2009-04-01

Dynamic Multipoint Optimization Application to Corporate Portfolio Management

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http://hdl.handle.net/10945/33368

NPS-AM-09-018

EXCERPT FROM THE PROCEEDINGS

OF THE

SIXTH ANNUAL ACQUISITION RESEARCH SYMPOSIUM

DYNAMIC MULTIPOINT OPTIMIZATION APPLICATION TO CORPORATE PORTFOLIO MANAGEMENT

Published: 22 April 2009

by

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6th Annual Acquisition Research Symposium
of the Naval Postgraduate School:

Volume I:
Defense Acquisition in Transition

May 13-14, 2009

Prepared for: Naval Postgraduate School, Monterey, California 93943

ACQUISITION RESEARCH PROGRAM
GRADUATE SCHOOL OF BUSINESS & PUBLIC POLICY
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The research presented at the symposium was supported by the Acquisition Chair of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

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Dynamic Multipoint Optimization Application to Corporate Portfolio Management

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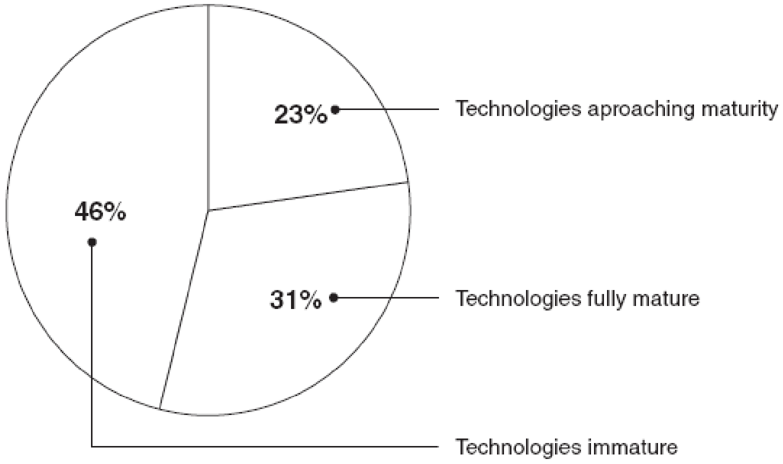
Abstract

There are many challenges facing complex system development in today's environments. Systems have become far more complex, operating in a net-centric environment, with ever-increasing threats to system security posing a challenging design and development task for program managers and systems engineers. We have seen an increasing number of major DoD system development programs experiencing difficulties and failing to achieve their intended goals successfully. Reasons for these difficulties and failures include both technical and programmatic type issues. At the top of the list has been the failure to properly assess the technical maturity of complex systems during system development, leading to cost overruns, program delays, program cancellations, and unacceptable system performance. Recently introduced corporate or program portfolio management ideologies supporting system development in the DoD have shown some promise in providing a more dynamic approach to project management. Advantages include the ability to make dynamic changes to the mixture of technology investments in a development program and increased probability of attaining the desired end-state goals at planned cost and on schedule. The programs need to consider external technology shifts and ensure the programs and their technology investments stay ahead of the critical "S-Curve." The dynamics of program management, including effective decision-making, also play an important role in ensuring end-goal success. Missing from corporate portfolio management are good maturity metrics to assess the system development process throughout the lifecycle. This paper addresses the application of system maturity

metrics and decision theory ideologies to a portfolio management framework supporting multi-technology-based system development. The application of previous research performed by the Stevens Institute of Technology in the area of system maturity metrics, including "systems readiness levels," will be leveraged and applied to existing problem sets—resulting in a dynamic decision-making process.

Introduction

As we look at current lifecycle system development, we see an increasing number of major Department of Defense (DoD) system development programs experiencing difficulties and failing to achieve their intended goals successfully. Reasons for these difficulties include both technical and programmatic type issues that are experienced throughout the system development lifecycle. At the top of the list has been the failure to properly assess the technical maturity of these complex systems during system development, leading to cost overruns, program delays, program cancellations, and unacceptable system performance. Evidence of this is seen in the often cited Government Accountability Office (GAO) report that reviewed and analyzed major defense acquisition programs. This report concluded that the causes and reasons for failure in major defense acquisition programs were due to a majority of programs failing to meet a TRL 7 level before entering the system development phase (1999). These findings were echoed again in a more recent GAO report that showed an increase from the previous year in the number of programs with immature technologies still maturing technologies late into the system development and production lifecycles (2008). It is troubling that nine years after the original report, we are still reporting the same types of problems with these acquisition programs. The evidence is overwhelming and shows that serious attention to the application of lifecycle system maturity metrics is essential to reversing the present trend in major acquisition program failures. Figure 1 below shows the maturity levels of critical technologies for DoD programs.



Source: GAO analysis of DOD data.

Figure 1. Maturity Levels of Critical Technologies for DoD Programs

System Development Challenges

There are many challenges facing system development in today’s fast-paced environments. Systems have become more complex, operating in a net-centric environment, with ever increasing threats to system security posing a challenging design and development task for program managers and systems engineers. Complicating this scenario are the added constraints of budget, shorter development lifecycles, and available experienced workers. These demands have further increased the pressure on program managers and systems engineers to achieve expected success in the areas of technical performance, budget, and schedule. Further concerns are the failure of developers to make the necessary decisions to integrate newer technologies, and they continue to invest in existing technologies that produce no added benefits while the rapidly changing technological world moves on. This is known as the “S Curve” effect and is illustrated in Figure 2 below. These developers face the risk and unintended consequences of becoming irrelevant quickly by not reacting fast enough to these external forces (Christensen, 2003).

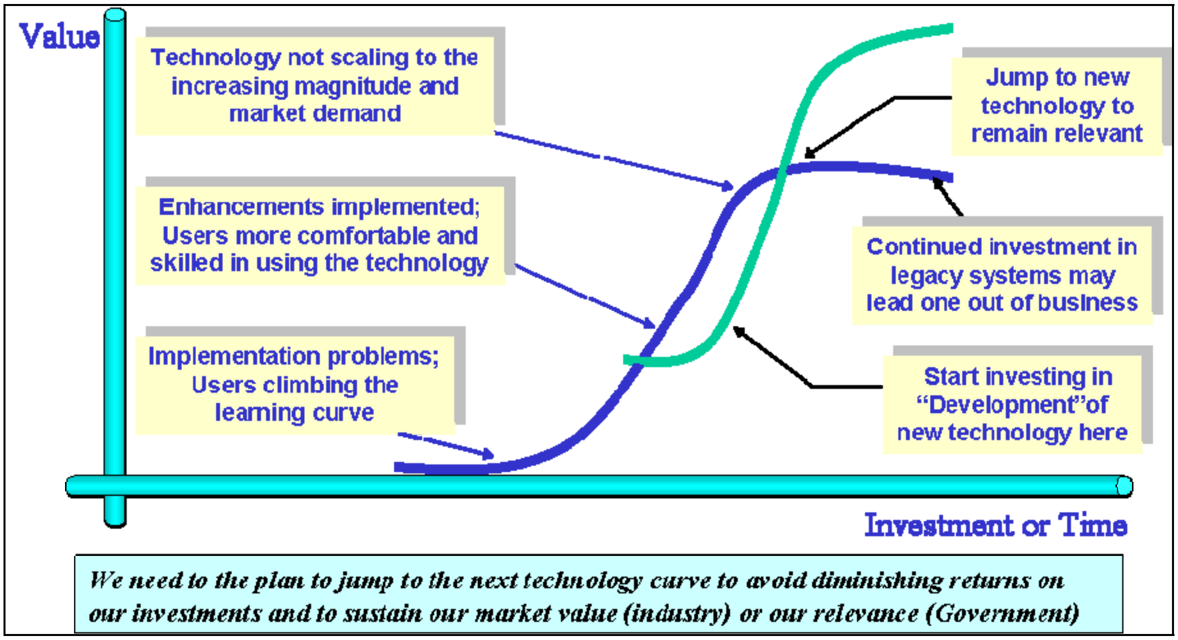


Figure 2. Technology S-Curve

Need for an Integrated Environment

For success in today’s accelerated, system acquisition development programs, we need to ensure the existence of an integrated environment that consists of a management process that is guided by a defined lifecycle framework and at the same time, a maturity metric process that maps to this same lifecycle framework and supports the management process. This integrated environment allows for maximum interaction between these domains to support the manager’s decision-making process, whether the organization is small, medium, or large. This integrated environment will consists of the following three components: a defined accepted lifecycle framework, a realistic portfolio management process, and metrics to include financial, technical, and technology maturation. Since this paper is looking at DoD based programs, we will refer to the *DoD 5000.2* lifecycle framework. For the system maturity metrics, we can apply the System Readiness Level (SRL) model, developed by Stevens Institute of Technology, to a portfolio management based environment, which is becoming more popular in DoD programs.

