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## **Lifecycle Value Framework for Tactical Aircraft Product Development**

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# Lifecycle Value Framework for Tactical Aircraft Product Development

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**Abstract.** Due to a dramatic reduction in defense procurement, the benchmark for developing new defense systems today is performance at an affordable cost. In an attempt to encircle a more holistic perspective of value, lifecycle value has evolved as a concept within the Lean Aerospace Initiative, LAI. The implication of this is development of products incorporating lifecycle and long-term focus instead of a shortsighted cost cutting focus. The interest to reduce total cost of ownership while still improving performance, availability, and sustainability, other dimensions taken into account within the lifecycle value approach, falls well within this context. Several factors prevent enterprises from having a holistic perspective during product development. Some important aspects are increased complexity of the products and significant technological uncertainty. The combination of complexity in system design and the limits of individual human comprehension typically prevent a best value solution to be envisioned. The purpose of this research was to examine relative contributions in product development and determine factors that significantly promote abilities to consider and achieve lifecycle value. This paper contributes a maturity matrix based on important practices and lessons learned through extensive interview based case studies of three tactical aircraft programs, including experiences from more than 100 interviews.

## INTRODUCTION

The discussion around value and different perspectives of value has become intensified lately due to changes over the last decade. Depending on the profession or background of the individual, the implication of value can vary significantly. In *Lean Thinking*, the following definition for value is suggested, "A capability provided to a customer at the right time and at an appropriate price, as defined in each case by the customer (Womack, 1996)." In an attempt to encircle a more holistic perspective of value, Best Lifecycle Value, BLV, has evolved as a concept within the Lean Aerospace Initiative, LAI. LAI is a consortium of U.S. military, industry, academia, and labor organizations interested in the aerospace industry. The academic branch of this consortium conducts research based on interest and support from the military, industry, and labor participants. A synergistic evolution of a holistic lean

perspective has evolved within the Lean Aircraft Research Program, LARP. LARP is a consortium similar to LAI involving Swedish military, industry, and academia. Collaborative efforts of these two consortiums has identified the need for and initiated research on the concept of lifecycle value.\*

Addressing lifecycle value includes assessing multiple dimensions of value and their implications throughout the lifecycle of a system. The implication of this is development of products from a lean perspective in a constructive way i.e. having a long term, value adding focus instead of a limited, cost cutting, short sighted focus. A candidate definition for BLV that has matured within LAI is:

*A system introduced at the right time and the right price offering best value in mission effectiveness, performance and affordability and retains these advantages through out its life.*

A dramatic reduction in U.S. defense procurement of about 70 percent following the collapse of the Soviet Union is the driving force for a changed view on development within the defense industry (Gansler, 2000). The benchmark for developing new defense systems today is therefore, mission effectiveness at an affordable cost. The interest to reduce total cost of ownership while still improving performance, availability and sustainability, which are other dimensions taken into account within the BLV approach falls well within this context.

Emphasis on accounting for the whole lifecycle when developing a system has grown since the mid-1960's. Publications from Blanchard et al., regarding lifecycle issues especially on the topic of Life Cycle Cost, are now sources for a variety of interests.

Life Cycle Cost, LCC involves all costs associated with a system including costs for, R&D, Production and Design, including operation and maintenance for production capability, Operation and Maintenance Costs as well as system retirement and phase out costs (Blanchard, 1992).

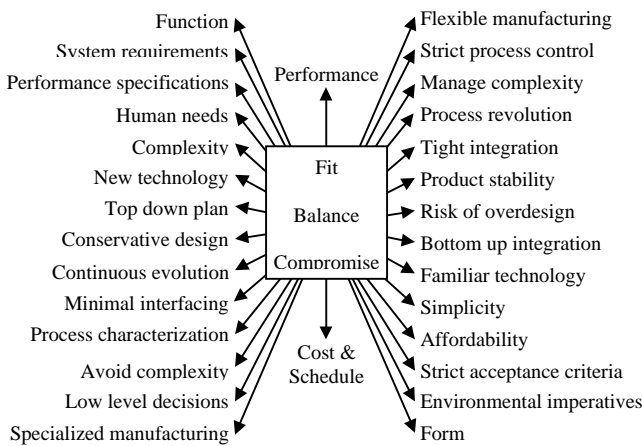
Recent research with similar thought has focused on how to take into account affordability (Mavris, 1998) and supportability issues in product development. Consideration of lifecycle issues, such

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\* More information regarding LAI and LARP can be found at [web.mit.edu/lean](http://web.mit.edu/lean) and [www.liu.se/org/imie/larp](http://www.liu.se/org/imie/larp) respectively.

as supportability, early in product development has proven to be economically beneficial for industries producing products with variable degrees of complexity. Xerox was one of the companies that evaluated support requirements early in the design stage. The company found that more money was saved by considering support issues than by implementing Design for Manufacturing (DFM) methods to increase productivity (Goffin, 2000).

