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System Capability Satisficing in Defense Acquisition via Component Importance Measures

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Abstract

With support from the Naval Postgraduate School and government/industry partnerships, the Systems Development & Maturity Laboratory (SD&ML) at Stevens Institute of Technology has successfully developed a systems maturity measure (i.e., System Readiness Level [SRL]) and supporting optimization models for inclusion in a Systems Earned Readiness Management methodology. We now believe it is time to spiral back to the beginning of the original developments of the SRL to enhance fundamental capabilities of assessing system maturity in order to address some recurring issues to its application. That is, systems have variants in their 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 paper enhances previously developed methodologies by addressing this fundamental question, “What are the trades-off in functionality, capability, cost, schedule, and maturity that will allow the deployment of a less-than-fully mature system that can still satisfy specific needs of the warfighter?” To answer this question, we formulate a capability-specific SRL and use multi-dimensional component importance analysis to identify which components of the system should receive the most application of resources when they are constrained.



Introduction

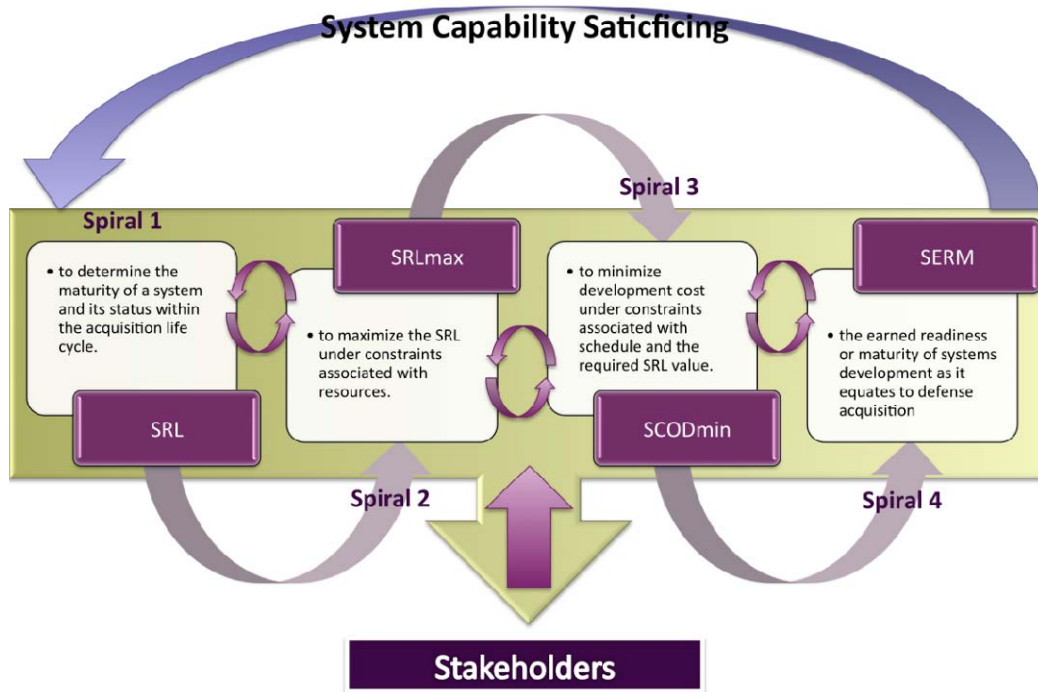
With the support of the Naval Postgraduate School (NPS) and government/industry partnerships, the Systems Development & Maturity Laboratory (SD&ML) at Stevens Institute of Technology has successfully:

1. Developed a methodology for determining a system's maturity using the System Readiness Level (SRL) scale (Sauser et al., 2008);
2. Used SRL to formulate two optimization models—SRLmax (Sauser, Ramirez-Marquez, et al., 2008) and SCODmin (Magnaye et al., 2010)—for predicting cost, schedule, and maturity performance, and
3. Proposed a methodology that combines items a and b into an approach called Systems Earned Readiness Management (SERM) (Magnaye et al., 2009).