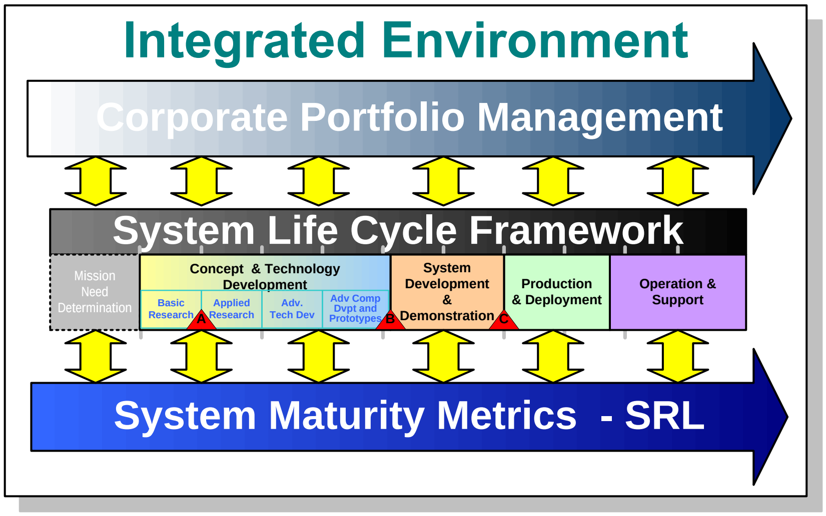


Figure 3. Integrated Environment

What is a Lifecycle Framework?

A lifecycle is an inherent part of all system development and encompasses a framework that that defines all the necessary systems engineering phases and lifecycle activities that are necessary to support system development production and post development activities. Within the lifecycle are decision points or milestones when technology, performance, and schedule are assessed (INCOSE, 2006). In its simplest definition, a lifecycle is described as “The system or product evolution beginning with the identification of a perceived customer need, addressing development, test, manufacturing, operation, support, and training activities, continuing through various upgrades or evolutions, until the product and its related processes are disposed of” (Kossiakoff & Sweet, 2003). Obvious in Kossiokoff and Sweet’s definition is the existence of least three stages, the conceptual development, engineering development, and post development. Within each stage are the activities described in Kossiakoff and Sweet’s lifecycle definition. In the real world, there are some subtle variations in the comparison of lifecycle models across the different system development domains. This paper will focus on the DoD’s “DoD 5000 Acquisition Lifecycle Framework” model, which has benefited DoD acquisition based programs successfully by provided a basic common system development lifecycle framework describing all the necessary processes and activities needed to support system acquisition.

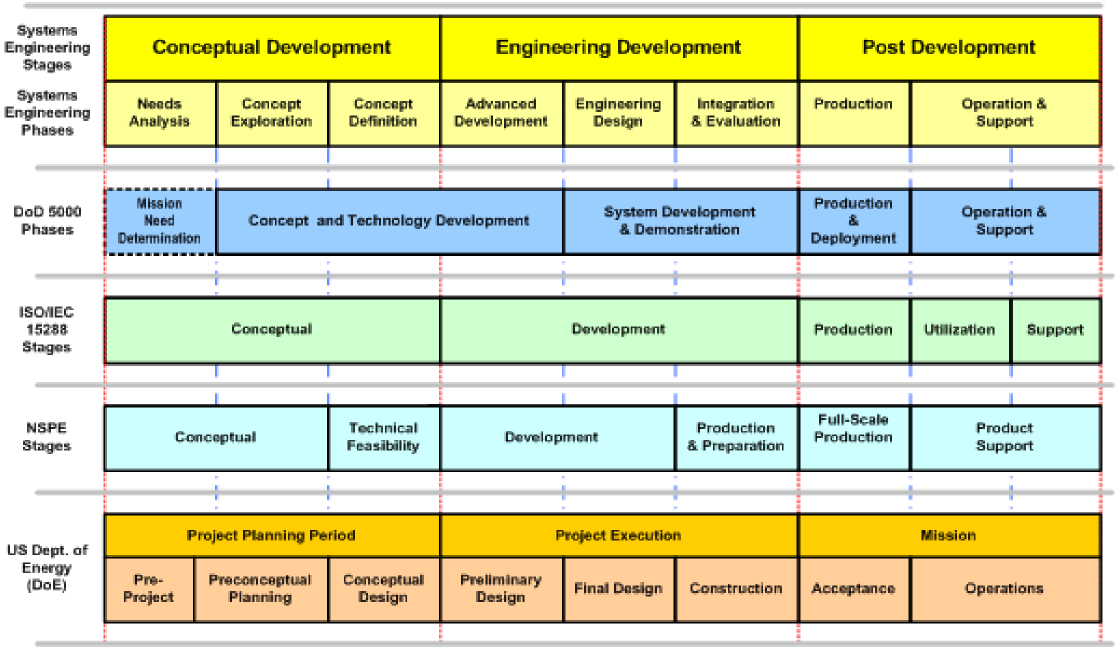


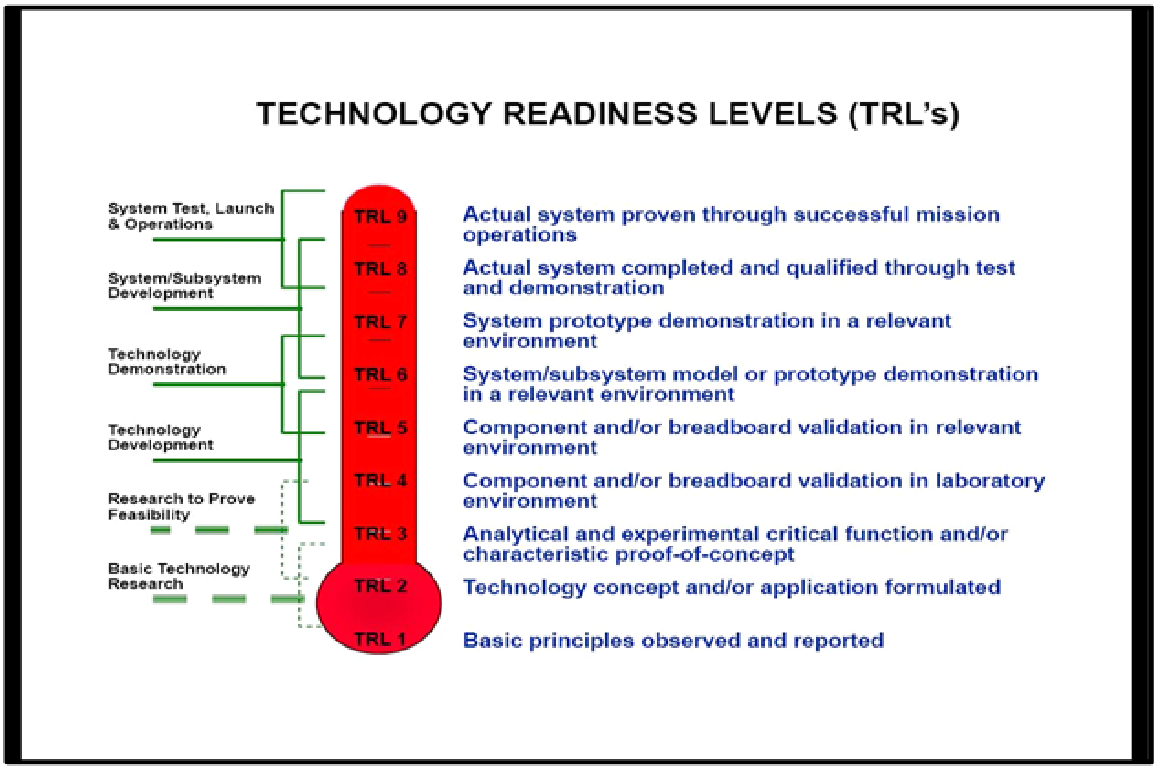
Figure 4. Lifecycle Model Comparisons

What are Maturity Metrics?