Several factors prevent companies from having a holistic perspective during product development. Some important aspects are increased complexity of the products, development, cycle time, significant technological uncertainty and communication and human issues. Under the development process several factors of an often-conflicting nature have to be considered, this is well illustrated in Figure 1 below. In addition to this, for complex systems with a long lifecycle different technologies age and become obsolete at varying rates (Fine, 1998).



**Figure 1: Tensions in Systems Architecting (Rechtin, 1997)**

The objective of this research was to examine relative contributions in product development work to determine factors that significantly promote abilities to consider and achieve lifecycle value. The scope of this research focuses on aerospace systems to characterize the dimensions of lifecycle value, enablers and barriers, as well as lessons learned from product development strategies and practices. This paper contributes a maturity matrix based on significant practices and lessons learned through three case studies of tactical aircraft programs.

The outline for this paper is to introduce a conceptual framework for lifecycle consideration in product design that was developed simultaneously with three case studies. Each case will then be described briefly, followed by a presentation of the aggregated results, aligning with the structure of the conceptual framework.

**LIFECYCLE VALUE FRAMEWORK**

To consider lifecycle value, a conceptual model combining lifecycle issues, such as cost and supportability, and other value characteristics, such as performance and development cost, is useful. More specifically, a framework for lifecycle value can provide a holistic view of system value throughout its lifecycle. It is believed that all stakeholders, regardless of individual differences, can agree on the importance of value as a system attribute. In many cases a particular group of stakeholders interacts with a system only during a portion of its entire lifecycle. Considering lifecycle value is therefore a unifying priority bringing all stakeholders together focusing on a common objective.

One conceptual framework for lifecycle value has evolved within LAI and is presented here. It has been further developed by the authors. Value creation can be thought of in three primary processes:

- Value Identification
- Value Proposition
- Value Delivery

**Value Identification.** This process involves identifying all stakeholders for a system, and articulating their needs and expectations in the form of system goals. Each stakeholder contributes unique information regarding corporate strategies, market analysis, consumer or operator needs, and the timing of system development and availability based on their perspective. Balance must then be established for the voice each stakeholder is given regarding the system development.

**Value Proposition.** A key aspect of value creation is the transition from goals and ideas to a system architecture and concept. Establishing a value proposition for a system involves balancing the stakeholder expectations and system goals based on the common objective of creating lifecycle value. The combination of complexity in system design and the limits of individual human comprehension typically prevent a best value solution to be envisioned. Involving multiple stakeholders to cooperatively conceive and develop a value proposition for a system is a practical way to manage the issues of system design. Although it is certainly not expected that all stakeholders disregard their individual differences, complete buy-in and support for a single value proposition for a system is a critical link between value identification and value delivery. The value proposition and stakeholder support must then be clearly communicated throughout the enterprise.

**Value Delivery.** Product development is focused on value delivery. Utilizing strategies, practices, tools, and methods to consider lifecycle value throughout product development facilitates value delivery. Although a value proposition influences the success

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of value delivery, there are many ways to develop and improve system lifecycle value working within a given value proposition. Follow through on a value proposition via successful value delivery can establish stakeholder reputation and credibility for future work.

**Research Focus.** Of the three processes, the focus of this paper is value delivery. This stems from an objective of this research to study the contributions in product development to total lifecycle value creation. Product development work centers on delivering the identified and proposed value. Understanding the implications of value identification and proposition provides the appropriate context to understand value delivery.

