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# Strategies for Lean Product Development

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## Introduction

The essence of lean is very simple, but from a research and implementation point of view overwhelming. Lean is the search for perfection through the elimination of waste and the insertion of practices that contribute to reduction in cost and schedule while improving performance of products.

This concept of lean has wide applicability to a large range of processes, people and organizations, from concept design to the factory floor, from the laborer to the upper management, from the customer to the developer. Progress has been made in implementing and raising the awareness of lean practices at the factory floor. However, the level of implementation and education in other areas, like product development, is very low.

The Lean Aerospace Initiative (LAI) has been producing research in support of the military and industry since 1993 on the topic of lean and its benefits. Implementation of the research has been shown to have significant impact and interest. LAI is in a very unique situation at MIT to influence and educate world-class engineering students we have exposure to every day. This research will take advantage of this situation and produce a strategic framework for educating engineers on the front-end lean product development findings that have been produced through LAI. These include topics of understanding the customer and the product value, evaluating multidimensional risk, organizational impact on program performance, and many others.

The research objectives are to: 1) synthesize the findings uncovered by LAI pertaining to non-manufacturing disciplines into a readily usable manner and 2) formulate a strategic approach for educating engineers on the tools and concepts that facilitate early problem synthesis, mission engineering, and front end product development.

## Overview

There are six modules into which the LAI product development research has been organized. Module I is used to provide a fundamental framework of lean and its application to product development. Module II identifies the impacts of organizational change on product development. Module III creates a more clear connection between lean and specific process steps in product development. Module IV introduces the research results that have been uncovered in the field of program planning and execution. Module V discusses the external environment relationships to the successful product development execution. Finally Module VI presents the tools and applications that have either been developed significantly researched through LAI

In each of these modules overviews of the research results can be found. By no means is this an exhaustive text on the research results. The text is used to highlight and direct interest toward certain references. Instead, an exhaustive reference section (with annotation where possible) is included in each of the modules which contains not only research produced though LAI, but also contains research that has been conducted through the Center for Innovation in Product Development which directly pertains to similar topics.

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# MODULE I: PROVIDE A FUNDAMENTAL FRAMEWORK OF LEAN AND ITS APPLICATION TO PRODUCT DEVELOPMENT

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## Module I Introduction

At the start of each module, it is important to understand how each relates to the overall goal of the project and also how each relates to concepts of Lean. Module I is the first in a series of six self-standing texts aimed at releasing research uncovered through the Lean Aerospace Initiative in the field of lean product development. This module focuses on the introductory aspects of lean. It creates a foundation of the origins of lean and the applicability to product development.

The first section addresses formally defines the principles of lean as they are currently understood.  The second section discusses the origins of lean, while the third section discusses its application to the product development process.  The final section sets forth some of the success stories of lean product development to justify its relevance.

## Defining Lean Concepts

Defining the concepts that are at the heart of lean has been the topic of many works, including Lean Thinking, The Machine that Changed the World, Learning to See, From Lean Production to the Lean Enterprise, Thinking Beyond Lean.  At the forefront of defining and applying concepts of Lean are James Womack and Daniel T. Jones. Although, none of these publications were developed through the Lean Aerospace Initiative, they cannot be left out in discussing Lean.

Although there is no comprehensive publications that has been produced by LAI for the discussion and description of lean, there is a extremely valuable resource that has been created in the form of the Lean Enterprise Model (LEM).  The LEM is the main vehicle that LAI uses to organize and disseminate the research findings that have been achieved.

> The LEM is a systematic framework for organizing and disseminating research results of the Lean Aerospace Initiative.  It encompasses lean enterprise principles and practices and is populated by research-based benchmarking data derived from surveys, case studies and other research activities.  The LEM is designed to help LAI members identify and assess the leanness of their own organizations and processes, and is intended to help leverage opportunities for organizations change and to support future lean efforts.[1]

The twelve overarching practices in the LEM although not explicitly stated in the text can easily be traced to the six modules that exist in this text.  These connections and traceability are presented in Figure 1.

[1] LAI (1998). The Lean Enterprise Model. Cambridge, MA, Massachusetts Institute of Technology.