In the past, we have made considerable improvements in the tracking and monitoring of program metrics focusing on the financial status through improved software IT systems. We have also done well in metrics associated with performance testing of systems. Missing is the lack of better metrics supporting support the lifecycle assessment of system maturity. Technology maturity is a main area of concern among developers as many system development efforts have failed because of the inability to assess the system technology's state of progress or development. This can often lead to failure of a technology to perform in a system or be integrated into a system. The need to assess the maturity level of the technologies and systems in the development process becomes a critical factor in the decision-making process throughout the system development lifecycle.

What Maturity Metrics Do We Have?—Technology Readiness Level (TRL)

The need to assess the maturity level of the technologies and systems in the development process becomes a critical factor in the decision-making process throughout the system development lifecycle. This has led to the introduction of a metrics assessment process supporting the assessment of maturity of different types of technologies used in a system development program. One of these metrics, the Technology Readiness Level (TRL) was originally introduced by the National Aeronautics and Space Administration (NASA) for the development and support of their space mission programs and later adapted for use by other agencies, including the DoD. The TRL describes the maturity level of that technology. There are nine TRL levels used to describe the maturity of a particular technology, starting from a TRL 1, in which basic principles have been observed and reported, and progressing to a maximum of TRL 9, in which the technology has been proven in a successful operational test (Mankins, 1995).



TECHNOLOGY READINESS LEVELS (TRL's)

System Test, Launch & Operations

System/Subsystem Development

Technology Demonstration

Technology Development

Research to Prove Feasibility

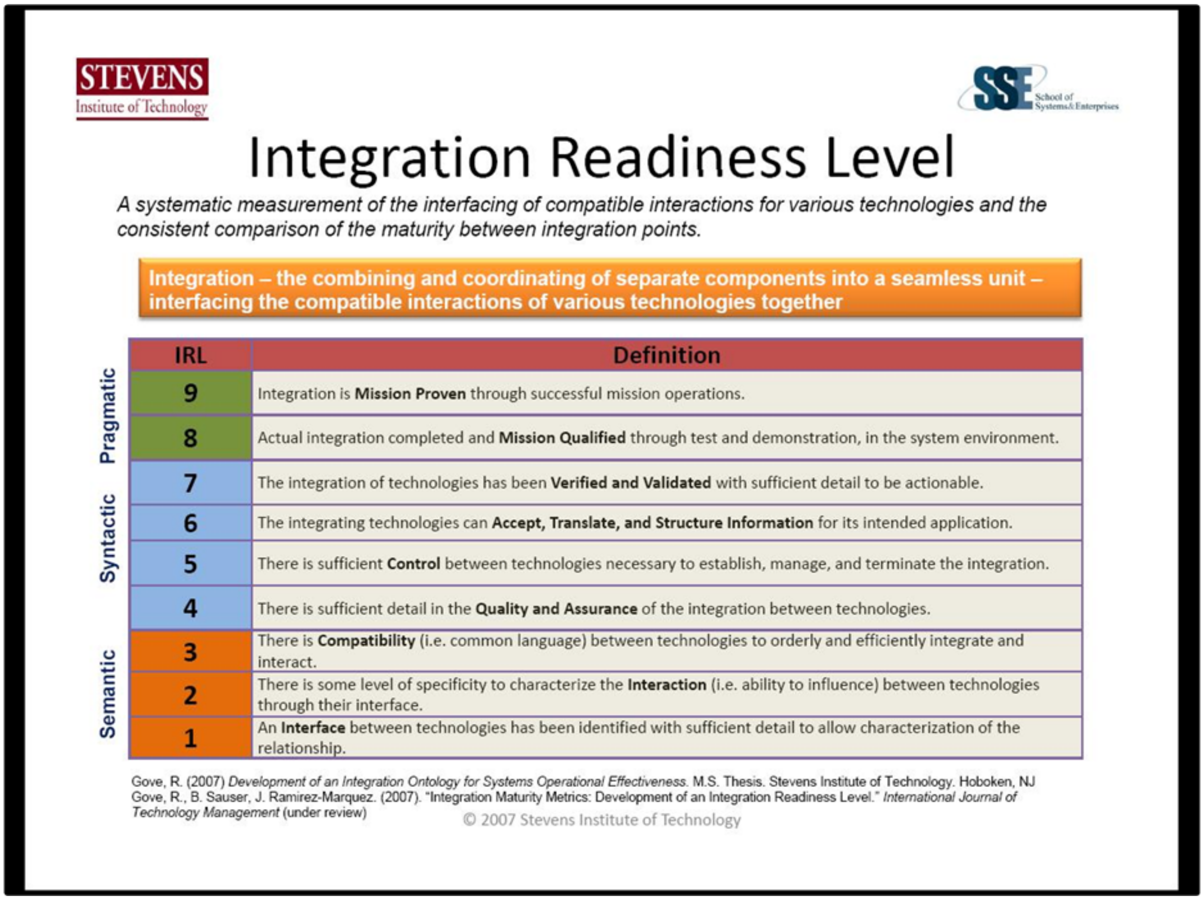
Basic Technology Research

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

Table 1. NASA's Technology Readiness Levels Summary

What's New in Maturity Metrics—System Readiness Level (SRL)

While the Technology Readiness Level (TRL) works well in providing a common maturity assessment metric in system development involving individual technologies, it does not address those projects with systems involving multiple technologies. The introduction and application of the System Readiness Level (SRL) provides a potential solution to this problem (Sauser, Verma, Ramirez-Marquez & Gove, 2006). The SRL metric indicates the systems maturity level of a system composed of multiple technologies undergoing a lifecycle system development effort. It is a system maturity index that can provide a "snapshot" view of the system maturity throughout a system development lifecycle. The SRL is formulated by incorporating the currently used TRL index along with a newly introduced index, Integration Readiness Level (IRL). The IRL describes the level of integration maturity between any two system components that are integrated. Applying the IRL methodology for a particular system yields a unique IRL matrix reflecting that system's physical architecture.



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Integration Readiness Level

A systematic measurement of the interfacing of compatible interactions for various technologies and the consistent comparison of the maturity between integration points.

Integration – the combining and coordinating of separate components into a seamless unit – interfacing the compatible interactions of various technologies together

	IRL	Definition
Pragmatic	9	Integration is **Mission Proven** through successful mission operations.
	8	Actual integration completed and **Mission Qualified** through test and demonstration, in the system environment.
Syntactic	7	The integration of technologies has been **Verified and Validated** with sufficient detail to be actionable.
	6	The integrating technologies can **Accept, Translate, and Structure Information** for its intended application.
	5	There is sufficient **Control** between technologies necessary to establish, manage, and terminate the integration.
	4	There is sufficient detail in the **Quality and Assurance** of the integration between technologies.
Semantic	3	There is **Compatibility** (i.e. common language) between technologies to orderly and efficiently integrate and interact.
	2	There is some level of specificity to characterize the **Interaction** (i.e. ability to influence) between technologies through their interface.
	1	An **Interface** between technologies has been identified with sufficient detail to allow characterization of the relationship.