### CASE WORK INTRODUCTION

**Research Methodology.** In addition to developing a conceptual framework, a case study methodology was chosen to achieve the objectives of this research. While this typically involves a loose format that is highly dependent on the researchers involved, the collaborative nature of this work required a more structured process. A hybrid structured survey interview technique was utilized to collect both quantitative and qualitative data. One part of the format consisted of questions with alternative answers, and the other part of the questionnaire consisted of open-ended questions that were discussed during an interview. The interview format was pre-tested with Saab Aircraft, on the Saab 2000 program, and Raytheon Aircraft, on the T1A Jayhawk program. Each of these tests was carried out in a joint LAI-LARP effort, and the material was subsequently refined. Interviewees were chosen with a variety of backgrounds, and they had the opportunity to complete the survey portion of the study before the structured interview. Qualitative responses were clustered into a number of different categories from which six main themes emerged.

**Case Selection.** There were specific selection criteria for the cases studied. Complex aerospace systems are the focus of this work. The criteria considered focus on establishing significant evidence to evaluate the concept of lifecycle value and at the same time studying practices and strategies that are modern. Only development work done recently was considered. Since development alone is insufficient to substantiate lifecycle value, in each case, the system considered is into the production and operations phase of the program. Although no criterion was based on evaluated achievement of lifecycle value, it is still appropriate to acknowledge the accomplishments of each system.

**Cases.** Three tactical aircraft cases have been selected for this work. Together they are a representative sample of tactical aircraft in the international market.

They also represent three primary development strategies used for complex systems. JAS 39 Gripen represents a “clean sheet” design; it is a new system developed for the Swedish Air Force. The F/A-18E/F Super Hornet is an upgrade from a previously developed system, developed for the U.S. Navy. The F-16 is a continual evolution design with changes and improvements integrated in blocks; the development work has primarily been done for the U.S. Air Force. These three programs have significantly different development strategies, but they have all shown evidence that they are examples of systems delivering best lifecycle value.

**Case Analysis.** Aggregation of data collected from more than 100 interviewees from the three cases introduced above has led to the results identified. The results are presented supporting the structure of the conceptual framework identified for best lifecycle value. Of the three parts of the framework, using a product development perspective focused the results into the area of value delivery more so than value identification and value proposition. This discussion focuses on primarily on the area of value delivery accordingly.

### JAS 39 GRIPEN CASE STUDY

The JAS 39 Gripen is a multi-role aircraft with ability to change roles in the air resulting in unique mission flexibility. JAS is the Swedish acronym for Fighter, Attack, Reconnaissance. The JAS 39A, the single-seat version was developed in the 80's followed by the development of the two-seat JAS 39B in the late 80's to early 90's.

In the light of the growing expenditures for the Viggen aircraft, the Swedish military's predecessor of the Gripen, it became evident that the next generation of aircraft had to be smaller, more flexible and significantly break the trend of the rapidly growing cost curve. As a result of this, the decision was made to develop a new small multi-role aircraft for the Swedish Air Force. The program was also different from the Viggen program due to changes in the contract structure. The Gripen program was a fixed price contract including product development work and the production of the first 30 aircraft.

New technologies and new technological solutions were developed in parallel to the product development of JAS 39 Gripen. The technological uncertainty was high, which is why overall program risk had to be minimized. This was partly done through risk sharing partnership with strong Swedish industry in the IG-JAS group.

From a national and international perspective JAS 39 Gripen is a successful project. Gripen has been in service in the Swedish Air Force for seven years and has gained significant international interest. Software-controlled systems facilitate future integration of new functions and the avionics system architecture provides significant development

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potential for the future. Considerable emphasis has been placed on reducing time required for routine maintenance resulting in rapid turn-around times and low operating costs. The program was able to reach targeted LCC goals of 40% reduction over the LCC of the Viggen. The JAS 39 Gripen is the first 4<sup>th</sup> generation, fully digital computerized system, with true multi-role capability to be delivered.

### F/A-18E/F CASE STUDY

The F/A-18E/F Super Hornets are an upgraded version of the F/A-18C/D Hornet models. The single seat E model and the two-seat F are multi-role tactical aircraft, having both air-to-air capability and air-to-ground capability. The F/A-18 family contains four sets of models, the A/B, the C/D, the C/D night strike, and the most recent E/F versions. With the exception of 90% commonality in avionics with the C/D models and limited similarity in the airframe, the E/F versions are significantly different than previous Hornets. The E/F planes are 25% larger, having a 40% increase in unrefueled range, 25% increase in payload, three times greater bring-back ordnance, and five times greater survivability, with 42% fewer parts. The F/A-18 fleet has been developed for the U.S. Navy's aircraft carrier environment and the A/B and C/D versions are currently operated internationally by the U.S. and several other countries.