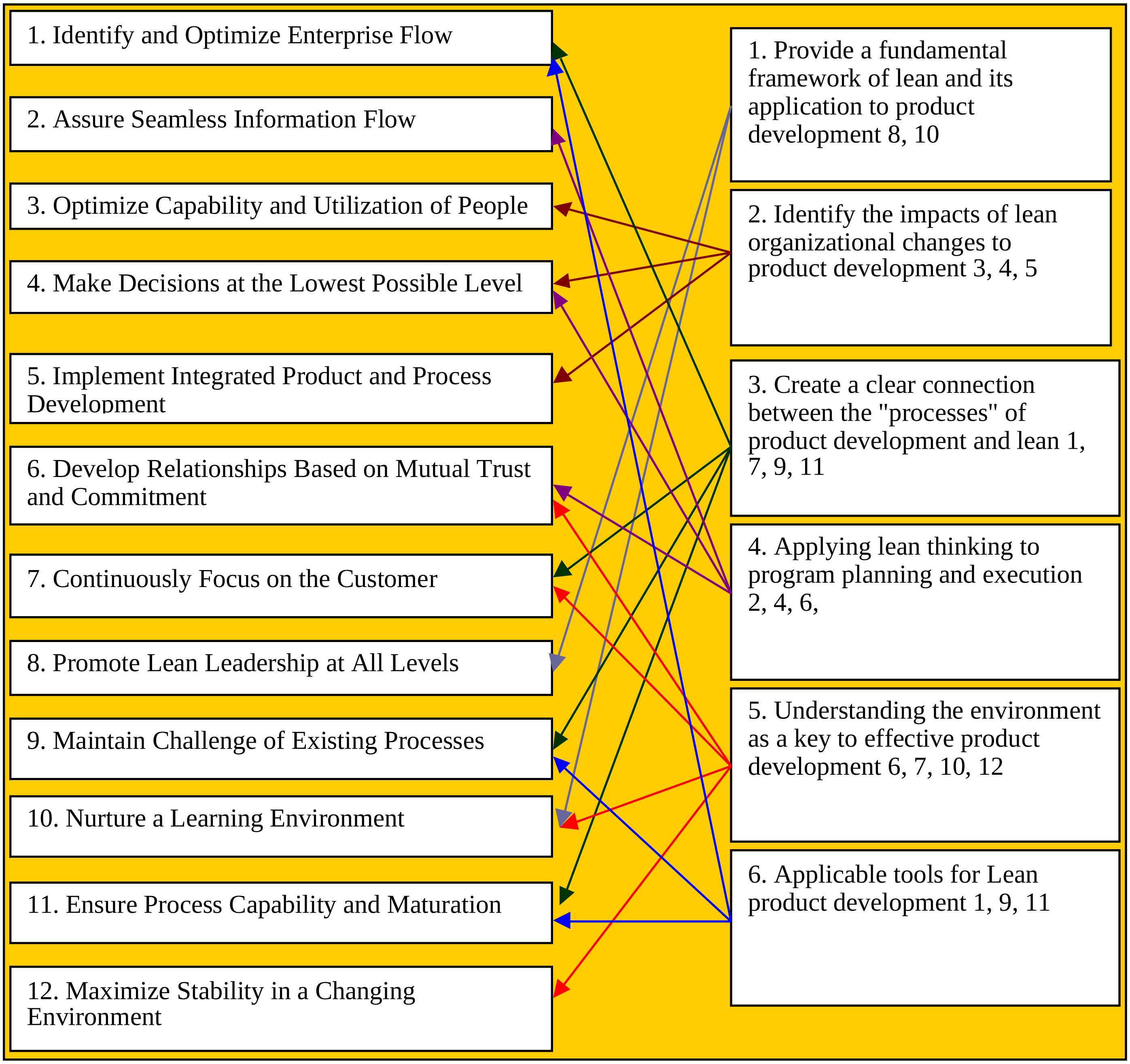


**Figure 1: Connecting the LEM Principles to this work**

The following are some definitions that are taken primarily from (Womack 1996), except when otherwise noted. They are included here as necessary background for the rest of the work.

### *Value and the Value Stream*

Identifying the value of a product and the most effective process (in terms of cost and schedule) to achieve that value is the one of the major goals of lean. Womack describes value as "a capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer." [2] The most effective process is achieved by performing the minimum number of value-added steps and no non-value-added steps. The method to maximize value-added steps in lean practice is through value stream mapping. The value stream is "the specific activities required to design, order, and provide a specific product, from concept to launch, order to delivery, raw materials into the hands of the customer."[3]

### *Waste*

Waste is often referred in the lean context as muda. There are two types of waste defined in the lean context, Type I Muda and Type II Muda. Type I Muda is found in activities that add no value to the customer, but are necessary, in the current development framework, to deliver the product. Type II Muda is found in activities that don't create value and can be eliminated immediately, such as waiting and unnecessary transport.