During the research that has fostered these developments, the SD&ML has maintained a spiral development approach where we have worked closely with industry and government to refine and implement our research in order to maintain its relevance and rigor. The outputs of our research to date have focused on the analysis of systems that were meant to deliver a single capability. We now believe it is 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 a situation where the system under development is intended to be multi-functional and is needed sooner rather than later by the warfighter.

Such systems 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 things in the field. Thus, we are confronted with the situation where complexity is increased by multi-functionality while the development time available is shorter.





Research Spiral Development Plan

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 US 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 System Readiness Level (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. However, although Volkert’s approach can provide timely data about the progress of the system, 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.



This paper proposes such 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. The paper reviews 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. The paper ends with the conclusion the exploration of future research.

Methodology for Measuring Achieved Capability

In the procurement and management of the Mission Packages (MPs) for a system, the designated program office and manager, such as the PMS420 for the Littoral Combat Ship (LCS) program, requires insight into the progress of the Development Program Offices’ (DPOs) constituent mission systems and knowledge about where they stand in terms of providing anticipated performance, especially the KPPs of the system. These insights are critical for requisite oversight and for management of development risks. However, the issue is how program managers accurately can predict the ability of the system to satisfy KPPs while development and integration are proceeding.

Previously, DPOs were able to use Technical Performance Measures (e.g., Technology Readiness Levels [TRL]) to monitor the developmental status of specific technologies. With the development of complex multi-capability systems, such as the LCS, understanding the status of technologies are no longer sufficient for managers to gain the requisite level of knowledge on the extent to which the KPPs, as designated by the Capability Development Document, can be accomplished for the designated system. Volkert (2009) has pointed out the compounding reasons:

1. The capabilities from the individual constituent mission systems are often being modified or utilized in manners different than that specified in their original requirement set. Thus, their known/predicted performance may be different when used in a MP SoS.
2. The constituent mission systems (capabilities) being developed by the DPOs are, in some cases, still maturing. This impacts the ability to determine KPP performance in two ways;
 - a. It drives an incremental fielding of capabilities by PMS 420, meaning the solution set for accomplishing (full or partially) a KPP will vary over time.
 - b. The capability delivered by the DPO may not provide the amount of performance anticipated/predicted by PMS 420 due to developmental challenges within the DPOs program.
3. The combination of capabilities available to choose from means that the usage and contribution of an individual capability to the performance of a KPP can vary depending upon the operational employment of the system within a SoS.

Therefore, for predicting the achieved proportional capability in a complex system, Volkert proposed an approach. Here we re-write his formula with minor changes:

$$T_{C(1,2,\dots)n} = \omega_n * \alpha_{C(1,2,\dots)}$$



Where $\alpha_{C(1,2,\dots)}$ represents the maximum level of performance capability the combination of technology packages (1, 2, ...) is expected to meet/provide. ω_n represents the weighting factor representing the proportional level of performance expected at the maturity stage of n . $T_{C(1,2,\dots)n}$ thus represents the achieved performance level of the capability which can contribute to the satisfaction of the KPP. The value of α would be expressed in the units of performance defined by the KPP while ω would be unit less.

For ω_n , Volkert suggested the use of the System Readiness Level (SRL) for the capability at that time. In order to differentiate this with the original SRL definition that is designed for assessing the development maturity of the whole system, we introduce the new notion of a Capability System Readiness Level (SRL_C) to measure ω_n which represents the readiness of the Capability comprised by a specific combination of technologies and the integrations among them. For simplicity, for the rest of this paper, whenever SRL is mentioned, it means the SRL_C.