Early in the 1990's after the cancellation of the A-12 program, the U.S. Navy needed to start a development program to modernize their fleet and support their mission into the 21<sup>st</sup> century. Following direction from the U.S. government an upgrade to the C/D Hornets was being considered. This investigation work was transitioned into a full-scale development program in 1992.

The F/A-18E/F Super Hornet successfully completed Operational Evaluation testing (OPEVAL) with the rating of "operationally effective and suitable", which is the highest rating achievable. The system was also found to have numerous enhancing characteristics that exceeded the requirements and specifications. The system also performed very well during the sea worthiness trials. In addition, the program was never rebaselined, and the early program goals set at the time of the contract award were met.

### F-16 CASE STUDY

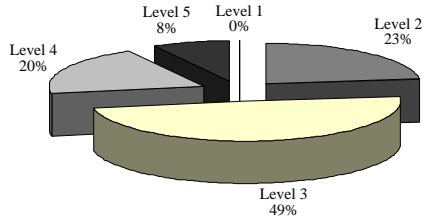
The F-16 was originally developed in the 1970's as a lightweight, "no-frills" aircraft (Clancy, 1995). The primary thrust behind the concept was lack of unlimited funds to acquire new systems. Although technical performance is a priority for any weapons

system, limiting the technical requirements to an acceptable level, preventing many "bells and whistles" from entering the design was a driving influence in the F-16 development. The F-16 is considered to be a small fighter. There are two sets of F-16 models. The F-16A/B were the first developed, the single-seat A as the combat version, and the two-seat B version as a fully operational trainer. The F-16C/D models were upgrades to the A/B developed about ten years after the original A/B. Although there are only two sets of models, there have been many smaller scale improvement efforts incorporated in various production groups of aircraft known as block upgrades. The F-16 has undergone extensive changes over the course of the system development, without significant change in the size of the airframe. Since the original A/B models, upgrades have continued to add increase the functionality of the system. The F-16 has been able to maintain the benefits of being a small fighter while improving the total system performance over the slow course of evolutionary upgrade efforts.

The focus of this study is on the recent F-16 development work. The evolutionary development approach taken by the F-16 program has led to a system that many years after the original conception, has become an example of sustaining value throughout the entire lifecycle of the system.

### RESULTS

Lifecycle value has been characterized by data collected regarding the level of understanding and consistency of deployment of the concept throughout the enterprises studied. As exhibited in Figure 2 below, the majority (49%) of respondents felt that the concept of lifecycle value is deployed to most areas with some variation in the level of understanding. The rest of the respondents felt that there was at least some awareness of the concept, with 8% identifying exceptional understanding and full deployment throughout the enterprise. The range of 92% of the responses from level 2 to level 4 illustrates the current awareness of lifecycle value and its significance.



- Level 1: There is no understanding of the concept.
- Level 2: There is some awareness of the concept, which is deployed to only a few areas.
- Level 3: The concept is deployed to most areas with variation between the level of understanding in each area.
- Level 4: The concept is undergoing refinement and continuous improvement. It is deployed throughout all areas of the extended enterprise (customer through suppliers).
- Level 5: The level of understanding is exceptional, the concept is well defined, and fully deployed across all areas throughout the extended enterprise (customer through suppliers).

**Figure 2: Level of Understanding and Deployment of Lifecycle Value**

The results are presented in the form of practices, both those observed in the particular cases and those identified as lessons learned. In some areas, quantitative data was useful to support the relevance of the practices identified. To categorize the practices, six main themes were extracted. The themes identified are:

- Holistic Perspective
- Organizational Factors
- Tools and Methods
- Requirements and Metrics
- Enterprise Relationships
- Leadership and Management

While each theme contributes significantly to achieving best lifecycle value, it was observed that these themes vary in both how much they are emphasized in terms of their importance and in how well they are currently incorporated and deployed in terms of strategies and practices. The figure below illustrates the authors' evaluation of both the importance and performance of each theme from the cases studied.

