez-Marquez et al. 2008);

b) Formulated two optimization models for predicting cost, schedule and maturity performance (i.e. SRL_{max} and $SCOD_{min}$) (Sauser and Ramirez-Marquez 2009; Magnaye, Sauser et al. 2010) to allow for an optimal follow-up to the system maturity development;

c) Explored a methodology that combines items a) and b) into an evolutionary approach called Systems Earned Readiness Management (SERM) (Magnaye, Sauser et al. 2009; Magnaye 2010).

During the research that has fostered these developments, the SysDML has maintained a spiral development approach where team members have worked closely with industry and government to refine and implement their research in order to maintain its relevance and rigor. For this effort we believed it was time to spiral back to the beginning of the life cycle (see Figure 1) to enhance fundamental capabilities of the SRL in order to address some recurring issues in its application (e.g. the linear nature of the methodology and formulation, and its relevance to systems functionality and capability for acquisition). We sought to address these issues with an approach we termed System Capability Satisficing (SCS). Our motivation for this approach has three gestations: *Systems Engineering, Satisficing Solutions,* and *Systems Maturity Assessment (SMA) Roundtable*.

Systems Engineering: In the practice of systems engineering, architectures are developed to illustrate the behavioral representation of the system (Maier 1998). These architectures have multiple instantiations based on "views," states, modes, or functionalities (Crawley, de Weck et al. 2004). As such, the maturity of a system can vary depending on the architectural representation which leads to some fundamental research questions (Jain, Chandrasekaran et al. 2008): "*What technologies and integrations are important or critical to each architectural view to achieve a functionality or capability?"… "How will the system maturity vary depending on the architectural variants?*"

Satisficing Solutions: The term "satisficing," introduced by Noble Prize Laureate Herbert A. Simon, indicates that in a complex dynamic environment true optimization or the "best" result cannot always be achieved (Simon 1996). Thus, he suggested the use of a "good enough" approach. We find in a wartime environment, the warfighter cannot afford to wait for the optimal solution but must accept one that is "good enough" (Gorod, DiMario et al. 2009). So a satisficing solution leads us to ask, "*What functionalities or capabilities are sufficient, critical, or important to achieving a level of system maturity that can satisfy a warfighter's needs?*"… It is very common that a systems engineer will trade-off system capability to reduce cost and shorten schedule, but "*What impact does this have on system maturity and ultimately the acquisition of a deployable system?*"

<u>*SMA Roundtable*</u>: As part of previous funding from the NPS Acquisition Research Program, the PIs hosted a roundtable that would inform a greater community of our research results and allow for an exchange of knowledge with others working in this area with the hopes of fostering collaborative research from the systems engineering research community. Thus, on March 12, 2009, a Roundtable was held in Washington, DC with thirty participants representing government, industry and academia. As part of this exercise, some of the following themes emerged: "*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?*" (For more information on the results of the SMA Roundtable see http://www.SysDML - Research/Design and Sustainment Community.)