Mathematically, the procedure for calculating the SRL_C is as follows (assuming the subset of n technologies from within the system, which will have to be integrated to deliver a capability C):

- a. Normalize the [1, 9] scale original TRLs and IRLs into (0,1) scale, and denote them by matrices:

$$\mathbf{TRL} = \begin{bmatrix} TRL_1 \\ TRL_2 \\ \dots \\ TRL_n \end{bmatrix} \xrightarrow{\text{Normalize}} \mathbf{TRL}' = \frac{\mathbf{TRL}}{9} = \begin{bmatrix} TRL'_1 \\ TRL'_2 \\ \dots \\ TRL'_n \end{bmatrix};$$

$$\mathbf{IRL} = \begin{bmatrix} IRL_{11} & IRL_{12} & \dots & IRL_{1n} \\ IRL_{21} & IRL_{22} & \dots & IRL_{2n} \\ \dots & \dots & \dots & \dots \\ IRL_{n1} & IRL_{n2} & \dots & IRL_{nn} \end{bmatrix} \xrightarrow{\text{Normalize}} \mathbf{IRL}' = \frac{\mathbf{IRL}}{9} = \begin{bmatrix} IRL'_{11} & IRL'_{12} & \dots & IRL'_{1n} \\ IRL'_{21} & IRL'_{22} & \dots & IRL'_{2n} \\ \dots & \dots & \dots & \dots \\ IRL'_{n1} & IRL'_{n2} & \dots & IRL'_{nn} \end{bmatrix}$$

Where $IRL_{ij} = IRL_{ji}$. When there is no integration between two technologies, an original IRL value of 0 is assigned; for integration of a technology to itself, an IRL value of 9 is used, that is original $IRL_{ii} = 9$.

- b. ITRL matrix is the product of TRL and IRL matrices:

$$\mathbf{ITRL} = \mathbf{Norm} \times \mathbf{IRL}' \times \mathbf{TRL}'$$

That is,



$$\begin{bmatrix} ITRL_1 \\ ITRL_2 \\ \dots \\ ITRL_n \end{bmatrix} = \begin{bmatrix} 1/m_1 & 0 & \dots & 0 \\ 0 & 1/m_2 & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & 1/m_n \end{bmatrix} \times \begin{bmatrix} IRL'_{11} & IRL'_{12} & \dots & IRL'_{1n} \\ IRL'_{21} & IRL'_{22} & \dots & IRL'_{2n} \\ \dots & \dots & \dots & \dots \\ IRL'_{n1} & IRL'_{n2} & \dots & IRL'_{nn} \end{bmatrix} \times \begin{bmatrix} TRL'_1 \\ TRL'_2 \\ \dots \\ TRL'_n \end{bmatrix}$$

$$= \begin{bmatrix} (IRL'_{11} TRL'_1 + IRL'_{12} TRL'_2 + \dots + IRL'_{1n} TRL'_n) / m_1 \\ (IRL'_{21} TRL'_1 + IRL'_{22} TRL'_2 + \dots + IRL'_{2n} TRL'_n) / m_2 \\ \dots \\ (IRL'_{n1} TRL'_1 + IRL'_{n2} TRL'_2 + \dots + IRL'_{nn} TRL'_n) / m_n \end{bmatrix}$$

Where m_i is the number of integrations of technology i with itself and all other technologies, and **Norm** is to normalize the SRL_i from $(0, m_i)$ scale to $(0, 1)$ scale for consistency; i.e., **Norm** = $diag[1/m_1, 1/m_2, \dots, 1/m_n]$.

a. SRL is the average of all ITRLs:

$$SRL = \frac{ITRL_1 + ITRL_2 + \dots + ITRL_n}{n} = \frac{\sum_{i=1}^n ITRL_i}{n}$$

See Sauser et al. (2008; 2010) for a more detailed description of how to calculate and apply the SRL.