<i>Significant Importance</i>	<ul style="list-style-type: none"> <li>• Enterprise Relationships                             <ul style="list-style-type: none"> <li>➢ Within the extended enterprise</li> </ul> </li> <li>• Holistic Perspective</li> <li>• Requirements</li> <li>• Organizational Factors                             <ul style="list-style-type: none"> <li>➢ To balance functional and product responsibilities</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• Enterprise Relationships                             <ul style="list-style-type: none"> <li>➢ Within the core enterprise</li> </ul> </li> <li>• Leadership and Management</li> <li>• Requirements</li> <li>• Organizational Factors                             <ul style="list-style-type: none"> <li>➢ To promote integration</li> </ul> </li> </ul>
	<ul style="list-style-type: none"> <li>• Metrics</li> <li>• Tools and Methods</li> </ul>	
	<i>Improvement Needed</i>	<i>Well Executed</i>

**Figure 3: Observed Level of Importance and Performance of Main Themes**

As this figure suggests, there is still work to be done in the area of considering and achieving lifecycle value in tactical aircraft programs.

**ANALYSIS AND DISCUSSION**

Value delivery is the basis for the following discussion of aggregated results from the three cases. The previous results regarding understanding and deployment of lifecycle value in the cases studied has led to development of a maturity matrix for the value delivery process.

The matrix is based on the observed practices and lessons learned for addressing and achieving lifecycle value during value delivery. The data shown in Figure 2 was used as a baseline to evaluate each of the practices identified. A maturity matrix was formed by first identifying the practices aligning with level 3 (corresponding to the majority of the data on level of understanding and deployment), and extrapolating to identify practices of levels 1, 2, 4, and 5.

It has been noted that the nature of product development has focused this work on value proposition and value delivery. Because product development does not address the value proposition completely, the results identified pertaining to product development alone would be insufficient to substantiate a maturity matrix for the value proposition process.

This matrix, shown in Figure 4, summarizes the practices and highlights significant development strategies extracted from the case studies. Level 1 represents no understanding or consideration of lifecycle value issues. Level 5 represents exceptional understanding and implementation of practices to support lifecycle value. Collected data does not indicate equal level of maturity for all practices.

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	<b>Level 1</b>	<b>Level 2</b>	<b>Level 3</b>	<b>Level 4</b>	<b>Level 5</b>
<b>Holistic Perspective</b>	Awareness of several levels of the system with little to no consideration of its lifecycle.	Awareness of entire system with little or no consideration of its lifecycle.	Good awareness of the entire system with some lifecycle considerations.	Good awareness of the entire system and its entire lifecycle.	Exceptional awareness of entire system and full implementation of lifecycle issues.
<b>Organizational Factors</b>	Functionally specialized working groups, with little cross-functional interaction.	Informal cross-functional working relationships.	Formal cross-functional structure, in effective product IPTs.	Alignment of business support with with effective product IPTs.	Coordination of business support with with effective product IPTs, balancing between functional and product responsibilities.
<b>Tools and Methods</b>	Tools may or may not be used on an individual basis.	Multiple tools serving the same functions.	Common tools for each function.	Common tools fully integrated between functions.	Single interface to access multiple services provided by common fully integrated tools.
<b>Requirements and Metrics</b>	Understood but may or may not be concretely established with little to no consideration of lifecycle issues.	Established that may or may not include lifecycle considerations.	Established and communicated throughout the enterprise including lifecycle aspects.	Established, articulated and communicated unambiguously including lifecycle considerations.	Established, articulated and communicated unambiguously including lifecycle considerations resulting from close interaction amongst enterprise stakeholders focused on lifecycle value.
<b>Effective Enterprise Relationships</b>	Inconsistent working relationships in some areas of the organization.	Consistent working relationships at some levels of the organization.	Consistent working relationships and communication at all levels of the organization and through some of the enterprise.	Consistent working relationships and communication throughout the extended enterprise.	Consistent working relationships and communication throughout the extended enterprise optimized for each stakeholder by differentiated levels of visibility.
<b>Leadership and Management</b>	Individual leadership characteristics exhibited inconsistently.	Good individual leadership.	Good individual leadership with clear roles and responsibilities.	Good individual leadership with clear roles and responsibilities with a management support mentality to create buy-in to program responsibilities.	Good individual leadership with clear roles and responsibilities with a management support mentality to create buy-in to program responsibilities following identified "best" management strategies that can be adhered to.

**Figure 4: Maturity Matrix for Delivery of Lifecycle Value**

Value delivery practices support all six themes, characterizing this process of the value creation framework.

**Holistic Perspective.** There are two main dimensions to the holistic perspective, consideration of the entire system and consideration of the entire lifecycle. These two dimensions are inter-related and often create unique considerations for product development work. Complex systems involve a wide range of requirements that are often conflicting. For products with long lifecycles, consisting of subsystems and components with different rates of technological advances, this is especially true. It is therefore essential to balance long-term demands such as upgradability and customer support, including

maintenance and repair, with more short-term demands, such as low unit costs and performance.