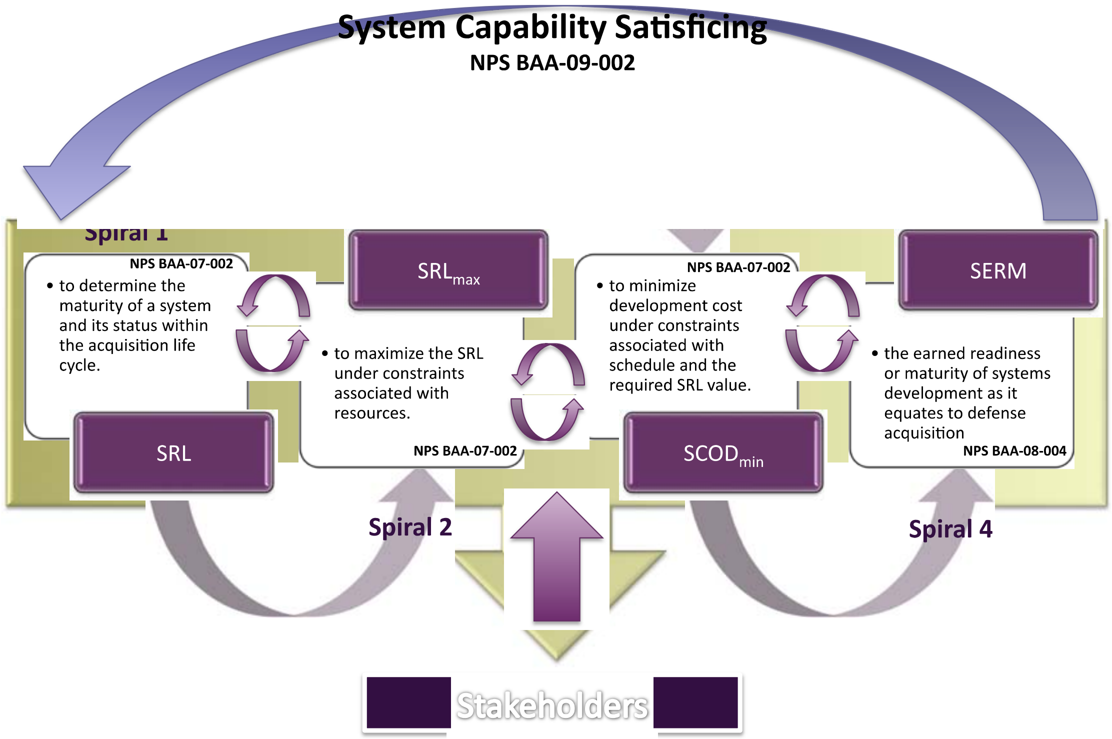

Figure 1: Research Spiral Development Plan

Thus, the fundamental question of this research as it relates to a Systems Engineer and Acquisition Manager is:

> ***What are the effects of necessary trade-offs in functionality, capability, cost, schedule, and maturity, that will allow the acquisition of a system that can still satisfy warfighter needs?***

2. Purpose and Focus of Research

Systems that provide a satisficing solution are becoming the norm given the urgency of the armed conflicts that we are currently fighting in Iraq, Afghanistan and against terrorism. However, the desire to deliver capabilities immediately has to be moderated by the reality that resources are tight such that where possible, we must deliver systems that can accomplish multiple functions and capabilities in the field. Thus, we are confronted with the situation where complexity is increased by multi-functionality while the development time available is shorter.

Since these systems are to provide multiple functionalities and capabilities, their complexity surpasses that of systems providing only single functionality with single capability. In order to secure the intended capabilities, the U.S. government mandates that the Key Performance Parameters (KPP) must be specified in the Capability Development Document (CDD) and Capability Production Document (CPD), and be verified by testing and evaluation or analysis (DAU 2009). According to the DAU Manual, Key Performance Parameters (KPP) are "those attributes or characteristics of a system that are considered critical or essential to the development of an effective military capability and those attributes that make a significant contribution to the characteristics of the future joint force as defined in the Capstone Concept for Joint Operations (CCJO)".

However, development of methodologies that can accurately predict the ability of systems to satisfy KPP while development is still ongoing poses challenges to the acquisition community. Volkert (2009) proposed an approach that used SRL as the indicator of the level of capability that is being realized. It answered the question of how to predict the achieved ability of a system while its development is underway. The objective of doing so is to monitor the system developmental progress and identify issues in a timely manner should there be any gap (e.g., schedule, cost, etc) between the preset plan and the accomplishments. The information gathered from his approach is very important because when it is coupled with further analysis, corresponding decisions can be made and measures can be taken so as to prevent the issues from getting worse. Volkert's approach can provide timely data about the progress of the system, but it does not address the question of how to solve development problems (should there be any), and thus is unable to prescribe methodologies for prioritizing resources allocation. Specifically, as problems arise or are anticipated, the program manager must be able to determine which of the system's components should receive resources based on their importance in achieving the capability in question.

3. Research Approach

This research proposes a methodology based on component importance analysis. We use the term capability to represent both the "capability" and the "physical structure of technology packages whose combination enables the capability. We review Volkert's approach for measuring the achieved KPPs in a system under development, and then proceeds by proposing three component importance measures. A system with notional data is presented to illustrate the application of the proposed IMs. It should be noted that in this research systems are coherent in the sense that each technology in the system has at least one link with others in the system, and thus a separate technology will not be considered part of a system.

In our statement of the problem, we established that a system would have variants in its physical architecture that realize certain functionality and capability of the system. We then explained that a systems engineer or acquisition manager would make trade-off decisions to find a satisficing solution for a deployable system. Thus, for the scope of this research we assessed a system's maturity (i.e. SRL) via three Importance Measures (IM) with respect to SCS: TRL/IRL, cost, and labor-hours.

3.1. SCS with respect to TRL/IRL (I^P)

The IM of TRL/IRL evaluates the impact of a change in element (i.e. technology or integration) maturity on system maturity. This measures the change of the composite SRL when a specific element TRL or IRL changes from its current readiness value to a target value. For example, let $SRL(TRL, IRL)$ denote the current SRL of the system, and $SRL(TRL, IRL \mid TRL_i = \overline{TRL_i})$ ($SRL(TRL, IRL \mid IRL_{ij} = \overline{IRL_{ij}})$) denote the resultant SRL when TRL_i (IRL_{ij}) changes to a target maturity level $\overline{TRL_i}$ ($\overline{IRL_{ij}}$) and all other *TRLs/IRLs* stay on their current maturity values. Then, the definition of IM with respect to TRL/IRL (I^P) is as follows:

$$For\ TRL, I_i^P = \frac{SRL(TRL, IRL \mid TRL_i = \overline{TRL_i})}{SRL(TRL, IRL)}$$

$$For\ IRL, I_{ij}^P = \frac{SRL(TRL, IRL \mid IRL_{ij} = \overline{IRL_{ij}})}{SRL(TRL, IRL)}$$

I^P measures the effect of change in the readiness level of a given element on the SRL. Therefore, the element for which a variation of the readiness level results in the largest variation of the system composite SRL has the highest importance.