Gove, R. (2007) *Development of an Integration Ontology for Systems Operational Effectiveness*. M.S. Thesis. Stevens Institute of Technology. Hoboken, NJ
Gove, R., B. Sauser, J. Ramirez-Marquez. (2007). "Integration Maturity Metrics: Development of an Integration Readiness Level." *International Journal of Technology Management* (under review)

Table 2. Integration Readiness Levels

Though the SRL concept is not fully mature or accepted universally, it provides the beginnings of an effective system maturity assessment process framework that can support and improve the decision-making process throughout the system development lifecycle by reducing uncertainty and risk. The SRL metric provides the following benefits:

- Common metric methodology that is easy to apply
- Integrates well into system lifecycle framework
- Supports the management decision-making process.
- Provide a more precise "system level" maturity assessment

Calculating the SRL

This excerpt for Sauser, Verma, Ramirez-Marquez, DiMarzio, and Devanandham (2008) describes the SRL computation as follows:

The computation of the SRL is a function of two matrices:

1. Matrix **TRL** provides a blueprint of the state of the system with respect to the readiness of its technologies. That is, **TRL** is defined as a vector with *n* entries for which the i^{th} entry defines the TRL of the i^{th} technology.

2. Matrix **IRL** illustrates how the different technologies are integrated with each other from a system perspective. **IRL** defined as an $n \times n$ matrix for which the element IRL_{ij} represents the maturity of integration between the i^{th} and j^{th} technologies.

In these matrices, the standard TRL and IRL levels corresponding to values from 1 through 9 should be normalized. Also, it has been assumed that on the one hand, a value of 0 for element IRL_{ij} defines that the i^{th} and j^{th} technologies are impossible to integrate. On the other hand, a value of 1 for element IRL_{ij} can be understood as one of the following with respect to the i^{th} and j^{th} technologies: 1) completely compatible within the total system, 2) do not interfere with each others functions, 3) require no modification of the individual technologies, and 4) require no integration linkage development. Also it is important to note that IRL_{ii} may have a value lower than 1, illustrating that the technology may be a composite of different sub-technologies that are not absolutely mature.

In any system, each of the constituent technologies is connected to a minimum of one other technology through a bi-directional integration. How each technology is integrated with other technologies is used to formulate an equation for calculating SRL that is a function of the TRL and IRL values of the technologies and the interactions that form the system. In order to estimate a value of SRL from the TRL and IRL values we propose a normalized matrix of pair-wise comparison of TRL and IRL indices. That is, for a system with *n* technologies, we first formulate a TRL matrix, labeled [TRL]. This matrix is a single column matrix containing the values of the TRL of each technology in the system. In this respect, [TRL] is defined in Equation 1, where TRL_i is the TRL of technology *i*.

(1)
$$[TRL]_{n\times 1} = \begin{bmatrix} TRL_1 \\ TRL_2 \\ \ldots \\ TRL_n \end{bmatrix}$$

Second, an IRL matrix is created as a symmetric square matrix (of size $n \times n$) of all possible integrations between any two technologies in the system. For a system with *n* technologies, [IRL] is defined in Equation 2, where IRL_{ij} is the IRL between technologies *i* and *j*. It is important to note that whenever two technologies are not planned for integration, the IRL value assumed for these specific technologies is the hypothetical integration of a technology *i* to itself; therefore, it is given the maximum level of 9 and is denoted by IRL_i

(2)
$$[IRL]_{n\times n} = \begin{bmatrix} IRL_{11} & IRL_{12} & \ldots & IRL_{1n} \\ IRL_{21} & IRL_{22} & \ldots & IRL_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ IRL_{n1} & IRL_{n2} & \ldots & IRL_{nn} \end{bmatrix}$$

Although the original values for both TRL and IRL can be used, the use of normalized values allows a more accurate comparison when comparing the use of competing technologies. Thus, the values used in [TRL] and [IRL] are normalized (0,1) from the original (1,9) levels. Based on these two matrices, an SRL matrix is obtained by obtaining the product of the TRL and IRL matrices, as shown in Equation 3.

(3)
$$[SRL]_{n\times 1} = [IRL]_{n\times n} \times [TRL]_{n\times 1}$$

The SRL matrix consists of one element for each of the constituent technologies and from an integration perspective, quantifies the readiness level of a specific technology with respect to every other technology in the system while also accounting for the development state of each technology through TRL. Mathematically, for a system with *n* technologies, [SRL] is as shown in DoD (2005).

$$(4) \qquad [SRL] = \begin{bmatrix} SRL_1 \\ SRL_2 \\ \dots \\ SRL_n \end{bmatrix} = \begin{bmatrix} IRL_{11}TRL_1 + IRL_{12}TRL_2 + \dots + IRL_{1n}TRL_n \\ IRL_{21}TRL_1 + IRL_{22}TRL_2 + \dots + IRL_{2n}TRL_n \\ \dots \\ IRL_{n1}TRL_1 + IRL_{n2}TRL_2 + \dots + IRL_{nn}TRL_n \end{bmatrix}$$

where $IRL_{ij}=IRL_{ji}$.

Each of the SRL values obtained in DoD (2005) would fall within the interval (0,n). For consistency, these values of SRL should be divided by “n” to obtain the normalized value between (0,1). Notice that [SRL] itself can be used as a decision-making tool since its elements provide a prioritization guide of the system’s technologies and integrations. Thus, [SRL] can point out deficiencies in the maturation process.

The SRL for the complete system is the average of all such normalized SRL values, as shown in Equation 5. Equal weights are given to each technology and hence a simple average is estimated. A standard deviation can also be calculated to indicate the variation in the system maturity and parity in subsystem development.

$$(5) \qquad SRL = \frac{\left(\frac{SRL_1}{n_1} + \frac{SRL_2}{n_2} + \dots + \frac{SRL_n}{n_n} \right)}{n}$$