### *Flow*

Flow is described as "the progressive achievement of tasks along the value stream so that a product proceeds from design to launch, order to delivery, and raw materials into the hands of the customer with no stoppages, scrap or backflows."[4]

### *Pull*

Pull is defined as "a system of cascading production and delivery instructions from downstream to upstream activities in which nothing is produced by the upstream supplier until the downstream customer signals a need."[5] The following three characteristics are necessary conditions for pull.

#### Synchronization (Timing)

Synchronization refers to aligning takt times of interconnected processes such that proper timing is in place, thus enabling flow and allowing for pull to be successful.

#### Alignment (Position)

Alignment describes proper positioning that is necessary for pull to occur. In a manufacturing sense this could mean physical position, in a development point of view, this could mean proper file format and location.

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[2] Womack, J. a. D. T. J. (1996). Lean Thinking. New York, NY, Simon & Schuster., p. 311

[3] Womack, J. a. D. T. J. (1996). Lean Thinking. New York, NY, Simon & Schuster., p. 311

[4] Womack, J. a. D. T. J. (1996). Lean Thinking. New York, NY, Simon & Schuster., p. 306

[5] Womack, J. a. D. T. J. (1996). Lean Thinking. New York, NY, Simon & Schuster., p. 309

### Transparency

Transparency describes the ability to see the process totally and without obstruction as a means for identifying problems quickly and efficiently.

### *Perfection*

Perfection is the continuous improvement aspect of Lean. Understanding that a process today is imperfect and that there is a need for continuous reexamination of the process/product is necessary to remain competitive and lean.

## Origins of Lean

The early phase of the M.I.T. International Motor Vehicle Program (IMVP) saw the first use of the term "lean manufacturing" (or "lean production") to describe a revolutionary approach to manufacturing observed in the study, as contrasted with the mass production tradition. As a concept, "lean" includes several of the popular concepts of management research, such as Total Quality Management (TQM), Continuous Improvement, Integrated Product Development (IPD), and Just-In-Time (JIT) inventory control. Lean manufacturing attempts to unite these niche topics into a unified philosophy for producing products.

The principles of lean manufacturing—as derived from the five year, five million dollar study of American, Japanese, and European auto makers by the IMVP (from 1985 to 1990)—were first documented in the highly visible bestseller, The Machine that Changed the World. The IMVP research presented in the book notes the broader scope of lean, which extends beyond the manufacturing realm. Indeed, to succeed as an overall business philosophy, lean principles must incorporate areas outside of manufacturing—the entire product development process. Much of the research related to these other areas has been incorporated into the lean paradigm. For example, much of the product development research in the auto industry done by Clark and Fujimoto at Harvard Business School fits into the IMVP work. Concepts of leadership, teamwork, communication, and simultaneous development all became aspects of lean. As the lean paradigm receives wider application, further refinement and elaboration of its tenets becomes necessary. One area currently attempting to apply lean principles to its unique context is the defense aircraft industry.[6]

### *Applications of Lean in Manufacturing/Production*

Lean production finds its origins in four well-known, but often-forgotten principles:

- The goal of a business enterprise is to create wealth for its owners by creating value for its customers
- Resources are limited--they must never go to waste
- Intensifying competition demands that all business enterprises continuously improve by endlessly striving for ever higher quality, ever lower costs, and ever faster response times

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[6] Browning, T. (1996). Systematic IPT Integration in Lean Product Development. Technology and Policy and Aeronautics and Astronautics. Cambridge, MA, MIT.

- People are intelligent and motivated to do a good job -- give them the right tools and adequate authority, and they will not only do their jobs well, but they will also make improvements on their own initiative.[7]

One of the individuals at the forefront of lean, Taiichi Ohno, enumerated seven forms of waste found in physical production

- *Over-Production* ahead of demand
- *Inventory* more than the absolute minimum
- *Transportation* of materials
- *Unnecessary Movement* by employees during the course of their work
- *Waiting* for the next process step
- *Defective Products* production
- *Over-Processing* of parts due to poor tool and product design

### *Industry Acceptance of Lean Principles*

The success of LAI as a consortium is a clear indicator of the acceptance of lean principles. Currently the consortium includes 19 industry members, government entities including the Air Force, the National Reconnaissance Organization, DARPA, and Academia through the Massachusetts Institute of Technology.