Component Importance Measures

A system has variants in its physical architecture that realize certain functionality and capability. A systems engineer or acquisition manager would make trade-off decisions to find a satisficing solution for a deployable system. Thus, in order to satisfy Key Performance Parameter during the development of the system, this paper proposes to perform component importance analysis by introducing three Importance Measures (IMs) for System Capability Satisficing (SCS) with respect to: TRL/IRL, cost, and labor-hours.

SCS with Respect to TRL/IRL (I^P)

The IM of TRL/IRL evaluates the impact of a change in the development maturity of an component (i.e. technology or integration) on system development maturity. That is, IM measures the change of the SRL when the TRL or IRL of a specific component changes from its current value to a target value. For example, let $SRL(TRL, IRL)$ denote the current SRL of the system, and $SRL(TRL, IRL | TRL_i = \overline{TRL}_i)$ ($SRL(TRL, IRL | IRL_{ij} = \overline{IRL}_{ij})$) 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 current maturity values. The definition of IM with respect to TRL/IRL (I^P) is as follows:



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

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

I^P implies the effect of change in the readiness level of a given component. A component for which the variation of the readiness level results in the largest variation of the system SRL has the highest importance.

SCS with Respect to Cost (I^{CT})

Zhang et al. (2007) suggests that classical component importance analysis ignores cost, and states that it is unrealistic to evaluate the importance of components without considering the cost. Hereby, for SRL component importance analysis, we propose to consider the economic factor. This is reasonable by noting that there are always situations where system developers have to make the investment decisions based on the comparison of the immediate return on the investment of dollars needed to mature components. Presumably, especially with a tight budget, developers allocate resources to the component that can result in the highest system maturity. Therefore, we propose I^{CT} as an IM that takes into account the cost for maturing components to facilitate such comparisons. Since the cost to mature different components varies and improvements in different components have different effects on SRL, the IM that takes into account the development cost serves as a baseline to compare the investment returns from different components. Let

$CT_i = CT_{\overline{TRL}_i} - CT_{TRL_i}$ denote the associated development cost for maturing TRL_i from its current readiness level to a target level \overline{TRL}_i , and $CT_{ij} = CT_{\overline{IRL}_{ij}} - CT_{IRL_{ij}}$ denote the associated development cost from maturing IRL_{ij} from its current readiness level to a target level \overline{IRL}_{ij} . The formula to calculate the I^{CT} is as follows:

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

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

I^{CT} implies the effect of the cost to mature a given component on SRL, and the component whose readiness improvement from the investment results in the largest gain of SRL has the highest importance.

SCS with Respect to Labor-Hours (I^{LH})

Besides the consideration of cost, there are other situations (e.g., when only certain labor-hours are available) where developers care more about the return on the effort needed



to improve components. Therefore, we propose another importance measure (I^{LH}) that takes into account the associated labor-hours to upgrade the component readiness level in order to mature the SRL. Let $LH_i = LH_{\overline{TRL}_i} - LH_{TRL_i}$ denote the associated development labor-hours for developing TRL_i from its current status to a target level \overline{TRL}_i , and $LH_{ij} = LH_{\overline{IRL}_{ij}} - LH_{IRL_{ij}}$ denote the associated development labor-hours for developing IRL_{ij} from its current status to a target level \overline{IRL}_{ij} , then the formula for I^{LH} is as follows:

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

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

I^{LH} implies the effect of the labor-hours or effort to mature a given component on SRL. The component whose readiness improvement from the investment of labor-hours results in the largest gain of SRL has the highest importance.

Notional Example

The following example was used in Forbes 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 paper, 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 et al., 2009), this value indicates that the capability is undergoing the Engineering and 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.