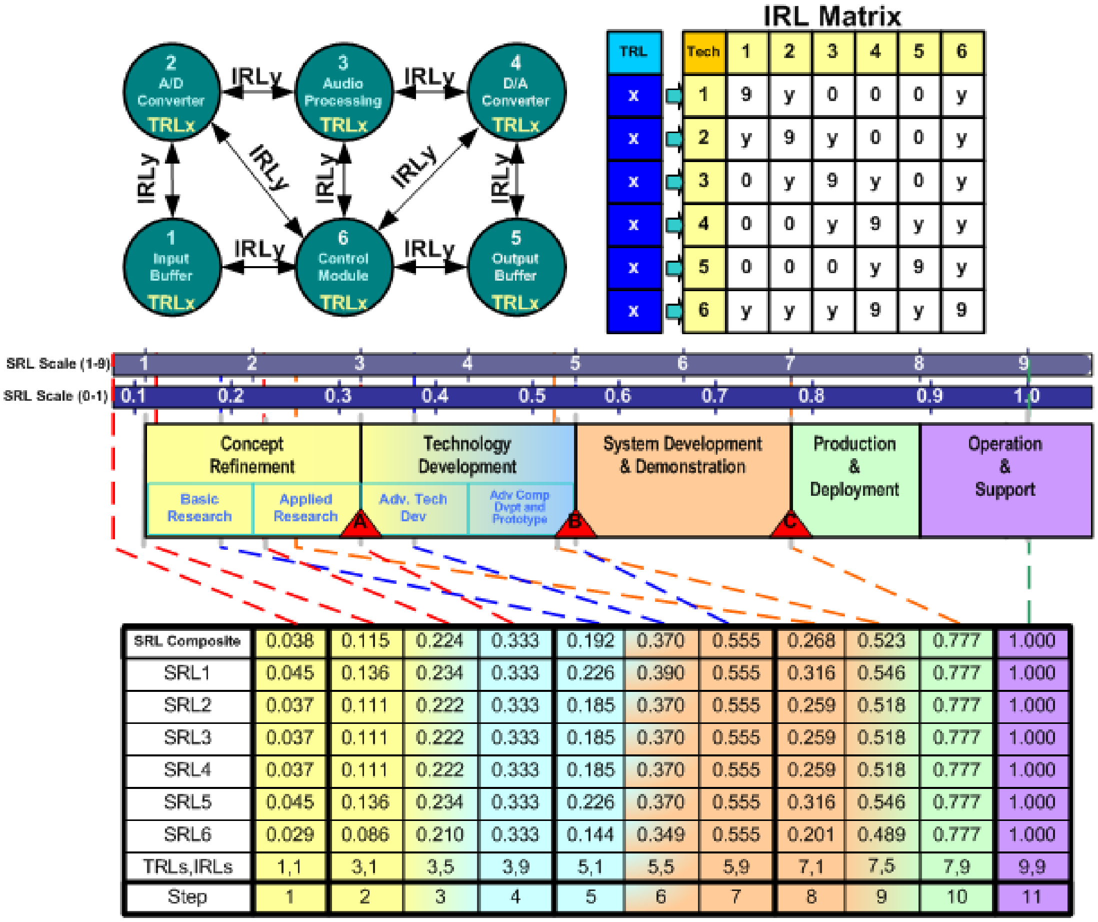
where n_i is the number of integrations with technology *i*.

The SRL metric can be used to determine the maturity of a system and its status within a developmental lifecycle.

Applying the SRL Methodology

In the following SRL examples, we take two different system architectures, each consisting of six technologies, and track the System Readiness Level metrics through the system development lifecycle, calculating the SRL metrics at each program decision point. We also look at the effects of IRL maturity on the composite SRL position along the system lifecycle by calculating the SRL for IRLs = 1, 5, and 9. This information can support the decision-making process by providing us with valuable information about the maturity of the system undergoing development and the status of the system’s individual components. The two examples shown in the following sections illustrate the SRL composites mapped across the entire system lifecycle. One can derive some interesting points by reviewing the data in these tables. For example, using the traditional TRL methodology and looking at Milestone C, we see that all the TRLs are equal to TRL 7. If we look at the SRL composite value for a maximum IRL value set equal to 9, we see that the table data shows the system maturity aligned with Milestone C, which in the traditional sense means we have a TRL equal to 7. Introducing the new SRL methodology, we can show that for a TRL 7, and a lower Integration Readiness Level of IRL 5, the SRL composite value then drops the SRL of the system to a point close to Milestone B. This point could perhaps shed some light in the area of COTS applications where developers have assumed their COTS components to be at a high TRL level, assuming easy and straightforward integration, and find themselves with great difficulty in the integration process.

SRL Example 1

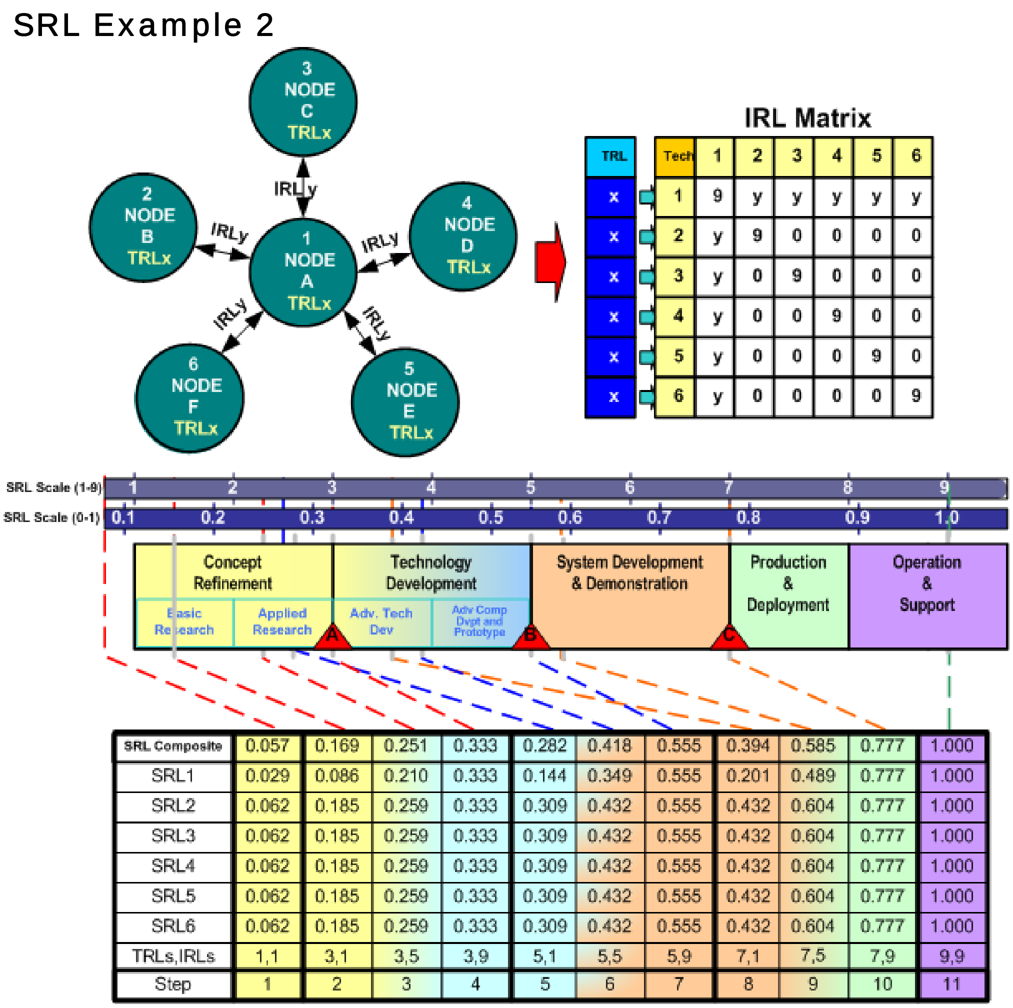


IRL Matrix

TRL	Tech	1	2	3	4	5	6
x	1	9	y	0	0	0	y
x	2	y	9	y	0	0	y
x	3	0	y	9	y	0	y
x	4	0	0	y	9	y	y
x	5	0	0	0	y	9	y
x	6	y	y	y	9	y	9

SRL Composite	0.038	0.115	0.224	0.333	0.192	0.370	0.555	0.268	0.523	0.777	1.000
SRL1	0.045	0.136	0.234	0.333	0.226	0.390	0.555	0.316	0.546	0.777	1.000
SRL2	0.037	0.111	0.222	0.333	0.185	0.370	0.555	0.259	0.518	0.777	1.000
SRL3	0.037	0.111	0.222	0.333	0.185	0.370	0.555	0.259	0.518	0.777	1.000
SRL4	0.037	0.111	0.222	0.333	0.185	0.370	0.555	0.259	0.518	0.777	1.000
SRL5	0.045	0.136	0.234	0.333	0.226	0.370	0.555	0.316	0.546	0.777	1.000
SRL6	0.029	0.086	0.210	0.333	0.144	0.349	0.555	0.201	0.489	0.777	1.000
TRLs,IRLs	1,1	3,1	3,5	3,9	5,1	5,5	5,9	7,1	7,5	7,9	9,9
Step	1	2	3	4	5	6	7	8	9	10	11