## Product Development Defined

This section introduces definitions and boundaries of product development that are defined in the literature. It contains the perspectives of four major books on product development.

> *Product development* is the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product.[8]
>
> ***Subtleties thereto:***
> *Agile product development* process is one that can rapidly introduce a steady succession of incremental product improvements-which can be called "new" products-that are really planned "variations on a theme," based on common parts and modular product architecture. This capability results in ultra-fast time-to-market, much faster than possible with independent products that do not benefit from product-family synergies in design and manufacture.[9]

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[7] Rosson, R. (1994). Self-Directed Work Teams at Texas Instruments Defense Systems & Electronics Group. Management. Cambridge, MA, MIT.

[8] Ulrich, K. a. S. E. (1995). Product Design and Development. New York, NY, McGraw-Hill, Inc., p. 15.

[9] Anderson, D. M. (1997). Agile Product Development for Mass Customization. Chicago, Irwin Professional Publishing., p. 215.

### *Identifying the boundaries of product development*

**1.) Anderson**

For advanced product development, a minimum of the following phases is recommended. Each phase emphasizes a clear focus with important deliverables. The first two phases represent the all important thorough up-front work that will ensure that the subsequent progress will be rapid and that all design goals will be accomplished right the first time. Resolution of these issues should start early and be continuously emphasized, especially in the early phases when issues are easier to resolve.

Some phase/gate methodologies recommend "bread-board" and "prototype" phases without really having a design phase. This places too much emphasis on building breadboards and prototypes instead of on thorough product design. Similarly, rapid production ramp-up should be emphasized instead of pilot activities. Introducing new products into a flexible manufacturing environment should be easier because the "new" products may really be "variations of a theme" if the products were designed around common parts, modules and processes.

Finally, the lessons learned from every product development should be captured, documented, and applied to all future product developments.

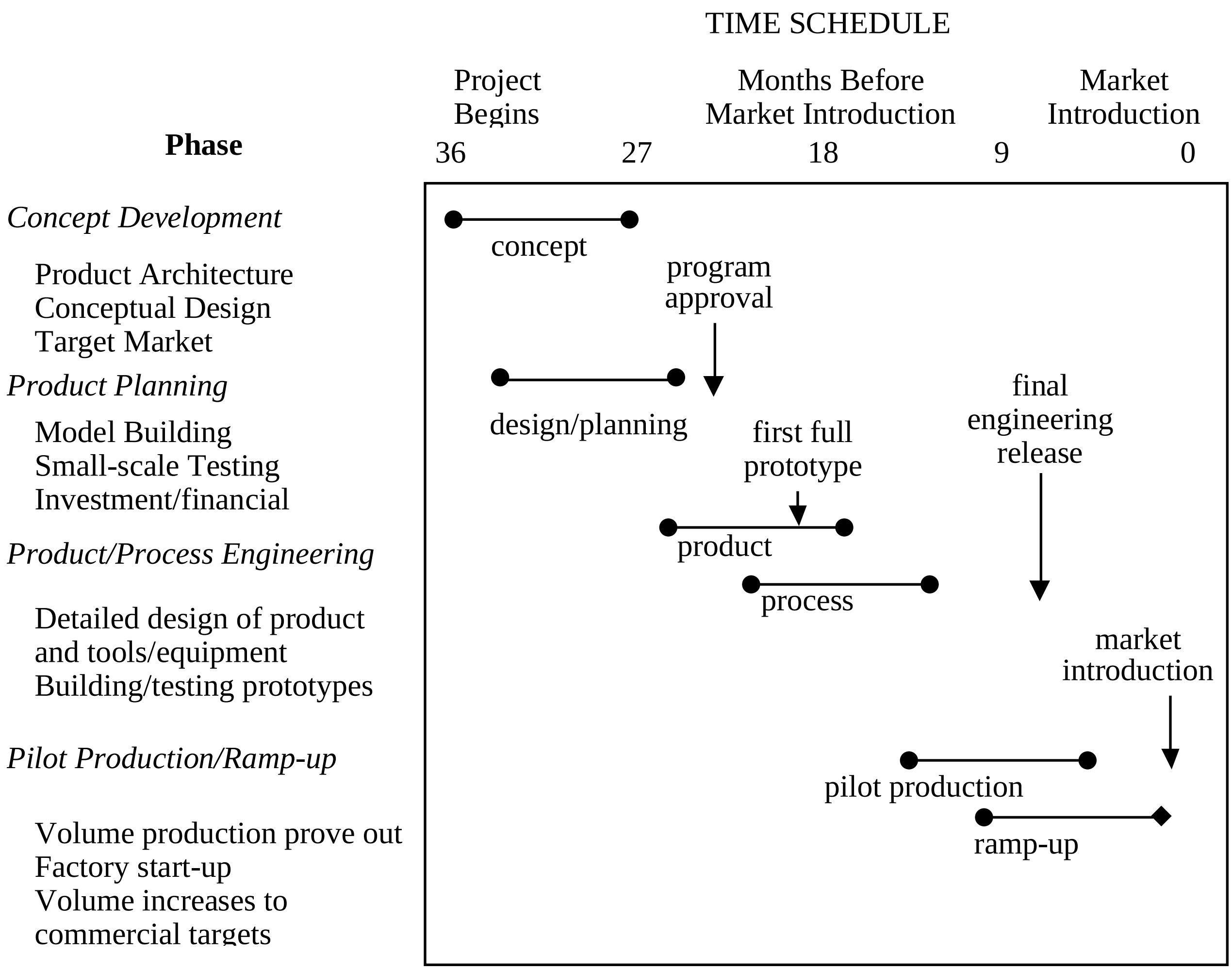
Advanced Product Development Phases:

| Phase | Definition |
|---|---|
| 1. Product Definition | Product specifications and resource prioritization |
| 2. Architecture | Simplified concept and optimized architecture including modularity and customization strategies |
| 3. Design | Product/Process design so thorough that the need for prototype testing and pilot production is minimized or eliminated |
| 4. Ramp-up | Smooth introduction into production with rapid volume ramp-up |
| 5. Follow-up | Postmortem to capture lessons learned that can be applied to future projects.[10] |

**2.) Wheelwright and Clark**

Typical Phases of Product Development

[10] Anderson, D. M. (1997). Agile Product Development for Mass Customization. Chicago, Irwin Professional Publishing.




*This development process assumes a thirty-six month cycle time and four primary phases. Vertical arrows indicate major events; horizontal lines indicate the duration of the activities.[11]

### 3.) Ulrich and Eppinger

Ulrich and Eppinger's generic model of product development contains five phases as shown in Figure 2.

[11] Wheelright, S. a. K. C. (1992). Revolutionizing Product Development. New York, NY, The Free Press., p. 7.

| | Phase1 Concept Development | Phase2 System-Level Design | Phase3 Detail Design | Phase4 Testing and Refinement | Phase5 Production Ramp-up |
|---|---|---|---|---|---|
| *Marketing* | • Define market segments.<br>• Identify lead users<br>• Identify competitive products. | • Develop plan for product options and extended product family | • Develop marketing plan | • Develop promotion and launch materials<br>• Facilitate field testing | • Place early production with key customers |
| *Design* | • Investigate concept feasibility<br>• Develop industrial design concepts<br>• Build and test experimental prototypes | • Generate alternative product architectures<br>• Define major sub-systems and interfaces.<br>• Refine industrial design | • Define part geometry<br>• Choose materials<br>• Assign tolerances<br>• Complete industrial design control documentation | • Do reliability, life , and performance testing<br>• Obtain regulatory approvals<br>• Implement design changes | • Evaluate early production output |
| *Manufacturing* | • Estimate manufacturing cost<br>• Assess production feasibility | • Identify suppliers for key components<br>• Perform make-buy analysis<br>• Define final assembly scheme | • Define piece-part production processes<br>• Design tooling<br>• Design quality assurance processes<br>• Begin procurement of long-lead tooling | • Facilitate supplier ramp-up<br>• Refine fabrication and assembly<br>• Train work force<br>• Refine quality assurance processes | • Begin operation of entire production system |
| *Other Functions* | • Finance: Facilitate economic analysis.<br>• Legal: Investigate patent issues. | • Finance: Facilitate make-buy analysis.<br>• Service: Identify | | • Develop promotion and launch materials<br>• Facilitate field testing | |