The research shows that 49% of respondents felt that the concept of lifecycle value was deployed in most areas of the enterprise, but that the level of understanding was inconsistent. Only 8% considered the concept to be fully deployed through the extended enterprise. At the same time, 57% of respondents identified lack of visibility across the lifecycle as a barrier to achieving lifecycle value to some extent.

Observed Practices:

- Use systems engineering practices in product design.
- Incorporate design for manufacturing and assembly.

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- Create lessons learned databases to capture, communicate, and apply experience-generated learning.
- Utilize multi-year contracting where possible.
- Educate designers on lifecycle maintainability and reliability issues.
- Incorporate design recommendations communicated from a variety of lifecycle perspectives.
- Incorporate flexibility and consideration of lifecycle issues into early systems architecture.
- Acknowledge and plan to accommodate the dynamic nature of a system's lifecycle.

### Lessons Learned:

- Coordinate design maturation and production planning to account for differences in sub-systems and components.
  - One example is the coordination of interdependent development efforts with long production lead-time items.

**Organizational Factors.** Cross-functional product development teams in early phases can be very beneficial for a project especially considering the increased collaboration between many functions that span the system's lifecycle. This research has brought out an appropriate caution that the institutionalization of IPTs can lead to increased integration experience at the cost of specialized competence. Although IPTs are an important organizational factor, there are other factors that also contribute to lifecycle value.

### Observed Practices:

- Collocation of product and people
- Alignment of organizational structure to the product work breakdown structure, establishing multi-disciplinary teams
- Maintain a stable workforce capability by creating opportunities for career and skill development programs.
- Use IPT structure to broaden functional responsibilities to facilitate the development of a flexible workforce.
- Hold coordination meetings between leaders of different projects to communicate status of cost and schedule.
- Incorporate specialization at company core competency level and integration at system development level.

### Lessons Learned:

- Balance functional specialization with integration knowledge by shifting the focus of support between functional and IPT organizations throughout development efforts as appropriate.
  - As an example, development work can be done either in a functional organization, promoting specialization, or in an IPT organization, promoting integration experience, and while neither is optimal for all development work, both

have advantages that can be utilized more effectively.

**Tools and Methods.** During the product development process some tools and methods have proved to be strong enablers for the design work. For development of increasingly complex products there has been a growing need for tools to support this. The development of these types of tools has been propelled by the rapid development in the information technology industry. Many of the issues with supporting tools are due to difficulties in integrating the tools.

### Observed Practices:

- Use common CAD modeling software across the enterprise. 81% of the respondents considered this to be an important or critical tool. Further, 71% considered the tool to be well or fully utilized.
- Evaluate design changes using a structured methodology from an operations perspective to reduce preventative maintenance.
- Internet technology and company web sites enable sharing data and information within the enterprise, ensuring timely and efficient access to data.
- Define common databases, tools, and practices for use throughout the value chain. 81% of the respondents considered this to be important or critical.
- Risk management process includes mitigation plans to fix problems systematically using root cause analysis.
- Roadmap emerging technology to plan for technology insertion accordingly.

### Lessons Learned:

- Increase compatibility between modeling and analysis tools to increase productivity.
- Integrate Product Data Management (PDM) and configuration management databases to enable seamless information flow.

**Requirements and Metrics.** The importance of clearly establishing and articulating customer desires has been discussed as an essential part of the value proposition work. In a complex system, incorporating, allocating, and measuring technical requirements is an integral part of the value delivery for the system. Monitoring progress of the system development through common, well understood, and well communicated metrics enables assurance of thorough incorporation of the system requirements. Appropriate management of these requirements is a key factor in the success of programs with the focus on affordable and timely systems gaining importance in the modern aerospace industry.

### Observed Practices:

- Metrics shared weekly throughout the enterprise
- People are empowered to make decisions through the flow down of requirements and metrics creating



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Responsibility, Authority, and Accountability (RAA).

- Earned Value tracking of cost and schedule metrics incorporated through a “perform to plan” philosophy.
- Incorporate plans for growth, upgradability, and technological development in design work.
- A fixed total development cost target contributes to focusing on near-term development cost and schedule.