Table 3. SRL Example 1 Mapping to System Lifecycle



TRL	Tech	1	2	3	4	5	6
x	1	9	y	y	y	y	y
x	2	y	9	0	0	0	0
x	3	y	0	9	0	0	0
x	4	y	0	0	9	0	0
x	5	y	0	0	0	9	0
x	6	y	0	0	0	0	9

SRL Composite	0.057	0.169	0.251	0.333	0.282	0.418	0.555	0.394	0.585	0.777	1.000
SRL1	0.029	0.086	0.210	0.333	0.144	0.349	0.555	0.201	0.489	0.777	1.000
SRL2	0.062	0.185	0.259	0.333	0.309	0.432	0.555	0.432	0.604	0.777	1.000
SRL3	0.062	0.185	0.259	0.333	0.309	0.432	0.555	0.432	0.604	0.777	1.000
SRL4	0.062	0.185	0.259	0.333	0.309	0.432	0.555	0.432	0.604	0.777	1.000
SRL5	0.062	0.185	0.259	0.333	0.309	0.432	0.555	0.432	0.604	0.777	1.000
SRL6	0.062	0.185	0.259	0.333	0.309	0.432	0.555	0.432	0.604	0.777	1.000
TRLs,IRLs	1,1	3,1	3,5	3,9	5,1	5,5	5,9	7,1	7,5	7,9	9,9
Step	1	2	3	4	5	6	7	8	9	10	11

Table 4. SRL Example 2 Mapping to System Lifecycle

Push for Portfolio Management

As systems become more complex, management of their development efforts become more difficult. The management environment has become a critical focus for many organizations seeking to ensure the success of their programs and projects. The quest for new innovative approaches supporting the management decision-making process, including new software management tools, are at the top of the list. Portfolio management is defined as the management of an optimized group of projects aligned towards a central goal, theme, or strategy—sharing common resources within an organization. Portfolio management principles can be applied on the corporate level as well as the program or project level. In order to corporate portfolio management principles to be effective in an organization, that organizational behavior and process must be aligned towards a common goal or strategy (Sanwal, 2007). Though, the application of portfolio management strategies to different domains are evident from the many coined references like “corporate portfolio management,” “project portfolio management,” and “enterprise portfolio management,” their basic approaches are the same. Recently introduced corporate portfolio management (CPM) ideologies supporting system development in the DoD have shown some promise in providing a more dynamic approach to project management. The DoD’s Joint Net-Centric Operations (JNO) group has adopted a capability portfolio management process to ensure that the portfolio is aligned with strategic objectives, the capability mix is synchronized, integrated, and optimized to meet warfighter needs, while being delivered more rapidly and efficiently. The overall goal of applying joint capability portfolio management is to help manage groups of similar and like capabilities across the DoD enterprise to improve interoperability, minimize capability redundancies and gaps, and maximize capability effectiveness (JNO, 2007, April).

Developing a CPM Strategy

The portfolio management process begins with a vision or desired capability that defines the strategic focus of the organization. This can be driven by internal corporate goals and/or by external customer/stakeholder requirements or needs. These requirements or needs are then translated to high-level, long-term research development goals and objectives, which can then be developed and achieved through a well defined, executed program. The final deliverable to the customer will be a technological capability, which is delivered to the customer through a technology transfer process. These high level principles are highlighted in a recent INCOSE paper titled, “A Systems Approach to the Transition of Emergent Technologies into Operational Systems—Herding the Cats, the Road to Euphoria and Planning for Success,” which discusses the critical elements needed to support and enable successful technology transition through the lifecycle development process (Austin, Zakar, York, Pettersen & Duff, 2008).

Four Key Questions Driving CPM Strategy

1. **What are we trying to Accomplish?** (Euphoria)

This question asks “”Where do you want to be?” and drives an end-state vision and goal based on high-level corporate strategy and stakeholder requirements.

2. **What can we do now?** (Herding the Cats)

Here, we must determine “Where are we now?,” “What can we do now?,” “What are our technical assets, past accomplishments, and available resources?” and “Can they be aligned with the desired end-state goals?

3. **What is our plan to get there?** (the Road to Euphoria)

Based on the answers to the first two questions, identify the technology gaps, and develop a roadmap or plan to reach the desired goals.

4. **How are we doing?** (the Metrics)

Here, we need to determine how well the system lifecycle development is maturing so that corrections and modifications can be implemented if necessary.

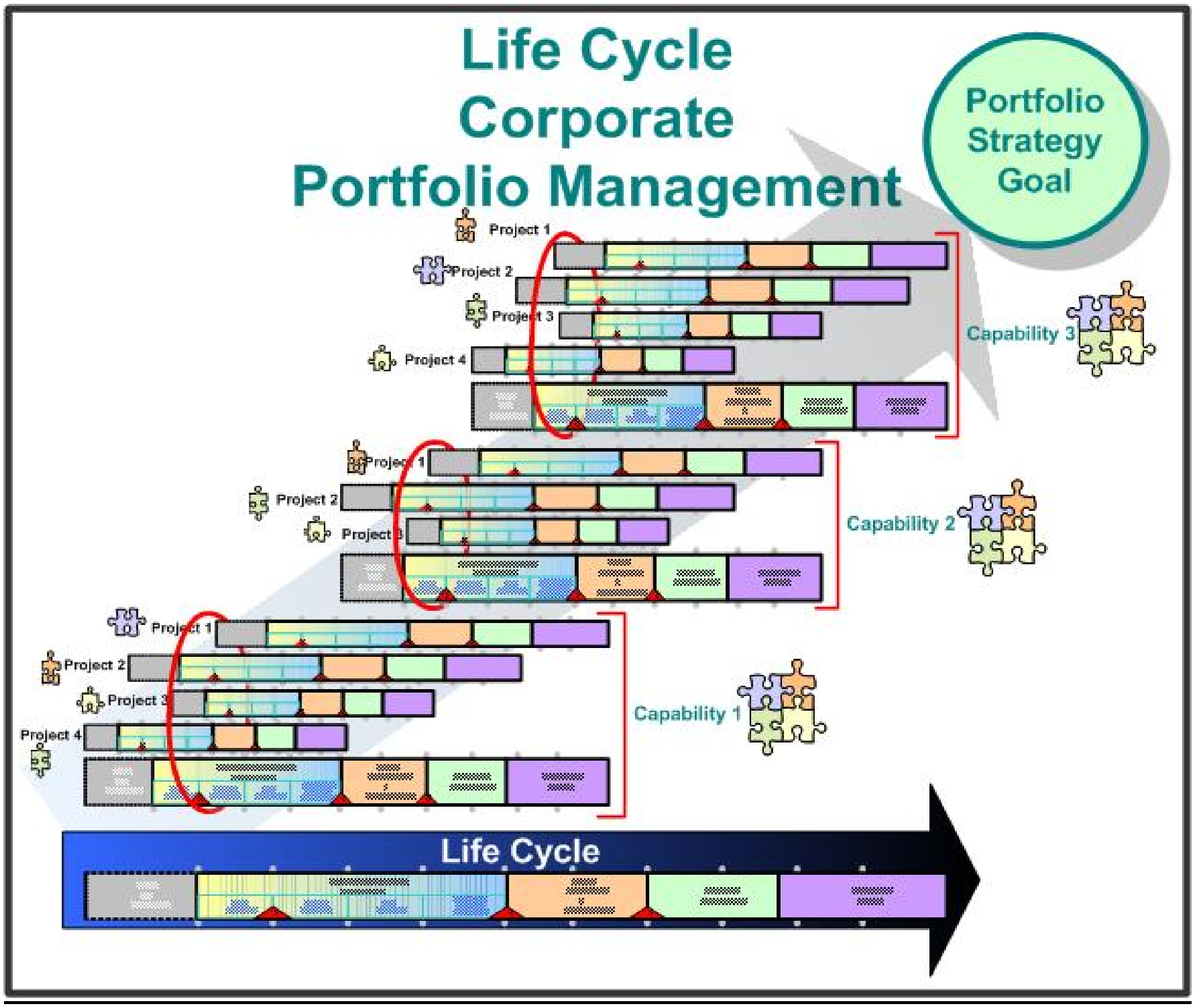


Figure 5. Lifecycle Corporate Portfolio Management

Portfolio Enterprise View

Based on the answers to the “Four Key Questions Driving CPM Strategy” discussed in the previous section, the selection of projects is based on their alignment to the desired capabilities and sub-objectives as well as available resources, including funding and available manpower.