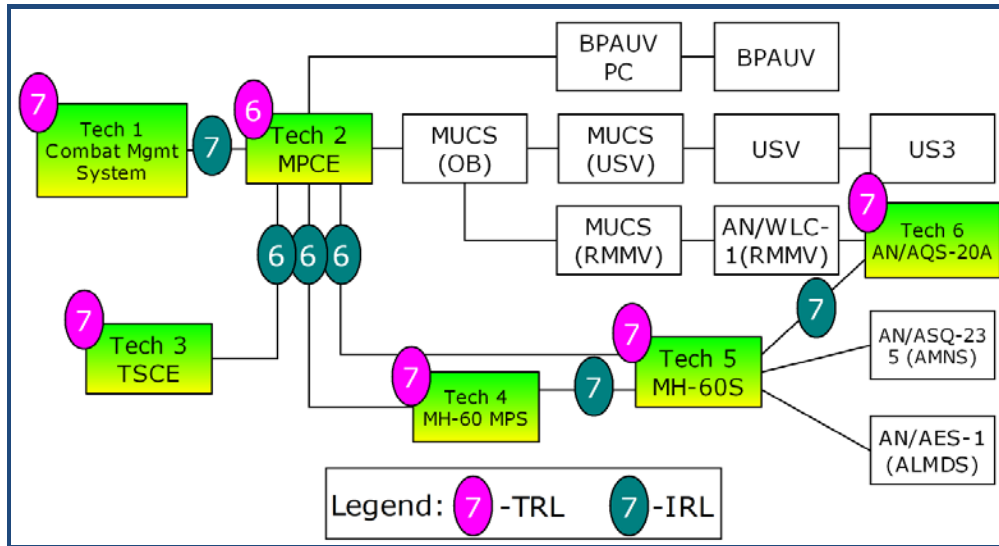


Figure 1. Diagram of a System with Components Shaded for the KPP

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 thousands 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 IRL Upgrade

TRL	Tech 1		Tech 2		Tech 3		Tech 4		Tech 5		Tech 6	
	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
SSum	\$1,800	889	\$1,654	897	\$1,377	1123	\$1,051	495	\$933	855	\$1,281	938



Table 2. Resource Consumption for IRL Upgrade

ITRL	1,2		2,3		2,4		2,5		4,5		5,6	
	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
SSum	\$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 $\overline{IRL}_{ij} = 9$.

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.