3.2. SCS with respect to cost (I^{CT})

There are situations where system engineers or acquisition managers want to make investment decisions based on the comparison of the return in terms of system readiness on the investment needed to mature elements (Dillon, Pate'-Cornell et al. 2005; Galway 2007). Presumably, especially with a limited budget, the inclination is to allocate resources to the elements that can result in the greatest system maturity achievement. Therefore, the IM of Cost takes into account the cost for maturing elements to facilitate such comparisons. Since the cost to mature different elements varies and improvements in different elements have different effects on overall system maturity, the IM that takes into account the development cost serves as a baseline to compare the investment returns from different elements. Let $CT_i = CT_{\overline{TRL_i}} - CT_{TRL_i}$ ($CT_{ij} = CT_{\overline{IRL_i}} - CT_{IRL_{ij}}$) denote the associated development cost for maturing TRL_i (IRL_{ij}) from its current readiness level to a target level $\overline{TRL_i}(\overline{IRL_{ij}})$. The formula to calculate the (I^{CT}) is as follows:

$$For\ TRL, I_i^{CT} = \frac{\Delta SRL}{CT_i} = \frac{SRL(TRL, IRL \mid TRL_i = \overline{TRL_i}) - SRL(TRL, IRL)}{CT_{\overline{TRL_i}} - CT_{TRL_i}}$$

$$For\ IRL, I_{ij}^{CT} = \frac{\Delta SRL}{CT_{ij}} = \frac{SRL(TRL, IRL \mid IRL_{ij} = \overline{IRL_{ij}}) - SRL(TRL, IRL)}{CT_{\overline{IRL_{ij}}} - CT_{IRL_{ij}}}$$

I^{CT} deals with the effect of the budget to mature a given element. Elements whose readiness improvement from the budget investment results in the largest gain of the system readiness have the highest importance.

3.3. SCS with respect to labor-hours (I^{LH})

In our third IM, we take into account the associated labor-hours to upgrade an element's readiness level to thus mature the system's composite SRL. Let $LH_i = LH_{\overline{TRL_i}} - LH_{TRL_i}$ ($LH_{ij} = LH_{\overline{IRL_i}} - LH_{IRL_{ij}}$) denote the associated development labor-hours for developing TRL_i (IRL_{ij}) from its current status to a target level $\overline{TRL_i}(\overline{IRL_{ij}})$, the formula for I^{LH} is as follows:

$$For\ TRL,\ I_i^{LH} = \frac{\Delta SRL}{LH_i} = \frac{SRL(TRL, IRL \mid TRL_i = \overline{TRL_i}) - SRL(TRL, IRL)}{LH_{\overline{TRL_i}} - LH_{TRL_i}}$$

$$For\ IRL,\ I_{ij}^{LH} = \frac{\Delta SRL}{LH_{ij}} = \frac{SRL(TRL, IRL \mid IRL_{ij} = \overline{IRL_{ij}}) - SRL(TRL, IRL)}{LH_{\overline{IRL_{ij}}} - LH_{IRL_{ij}}}$$

I^{LH} deals with the effect of the effort to mature a given element. Elements whose readiness improvement from the effort investment results in the largest gain of the system readiness have the highest importance.

3.4. Approach Development Path

The development path for this research proceeded along three phases. Each phase served as a foundation for the development of more complex concepts while also transitioning knowledge, information, and tools to a practitioner community. Likewise, each phase was closely linked to the previous in order to further develop the proposed concepts.

Phase 1 – Development of SCS Models: This first phase developed the fundamental models for SCS as it related to the IMs of TRL/IRL, cost, and labor-hours. What we have proposed were preliminary representations, which needed further work and understanding on how they relate to architectural variants in functionality and capability for acquisition.

Phase 2 – Verification of the SCS Models with Systems: We applied these models on real systems from Lockheed Martin (Morristown, NJ; Orlando, FL), Northrop Grumman Integrated Systems, U.S. Army Armament Research, Development and Engineering Center (ARDEC), and the U.S. Navy PMS 420. This resulted in refinement and adjustment to the qualitative correlations of the models based on Phase 1.

Phase 3 – Development of a Methodology (months 8-12): We documented a process methodology for use of the SCS Models so further work can be carried out with validation of the models with those stakeholders identified in Phase 2.

4. Illustrative Example

The following example was used in (Forbes, Volkert et al. 2009) to illustrate the application of SRL. The system is designed to perform six capabilities. For the illustration of the proposed methodology in this research, it is assumed that the *mine-detection capability* that is enabled by the combination of the shaded components is the KPP of interest. This capability has six components with six integrations among them, and the corresponding TRLs and IRLs are shown in Figure 2.

The current capability SRL for the Mine-Detection is 0.622. According to the definition of SRL (Magnaye, Sauser et al. 2009), this value indicates that the capability is undergoing the Engineering & Manufacturing Development phase. During this phase, the major assignments are to develop system capability or (increments thereof), reduce integration and manufacturing risk, ensure operational supportability, minimize 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.