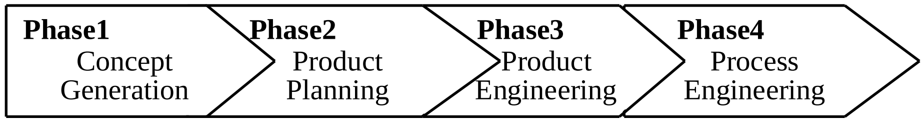
**Figure 2: Ulrich and Eppinger generic product development process**[12]

### 4.) Clark and Fujimoto

The product development process contains four major developmental stages: concept generation, product planning, product engineering, and process engineering. Although

[12] Ulrich, K. a. S. E. (1995). Product Design and Development. New York, NY, McGraw-Hill, Inc., p. 9.

in practice the development process has many loops, parallel steps, and obscure boundaries that render it far from linear, we portray the process as sequential for purposes of description. These four steps are similar in content to the first four steps proposed by Wheelright and Clark.[13]




## Applying Lean to Product Development

The majority of information contained in this section is the joint work of the product development team in the Lean Aerospace Initiative. It has been synthesized through continuous conversation and workshops with industry government and academic team members. The following definitions have been under work in LAI since the summer of 1998. But first, to give an idea of some of the differences between lean product development and functional product development, Table 1 is provided.

| ***Lean*** | ***Functional Product Development*** |
|---|---|
| Lean Thinking | Functional Management |
| Rapid Model Replacement | Slow model replacement |
| Frequent model-line expansion | Infrequent model line expansion |
| More incremental product improvements | More radical product improvements |
| Heavyweight project managers | Lightweight project coordinators |
| Overlapping compressed phases | Sequential long phases |
| High levels of supplier engineering | High levels of in-house engineering |
| Design team and project-manager continuity continuity | Department member |
| Good communication mechanisms | Walls between departments |
| Cross-functional teams departments | Narrow skills in specialized |

**Table 1: Lean versus functional product development[14]**

### *Value and Value Stream*

In *Lean Thinking* value is defined as "A capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer." An immediate difficulty presents itself when attempting to define value solely in the context of product development. At the end of the PD process, value has only partially been realized. The design may eventually satisfy the end user, but it must pass through

[13] Clark, K. a. T. F. (1991). Product Development Performance. Boston, MA, Harvard Business School Press., p. 26.

[14] Cusumano, M. a. K. N. (1998). Thinking Beyond Lean. New York, NY, The Free Press., p. 5.

production, operations, sustainment, and possibly upgrades before life-cycle value can be assessed. Aspects of "value" can include a producible, low cost design; a design that is expected to satisfy customer requirements with an acceptable level of risk; or a supplier infrastructure which supports production as well as the operations and sustainment. All of these contribute to a successful product. There is also value which flows to future developments (e.g. human capital preservation and experience, synergies to other products, etc.). The PD process also pulls in value from organizations or tasks that do not at first appear to be in the direct value stream, (e.g. research groups, internal information infrastructure and tool creation groups, etc.).

For the purposes of the initial value stream definition, it is recommended that only the direct value to the product being developed will be addressed. A plausible definition of value in product development is: the right information products delivered at the right time, to downstream processes/customers, where it is quantified by form, fit, function and timeliness of information products.[15]

*The product development value stream* consists of tasks that transform information and allow for the convergence of the segmented information to define a final design. Figure 3 represents the product development value stream as only part of the larger product life-cycle value stream where the customer achieves the desired product value.[16]

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[15] LAI, M. P. D. T. (1998). Identifying the Value Stream in Product Development. Cambridge, MA, Massachusetts Institute of Technology.

[16] McManus, H. (1999). Lean Engineering. Cambridge, MA, Massachusetts Institute of Technology.