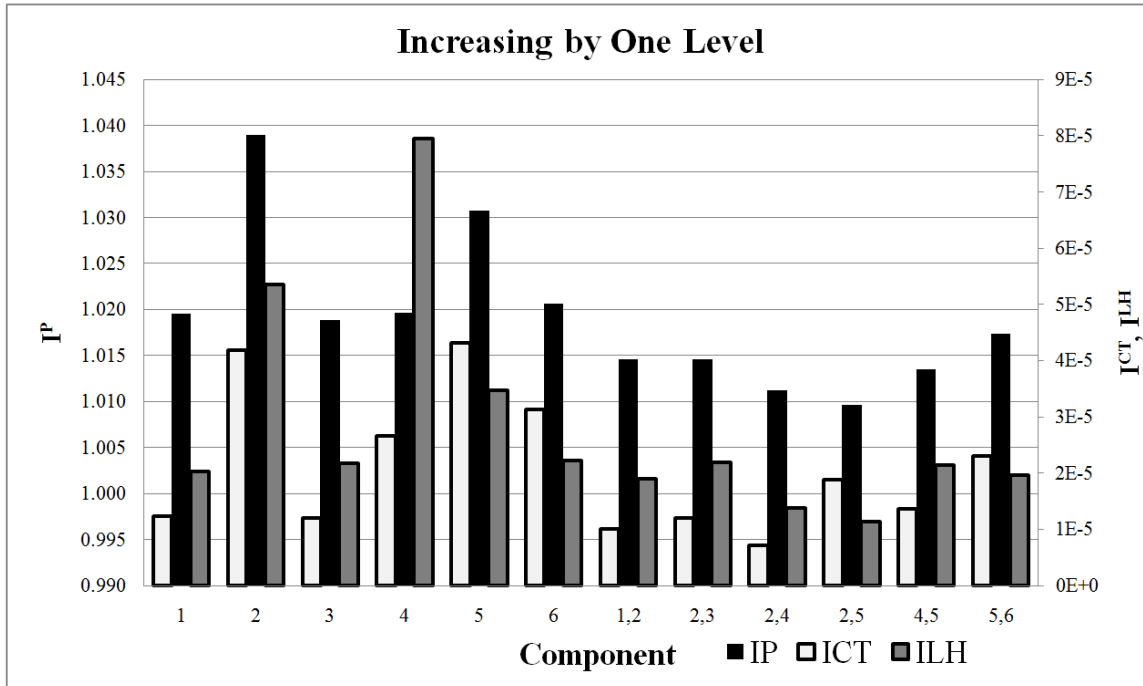


Figure 2. Component Importance Comparison for Increasing by One level

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 purposes.



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

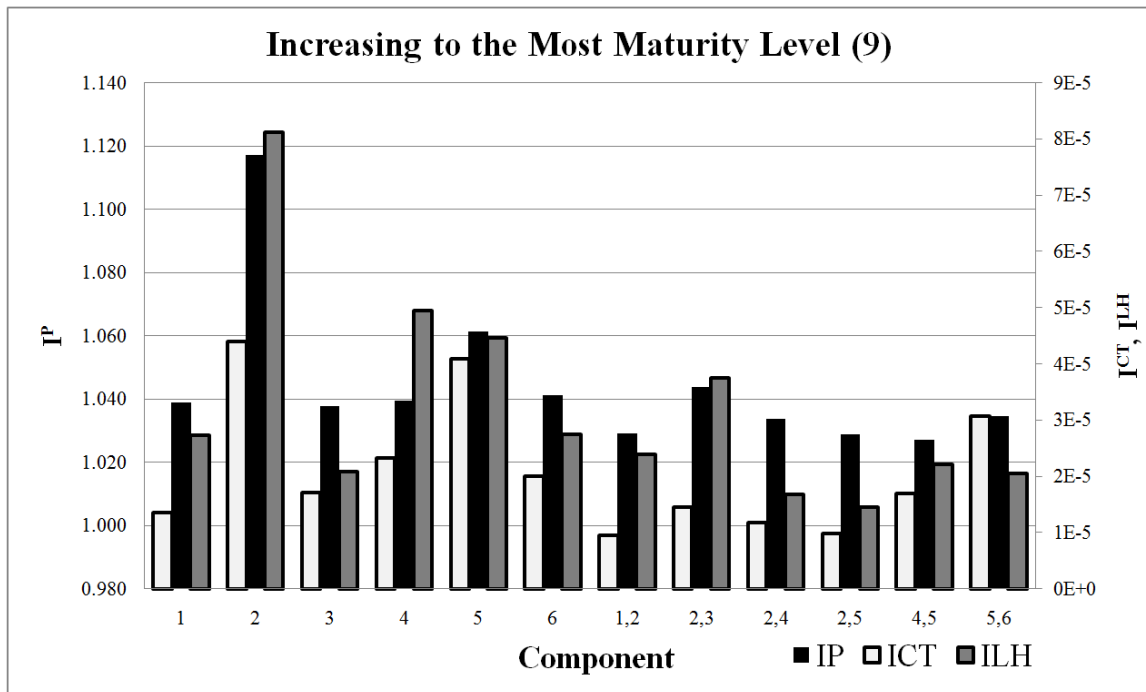


Figure 3. Component Importance Comparison for Increasing to the Most Maturity level



Conclusion

The complexity of developing systems that provide multiple functionalities and capabilities poses challenges to systems engineering managers. One of 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 paper proposes an approach for performing component importance analysis to identify the contributions of maturing components towards the maturity of a capability. Using their contributions as a guide, components can be ranked. The ranking can then serve as a guide for allocating resources when they are constrained. 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, and this paper 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 though 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 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.

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