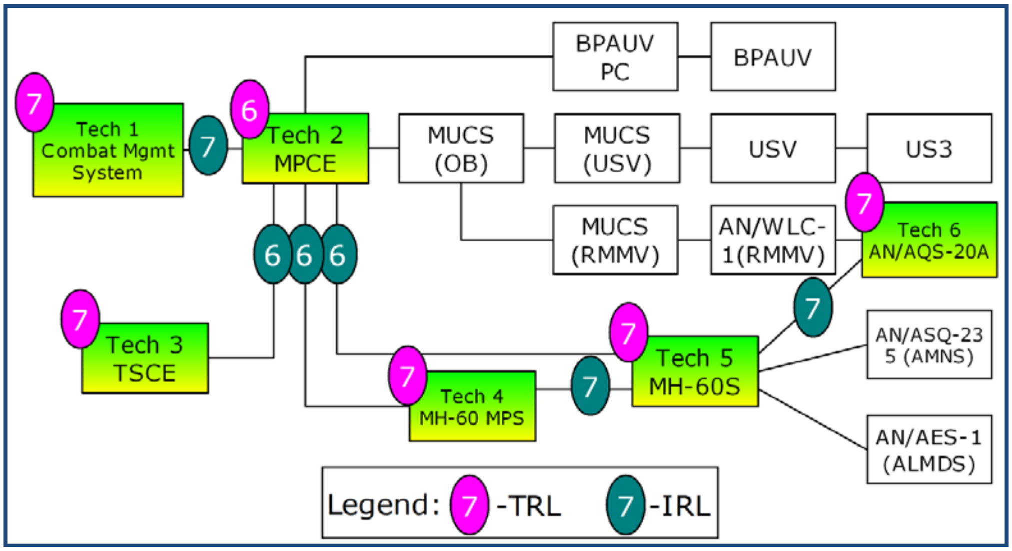

Figure 2 – Diagram of a System with Components Shaded for the KPP

Since we are proposing to take into account the resource consumption (cost and labor-hour) in the component importance evaluation, Tables 1 and 2 show these values for maturing the components (i.e., TRL and IRL) of the capability of interest. The cost is in thousand of dollars ($1,000), and the effort is in labor-hours. For example, it requires 599 hours of effort and $980,000 to move technology 1 from level 7 to level 8. It is the obligation of the program manager to obtain these estimates of resource consumption in reality. To mature the whole capability, the estimated cost and effort equal $17,141,000 and 10,976 of labor-hours, respectively.

Table 1 – Resource Consumption for TRL Upgrade

	Tech 1		Tech 2		Tech 3		Tech 4		Tech 5		Tech 6	
TRL	Cost	Time	Cost	Time	Cost	Time	Cost	Time	Cost	Time	Cost	Time
1	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0
2	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0
3	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0
4	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0
5	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0
6	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0
7	$0	0	$579	453	$0	0	$0	0	$0	0	$0	0
8	$980	599	$157	177	$973	541	$459	154	$443	551	$410	580
9	$820	290	$918	267	$404	582	$592	341	$490	304	$871	358
Sum	**$1,800**	**889**	**$1,654**	**897**	**$1,377**	**1123**	**$1,051**	**495**	**$933**	**855**	**$1,281**	**938**

Table 2 – Resource Consumption for IRL Upgrade

	1,2		2,3		2,4		2,5		4,5		5,6	
IRL	Cost	Time	Cost	Time	Cost	Time	Cost	Time	Cost	Time	Cost	Time
1	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0
2	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0
3	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0
4	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0
5	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0
6	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0
7	$0	0	$754	414	$968	509	$317	524	$0		$0	0
8	$906	478	$382	90	$159	490	$853	563	$613	392	$468	551
9	$983	280	$735	220	$648	248	$648	147	$374	370	$237	503
Sum	**$1,889**	**758**	**$1,871**	**724**	**$1,775**	**1247**	**$1,818**	**1234**	**$987**	**762**	**$705**	**1054**

With the proposed component Importance Measures for I^P, I^{CT}, and I^{LH}, this paper considers two scenarios for each measure to identify the importance of components towards achieving the KPP in question. While keeping all the other components constant, the two scenarios are to advance the current maturity of a component to (1) the next level, which is $\overline{TRL_i} = TRL_i + 1$ or $\overline{IRL_{ij}} = IRL_{ij} + 1$, and (2) increasing to its highest level, which is $\overline{TRL_i} = 9$ or $\overline{IRL_{ij}} = 9$.

4.1. Increasing Component Readiness by One Level

By increasing the component maturity by one level, table 3 shows the results of the calculation. For the I^P component importance, Technology 2 is the most important component whose change in maturity has the largest impact on the maturity of the capability. When technology 2 is increased by one level, the Capability SRL is upgraded from its current value of 0.622 to 0.646, and gives an I^P of 1.039. If the objective is to have the most increase in Capability SRL if only one component can be changed by one level, then technology 2 is the most important one. The second and third most important components identified are technologies 5 and 6, with an I^P of 1.031 and 1.021, respectively.