Implementation of the portfolio management approach to project management eliminates the traditional approaches that led to multiple concurrent, often duplicative and “stove-piped” solutions that were inefficient, often subjected to irrational, “below the line” and “salami slice” budget cuts. These cuts can result in key capabilities being lost, leading to programs not being able to meet their objectives. Portfolio management presents an “enterprise” approach, providing for synchronized investments to deliver maximum capability through the prioritization of your investments by maintaining an optimal mix of investments in objectives aligned to your strategy.

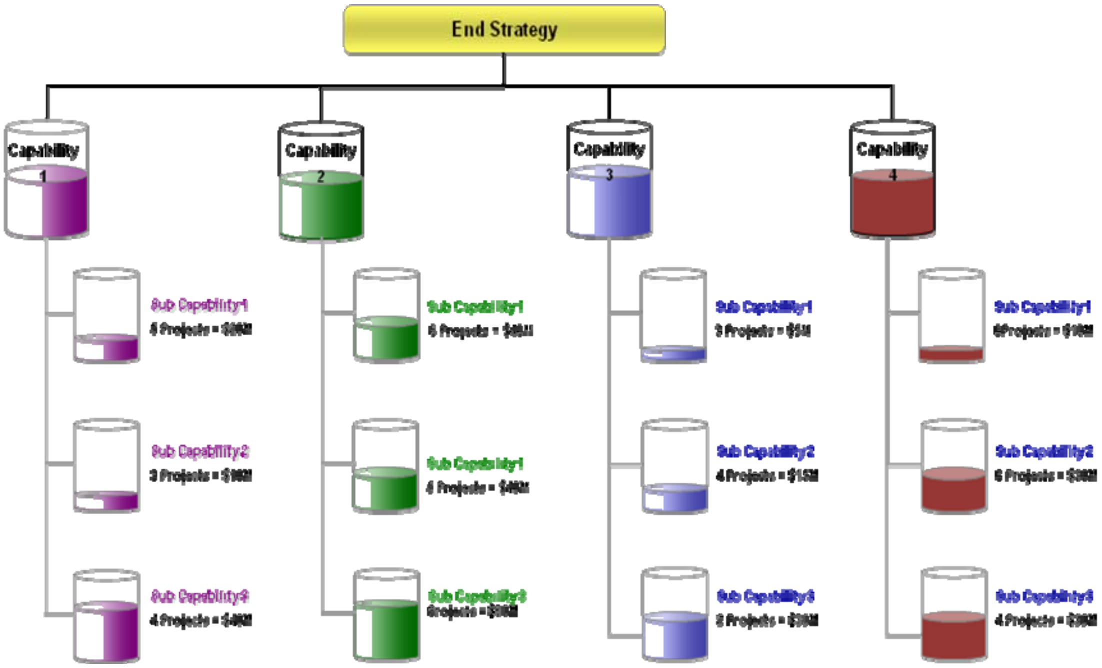
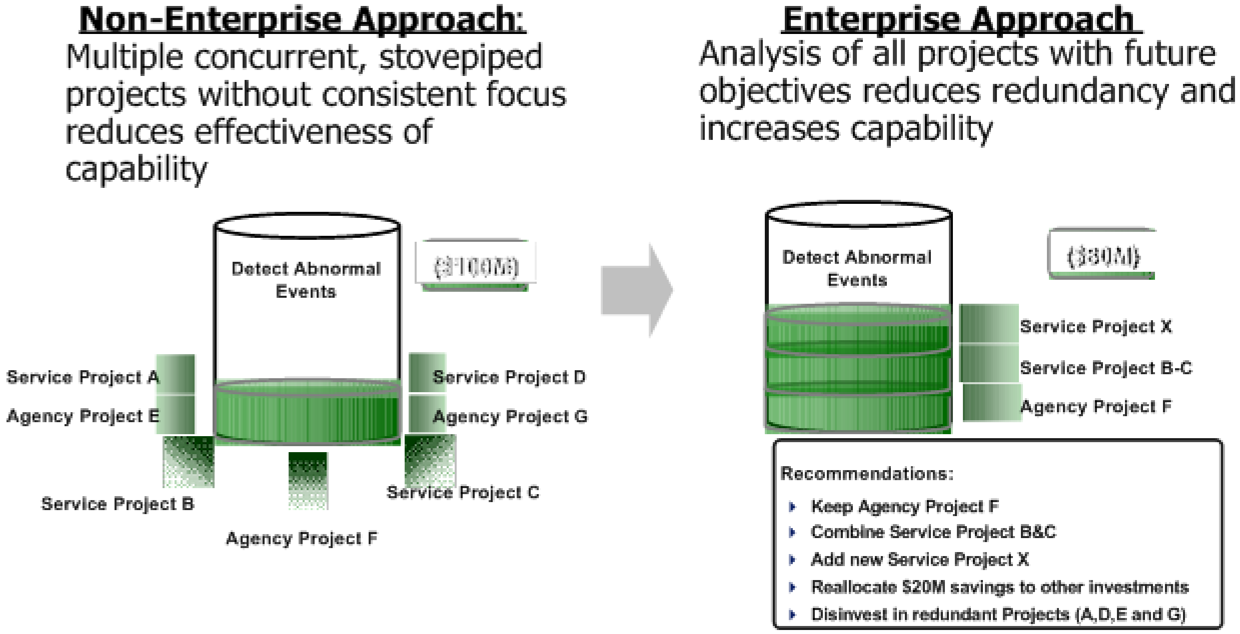


Figure 6. Portfolio Project Enterprise View


Non-Enterprise Approach: Multiple concurrent, stovepiped projects without consistent focus reduces effectiveness of capability

Enterprise Approach Analysis of all projects with future objectives reduces redundancy and increases capability

Recommendations:
- Keep Agency Project F
- Combine Service Project B&C
- Add new Service Project X
- Reallocate $20M savings to other investments
- Disinvest in redundant Projects (A,D,E and G)

Figure 7. Historical/Enterprise Approaches

Lifecycle Portfolio Management

Lifecycle portfolio management includes the capture of a variety of metrics (financial, performance, and maturity metrics) that are analyzed and the results support some type of decision-making process. At this point, optimization is considered a way to keep the portfolio better aligned to meet it strategic goals.

Metrics Assessments

The strength of portfolio management lies in the capture of metrics that measure the vital functions of a development effort and how well the development process is going. These metrics provide input to the optimization and decision-making process. These metrics can be captured on a quarterly basis and/or tied to key, program-specific development milestones. Progress against these milestones can provide key insight to the user regarding current program status, risk and progress. After the initial strategy development phase, a proposed approach for applying the maturity metrics to the portfolio management process would include performing the following:

- Initial assessment of selected technologies in portfolio mix, which includes the initial assessment TRL/IRL/SRL data, resource data.
- Quarterly cycle assessments of TRL/IRL, SRL, and funding and at milestones A, B, C of the DoD 5000.2 system lifecycle framework.
- Ongoing, search for new and viable technologies that may be available now or in the near future for possible integration or substitution into existing portfolio mix.
- Analysis of data to see if optimization opportunity is available.