### Lessons Learned:

- Work within specification framework and terminology to establish actual goals for development efforts.
  - Specifications are often not clearly written and may not adequately communicate the system requirements. This is also supported by earlier research within LARP, (Backlund, 1999).
- Determine when a “good enough” solution is achieved and move on in the development work to maintain schedule performance.

**Enterprise Relationships.** Building on the relationships that have been established through the value identification and proposition work maintains continuity of program goals through the lifecycle of the system. Value delivery typically requires an increase in work force to meet the established targets set in the value proposition. Significant changes in organizational size and structure can add pressure to relationships in the enterprise. To effectively sustain these relationships, there are several approaches that may be uniquely appropriate to various common interactions. For instance, supplier management extends beyond the core of the system enterprise requiring practices that may not apply as directly to relationships between members of the core enterprise.

### Observed Practices:

- Require open and honest communication.
  - Encourage and reward asking for help needed.
- Follow a “Drop Dead” philosophy.
  - Document your job so that someone could come in the next day and pick it up where you left off.
- Utilize knowledge throughout the enterprise regardless of where it originates.
- Share responsibility for decisions throughout the value chain using a well-defined process.
- Jointly establish a design verification program.
  - One example is utilizing an Integrated Test Team to work effectively with all enterprise stakeholders to resolve issues found during test.
- Maintain organizational counterparts throughout the enterprise with active working relationships to facilitate efficient communication and problem solving.
- Create and maintain leadership alignment across enterprise.
- Jointly establish targets for continuous improvement using a structured process.

### Lessons Learned:

- Maintain visibility of enterprise relationships throughout levels of each organization to prevent sub-optimization.
- Incentivize behavior corresponding to development targets.
  - One example is an “incentive ladder” to promote on-schedule development activity.
- Manage out-sourced development work according to the level of maturity of the technology.
- Treat technical intellectual property of all stakeholders with respect to build trust.

**Leadership and Management.** Leadership and management practices are important facilitators to achieve best lifecycle value for a system. In many cases, the external view of a program relies on the reputation and credibility of the leadership involved. It is this external view that ultimately determines how well the program has delivered on the system value proposition. Appropriate program management training and implementation are essential to realize the value proposition for the system. Perhaps the most important role of leadership and management practices is in establishing the appropriate program culture that ties together many of the individual practices and strategies that have been observed and identified through lessons learned from this case work.

### Observed Practices:

- Create strategies and practices that can be adhered to through leadership transitions.
- Maintain high expectations for program success.
- Program leadership emphasis on maintaining credibility.
- Establish clear roles for decision makers within a well defined process to facilitate decision making.
- Leadership brings people together and facilitates working together by preventing strong personalities from taking over.
- Management support mentality to provide adequate resources to solve development issues effectively.
  - Upside down organization chart.
- Utilize program management training.
- Management push to evaluate the alternative no growth (in cost or weight) solution in terms of risk to understand complete set of decision alternatives.
- Model and promote a proactive culture to address program issues.

### Lessons Learned:

- Create buy-in of schedules and resource allocation for the program.
- Emphasize the importance of schedule performance to prevent coordination problems and bottlenecks that may cause unnecessary design changes.
- Promote excellence under “normal” circumstances instead of hero behavior in “crisis” situations.

## CONCLUSIONS

This research has focused on identifying the enabling factors in product development for achieving lifecycle value. Focusing on value delivery, six main factors have been extracted from three cases studied. The relative importance of each factor was not identified by this research. Similarly, variation in level of maturity for each factor was not considered regarding how it influences achievement of lifecycle value. Each case studied delivered value in different ways depending on the value proposition for each system.

## SUMMARY

Improvements in technologies and tools have facilitated capabilities to coordinate development efforts throughout an enterprise. This combined with increased pressure to develop affordable systems has created the need for system approaches to development work based on common objectives. This research investigated one such approach, the consideration of best lifecycle value in the defense aerospace industry. Three cases were studied to characterize the dimensions of lifecycle value, as well as to capture enabling practices and strategies and potential barriers. Evaluation of the results in a lifecycle value framework consisting of value identification, value proposition, and value delivery has led to codification of the observed practices into a maturity matrix for the delivery of lifecycle value based on six main emergent themes. The systems investigated exhibited variation in the maturity level of lifecycle value consideration for each theme. Although each system exhibited significant awareness of lifecycle value, there is still work to be done in achieving the goal of lifecycle value delivery.

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