Table 3 – Component Importance for the Scenario of Increasing by One Level

	Component	Current Readiness Level	SRL	I^P	I^P Rank	I^{CT}	I^{CT} Rank	I^{LH}	I^{LH} Rank
Technology	1	7	0.634	1.0195	5	1.2E-5	8	2.0E-5	8
	2	**6**	**0.646**	**1.0390**	**1**	4.2E-5	2	5.4E-5	2
	3	7	0.634	1.0189	6	1.2E-5	9	2.2E-5	6
	4	**7**	**0.634**	1.0197	4	2.7E-5	4	**7.9E-5**	**1**
	5	**7**	**0.641**	1.0307	2	**4.3E-5**	**1**	3.5E-5	3
	6	7	0.635	1.0207	3	3.1E-5	3	2.2E-5	4
Integration	1,2	7	0.631	1.0146	8	1.0E-5	11	1.9E-5	10
	2,3	6	0.631	1.0146	9	1.2E-5	10	2.2E-5	5
	2,4	6	0.629	1.0112	11	7.2E-6	12	1.4E-5	11
	2,5	6	0.628	1.0096	12	1.9E-5	6	1.1E-5	12
	4,5	7	0.631	1.0135	10	1.4E-5	7	2.1E-5	7
	5,6	7	0.633	1.0174	7	2.3E-5	5	2.0E-5	9

For the I^{CT} component importance, technology 5 is the most importance with an I^{CT} of $4.3*10^{-5}$ indicating that the capability SRL will be increased by $4.3*10^{-5}$ for each dollar spent on maturing this technology. When considering budget allocation from a perspective of maturing the capability, technology 5 is the most cost-effective component. The second and third most important components are technologies 2 and 6.

Analyzing the I^{LH} component importance in the same way, we found that technology 4, with an I^{LH} of $7.9*10^{-5}$ has the most impact on capability. The capability SRL will be upgraded by $7.9*10^{-5}$ for every labor-hour spent on maturing this technology. When considering effort allocation from a perspective of maturing the capability, technology 4 is the most effort-effective component. The second and third most important components are technologies 2 and 5.

Figure 3 puts together the component importance evaluation from applying the three IMs to the capability of the system. The left vertical axis is the scale for I^P, and the right for I^{CT} and I^{LH}. Black bars represent the I^P importance with respect to the importance factor of TRL/IRL for the corresponding component, white bars for the I^{CT} importance with respect to cost, and grey bar for the I^{LH} importance with respect to effort. The higher the bar, the more important is that component with respect to the importance factor represented by the corresponding color.

Therefore, for the scenario of increasing by one level, technologies 2, 5 and 6 are relatively more important than the other components with respect to TRL/IRL; technologies 5, 2 and 6 are relatively more important than others with respect to cost; technologies 4, 2 and 5 are relatively more important than others with respect to effort. When all three importance factors are considered simultaneously, technologies 2, 4 and 5 are comparably more important components for the capability development within the system. Furthermore, figure 3 implies, in general, that technologies are more important than integrations based on the current development maturity status of the system.