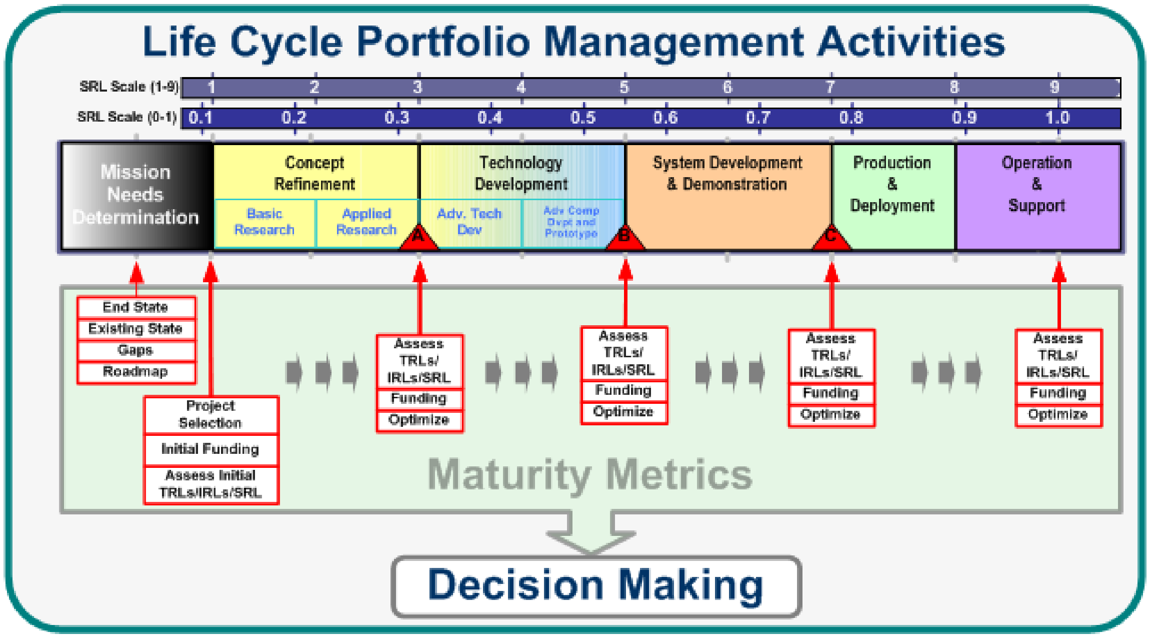


Figure 8. CPM Lifecycle Activities

Optimization

One of the key focuses of successful portfolio management is trying to maintain an optimal mix of technology development efforts aligned with the organizations strategic vision or goals. In addition, we need to understand how well or how fast these individual technologies are maturing relative to each other or if any new external technologies have been developed and can be immediately substituted, allowing for more dynamic changes to the portfolio mix. How do you decide between competing system design alternatives or which individual TRL or IRL to improve? The use of optimization modeling techniques can provide great insight and support to trade-off analysis and decision-making throughout the system development lifecycle.

Two recently developed optimization models, **System Cost of Development (SCOD) Minimization** and **SRL Maximization** are examples of using optimization techniques to help provide better decision-making, control-based resource constraints. The first model, **SCOD Minimization,** considers minimizing the development cost associated to increasing SRL to some predefined user level, λ. This model's objective is to minimize development cost (a function of TRL and IRL development) under constraints associated with schedule and the required SRL value (Magnaye, Sauser, Ramirez-Marquez & Tan, 2008). The second model, **SRL Maximization,** maximizes the SRL (a function of TRL and IRL) under constraints associated with resources. This model recognizes that the technologies compete for resources and that benefits can result in an improved SRL via the optimal allocation of such resources (Sauser & Ramirez-Marquez, 2009). In summary, optimization modeling should help provide the decision-maker, whether it is the program manager or the systems engineer with the best balance between the SRL and all the associated resources to help achieve the desired end-state goals. We must remember that optimization should be considered only a tool used along with other inputs, like metrics, to help provide depth to the decision-making process.

Decision-making

CPM decision-making is a complex undertaking as there are many elements and events that need to be understood and analyzed in a real-time manner. The pressures of schedule, cost and performance hold true along with an associated more real-time element. Adherence to the DoD 5000 acquisition framework's critical decision point assessments at milestones A, B, and C affects the optimization process.

1. **Optimal mix of research development investments to achieve capability goals based on maturation, cost, etc.**
2. **Allocation of resources to investments (Funding/Manpower)**
3. **Corrections to mix of research investments in reaction to the introduction of new technologies**

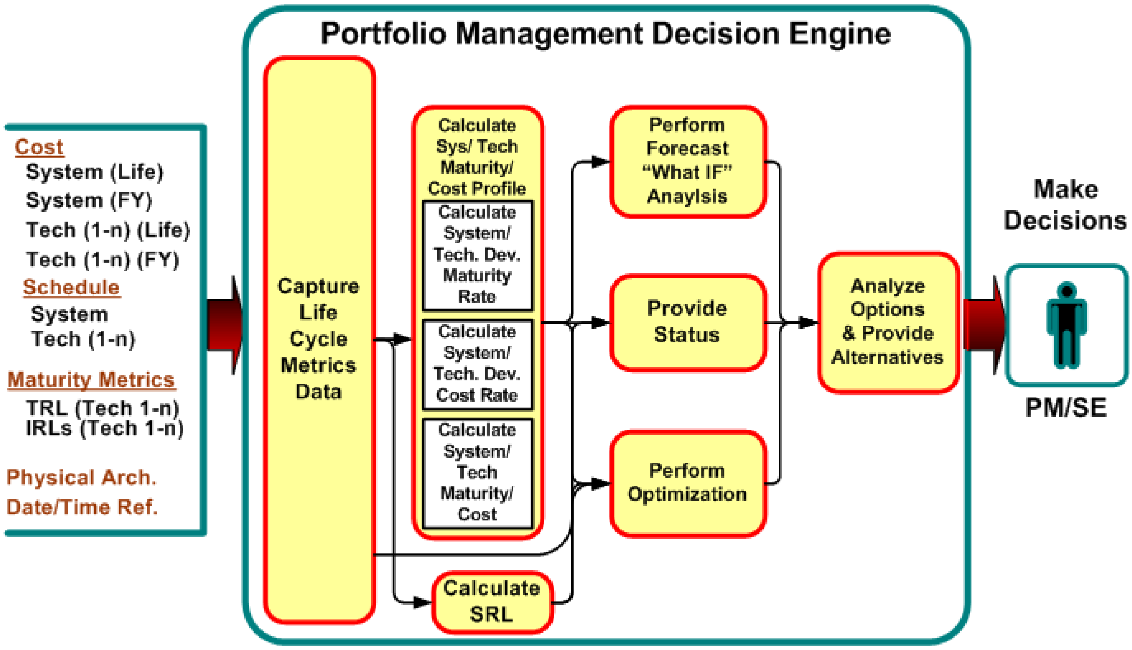


Figure 9. Portfolio Management Decision Engine

Summary and Conclusion

The purpose of this paper was to introduce the concepts of SRL metrics to multi-technology based system development environment in a portfolio management environment. The proposed application of these concepts and ideologies presents a new, potentially viable alternative to previously methodologies using TRL metrics. Stressed in this paper was the belief that you must consider an integrated approach to ensure that the portfolio management process and system maturity metric assessment process are synchronized closely to a lifecycle framework in order to meet your strategic goals. Looking ahead, research in the following areas would further contribute to the body of knowledge in System Maturity Metrics:

- SRL software tools to implement a combined SE, CPM and Road Mapping.
- Application of SRL metrics to support CPM environment.
- What additional maturity metric variables are needed to support the decision-making process?—security readiness
- Application of SRL model to other lifecycles outside the DoD.
- Robustness of SRL to variety of differing physical architectures.
- Impacts of disruptive technologies on systems maturity forecasting.
- SRL applications to COTS environment and lifecycle development

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