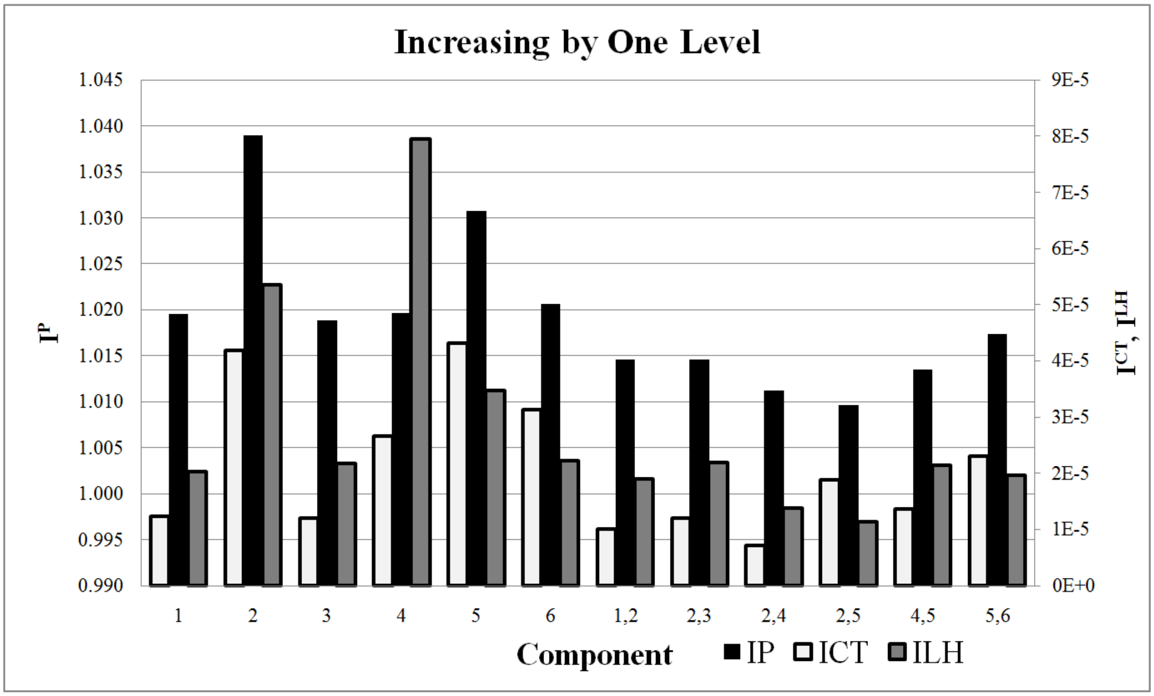

Figure 3 – Component Importance Comparison for Increasing by One level

4.2. Fully Maturing Components

For the scenario of increasing the component to its highest maturity level, table 4 shows the results for considering each importance factor. Technology 2 is the most important component for all three factors, indicating the significant impact of fully maturing this technology on the maturity of the capability of the system. Therefore, resources must be prioritized towards the development of technology 2 so as to ensure the satisfaction of the KPP of this system.

For the consideration of importance factor of TRL/IRL, technology 5 and integration 2, 3 are the second and third most important components. Technology 5 and integration 5, 6 are the second and third most important with respect to developmental cost. Technologies 4 and 5 are the second and third most important with respect to developmental effort. It should be noted here that some integrations also stand as very important components for maturing the capability to satisfy the KPP of the system.

Again, results of component importance calculation with respects to all three factors are plotted together in figure 4 for comparison purpose.

Table 4 – Component Importance for the Scenario of Increasing to the Most Maturity Level

	Component	Current Readiness Level	SRL	I^P	I^P Rank	I^{CT}	I^{CT} Rank	I^{LH}	I^{LH} Rank
Technology	1	7	0.646	1.0390	6	1.3E-5	9	2.7E-5	6
	2	**6**	**0.695**	**1.1171**	**1**	**4.4E-5**	**1**	**8.1E-5**	**1**
	3	7	0.646	1.0377	7	1.7E-5	6	2.1E-5	9
	4	7	0.647	1.0394	5	2.3E-5	4	4.9E-5	2
	5	7	0.660	1.0614	2	4.1E-5	2	4.5E-5	3
	6	7	0.648	1.0413	4	2.0E-5	5	2.7E-5	5
Integration	1,2	7	0.640	1.0291	10	9.6E-6	12	2.4E-5	7
	2,3	6	0.649	1.0437	3	1.5E-5	8	3.8E-5	4
	2,4	6	0.643	1.0337	9	1.2E-5	10	1.7E-5	11
	2,5	6	0.640	1.0288	11	9.8E-6	11	1.5E-5	12
	4,5	7	0.639	1.0270	12	1.7E-5	7	2.2E-5	8
	5,6	7	0.644	1.0347	8	3.1E-5	3	2.0E-5	10

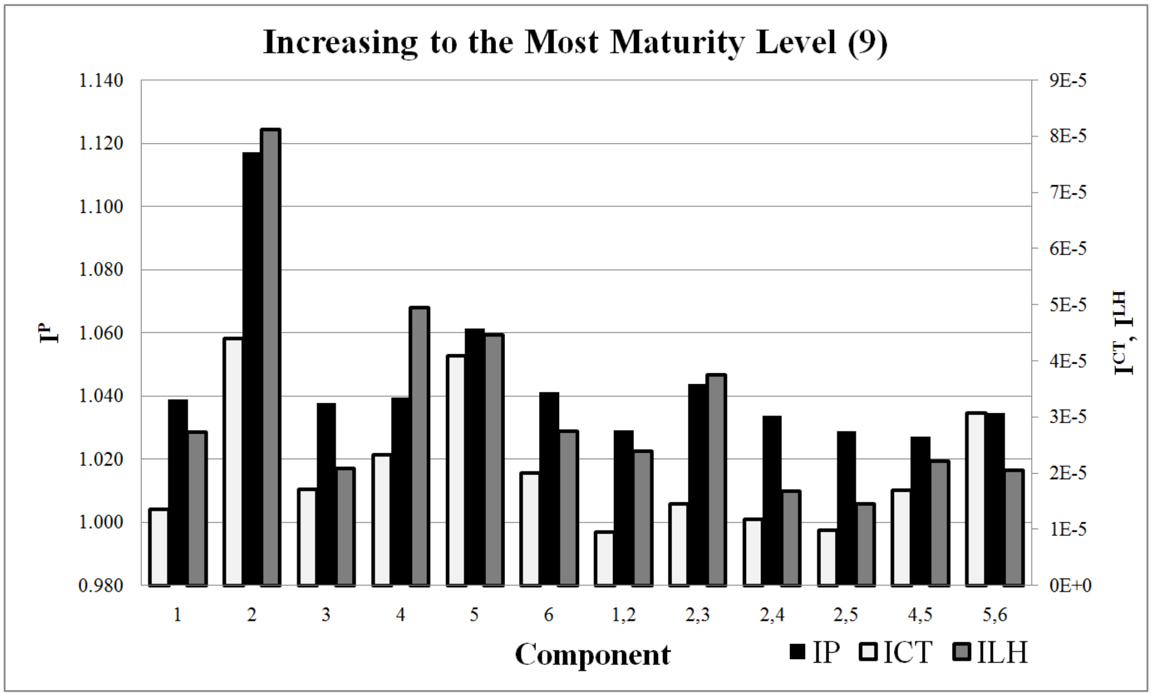

Figure 4 – Component Importance Comparison for Increasing to the Most Maturity level

5. Managerial Implications and Future Research

The complexity of developing systems that provide multiple functionalities and capabilities poses challenges to systems engineering managers. One of the challenges is how to predict the development progress of the KPPs, and another one is how to leverage the allocation of resources to develop the Key Performance Parameter of interest. Volkert (2009) suggested a method for predicting the KPP development progress with the use of SRL. Based on his method, this research proposes an approach to performing component importance analysis to identify the respective contributions of maturing components towards the maturity of a capability. Using their contributions as a guide, components can be ranked along importance. The ranking can then serve as a guide for allocating constrained available resources. With the component importance quantified and identified, managers can make use of the information to prioritize available resources to the more important components, and thus to satisfy the preset development expectations.

Since TRL/IRL, developmental cost and effort are the major factors for maturing a system, this research proposes three corresponding importance measures (IMs). The application of these IMs to a notional example shows that the components' importance can be identified and distinguished. It was found that for this particular example, technology components are generally more important than integrations. This may be a reflection of the fact that the development of technologies usually starts first and integrations are considered later. However, a lot of systems cannot wait for integration until all technologies are completely matured. Therefore, even development of integration may lag behind the development of technology, it is necessary to develop them in a parallel way. How the requirement of parallel development and implication from component importance analysis can jointly establish developmental strategy for determining resource allocation poses a research question for future research.

Another fact to be noted from the definition and application of these IMs is that the component importance is identified based on the current development maturity status. What will importance rank change if the components that were identified to be very important have been matured? Will a spiral methodology be needed to address component importance for the long system development life cycle? Future research is needed to investigate these problems.

6. Project Accomplishments

6.1. Publications

6.1.1. Journal

Tan, W., B. Sauser, and J.E. Ramirez-Marquez. (2011). Analyzing Component Importance in System Maturity Assessment. *IEEE Transactions on Engineering Management.* 58(2):275-294

Tan, W., J. Ramirez-Marquez, and B. Sauser. (2011). A Probabilistic Approach to System Maturity Assessment. *Systems Engineering.* 14(3):279-293

6.1.2. Conference Proceedings

Sauser, B., W. Tan, J. Ramirez-Marquez, R. Magnaye, D. Nowicki and A. Deshmukh. (2010). System Capability Satisficing in Defense Acquisition via Element Importance Measures. *Acquisition Research Symposium.* May 17-19, Monterey, CA

6.2. Presentations

"System Maturity Assessment for Managing Developmental Lifecycles." National Aeronautics and Space Administration – Johnson Space Center, Houston, TX, October 15, 2010 (invited)

"System Capability Satisficing in Defense Acquisition via Element Importance Measures." *7th Acquisition Research Symposium*, Monterey, CA, May 19, 2010

6.3. Awards

Davis Memorial Award in Research Excellence

"Systems Maturity Assessment via Systems Development Optimization" – This award is selected from across the university for the research that has had the greatest impact in the previous year.

Best Student Paper in the School of Systems and Enterprises

Awarded to Weiping Tan for his paper Analyzing Component Importance in System Maturity Assessment. *IEEE Transactions on Engineering Management.* 58(2):275-294

7. Knowledge Transfer to Industry/Government

We have continued to maintain a rich knowledge transfer relationship with industry and government. The following are some examples:

- U.S. Army Armament Research Development and Engineering Center (ARDEC) – ARDEC has implemented the SRL method on an innovative lightweight vehicle program that has allowed them to assess current development risks as well as create development plans for program reviews.
- Lockheed Martin (LMCO) – LMCO has piloted the SRL on four projects and based on its success and lessons learned from the application they are now using it on a major weapons program. In addition, they used internal corporate funds to create an SRL software tool that has allowed them to calculate an SRL and evaluate development risks for program reviews.
- Northrop Grumman (NGC) – NGC has continued to use SRL in support of their efforts with PMS420 and incorporated the methods into their own internal tool for program assessment.

8. Other Related Activities:

8.1. Web Page

From the birth of this research, we have believed in an open academic model of sharing our research outcomes in the broadest sense possible. Thus, we have created a web site, http://www.SysDML.com, for the distribution of our research results. At this web site you will find: Research Overview; Publications; Research Projects; Tools; and Who We Are.

8.2. Student Research Supported/Supervised

Our funding from the Naval Postgraduate School has afforded us the privilege to support one Ph.D. student to assist in the execution of this research. Besides, it has also allowed us the ability to attract graduate students to pursue related and supportive research. These students are:

Ivonne Donate. *Ph.D. Student*. "Evolutionary Lifecycle Assessment for Disruptive Technology Integration"

Ryan Gove. *Ph.D. Student.* (currently supported by Lockheed Martin) "Model Based Systems Engineering for Effective System Maturity Assessment"

Samuel Russell. *Ph.D. Student.* (currently supported by NASA) "The Thermodynamics of System Development: A Mechanistic Approach to System Maturity Assessment"

Matin Sarfaraz. *Ph.D. Student.* (currently supported by the *Innovation and Entrepreneurship Graduate Fellowship*) "Systems Engineering Artifact Correlation to Systems Maturity Assessment"

Weiping Tan. *Ph.D. Student*. (currently supported by NPS) "Methodologies for Component Importance Analysis in Multi-Function, Multi-Capability System Developmental Maturity Assessment."

Joseph Uzdzinski. (currently supported by Lockheed Martin) "System Maturity Assessment for Dynamic Interoperability in Complex Systems"

8.3. Student Projects Supervised

Within the School of Systems and Enterprises at Stevens Institute of Technology, students are encouraged to complete a 3-credit special problems project as part of their course requirements. Because of the success of this research, we have been able to attract a number of students to pursue projects related to SRL and related topics. Here is a list of these students and projects:

Bruich, G. (2010). "Development of Readiness Level Assessments for Risk Management Throughout a Project Life Cycle." M.S. Special Problems in Systems Engineering.

Donate, I. (2010). "Determination of Disruptive Technologies and Their Effects on Trusted Systems Integration." Ph.D. Special Problems in Systems Engineering.

Russell, S. (2010). "Long Life Battery and Lithium Ion Battery Charger for Extravehicular Mobility Unit: Project Development and Systems Maturation Analysis." Ph.D. Special Problems in Systems Engineering.

9. Bibliography

Crawley, E., O. de Weck, et al. (2004). The Influence of Architecture in Engineering Systems. Engineering Systems Monograph, ESD Architecture Committee: 1-29.

DAU (2009). Manual for the operation of the joint capabilities integration and development system (JCIDS). Defense Acquisition University.

Dillon, R. L., M. E. Pate'-Cornell, et al. (2005). "Optimal Use of Budget Reserves to Minimize Technical and Management Failure Risks During Complex Project Development." IEEE Transactions on Engineering Management 52(3): 382-395.

Forbes, E., R. Volkert, et al. (2009). Implementation of a Methodology Supporting a Comprehensive System-of-systems Maturity Analysis for Use by the Littoral Combat Ship Mission Module Program. 6th Annual Acquisition Symposium. Monterey, CA.

Galway, L. A. (2007). Subjective Probability Distribution Elicitation in Cost Risk Analysis: A Review, RAND Corporation.

Gorod, A., M. DiMario, et al. (2009). "“Satisficing” System of Systems (SoS) using Dynamic and Static Doctrines." International Journal of System of Systems Engineering (in review).

Jain, R., A. Chandrasekaran, et al. (2008). "Exploring the Impact of Systems Architecture and Systems Requirements on Systems Integration Complexity." IEEE Systems Journal **2**(2): 209-223.

Magnaye, R. (2010). Earned Readiness Management for Scheduling, Monitoring and Evaluating the Development of Systems. PhD, Stevens Institute of Technology.

Magnaye, R., B. Sauser, et al. (2009). Using a System Maturity Scale to Monitor and Evaluate the Development of Systems. 6th Annual Acquisition Symposium. Monterey, CA.

Magnaye, R., B. Sauser, et al. (2010). "System Development Planning Using Readiness Levels in a Cost of Development Minimization Model." Systems Engineering **13**(4): 311-323.

Magnaye, R., B. Sauser, et al. (2009). Using a system maturity scale to monitor and evaluate the development of systems. Sixth Annual Acquisition Research Symposium. Monterey, California, Naval Postgraduate School. 1: 95-112.

Maier, M. W. (1998). "Architecting principles for system-of-systems." Systems Engineering **1**(4): 267-284.

Sauser, B. and J. Ramirez-Marquez (2009). "System Development Planning via System Maturity Optimization." IEEE Transaction on Engineering Management **56**(3): 533-548.

Sauser, B., J. Ramirez-Marquez, et al. (2008). "A System Maturity Index for the Systems Engineering Life Cycle." International Journal of Industrial and Systems Engineering **3**(6): 673-691.

Simon, H. A. (1996). The Sciences of the Artificial. Cambridge, MIT Press.

Volkert, R. (2009). "Notional assessment methodology for KPP accomplishment in a SoS proposed methodology for measuring performance progress within a system of systems (SoS)." SSC-Pacific 10 Sept 2009, Version 1.4.