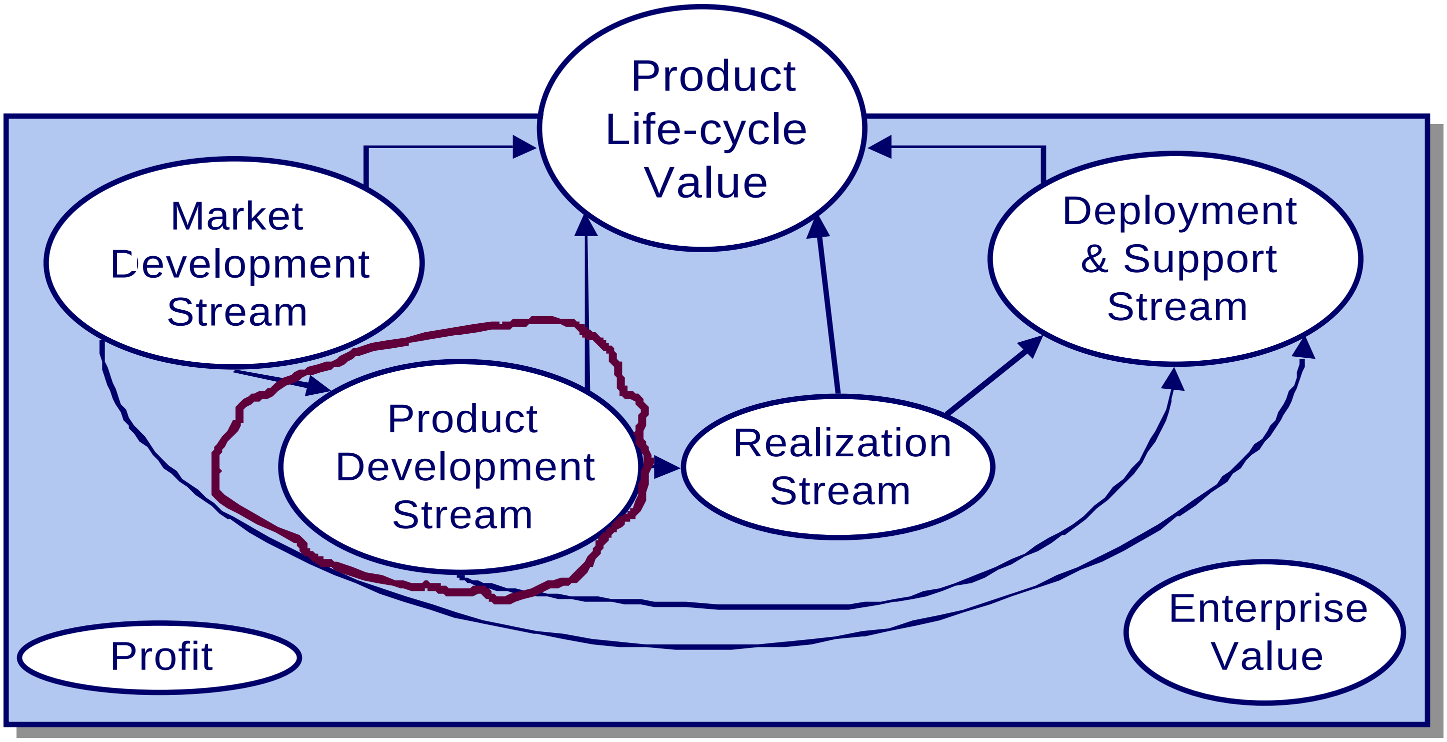


**Figure 3: Product Life-Cycle Value**[17]

### *Waste*

As presented above, manufacturing has identified seven types of waste that improvement teams can look for and eliminate. Continuing on the same idea, the LAI Product Development Team applied the same seven wastes to product development.

- **Over Production**
  - Too Much Detail
  - Unnecessary Information
  - Redundant Development(Reuse not practiced)
- **Transportation**
  - Information/Software Incompatibility
  - Communications Failure
  - Not Standards Based
  - Multiple Sources
  - Incompatible destinations requiring multiple transport
- **Waiting**
  - Information Created Too Early
  - Late Delivery of Information
  - Unavailable Information
  - Quality Suspect
- **Processing**
  - Unnecessary Serial Processing
  - Lack of Needed Information
  - Poor/Bad decisions affecting future

[17] Warmkessel, J. (1998). Introduction to the Product Value Stream. Cambridge, MA.

- Excess/Custom Processing
- Not processed per process
- Too Many Iterations/Cycles
- Unnecessary Data Conversions
- Excessive Verification
- No Transformation Instructions
- Decision Criteria Unclear
- Working WithWrong Level of Detail
- Propagation of Bad Decisions
- Processing of Defective Information
- Multiple Tasking When Not Required

- **Inventory**
  - Too Much Information
  - Incomplete Content
  - Poor Configuration Management
- **Unnecessary Movement**
  - Information User Not Connected to Sources Requiring Manual Intervention
  - Information Pushed to Wrong People
- **Defective Product**
  - Quality Lacking or Suspect
  - Conversion Error
  - Wrong Level of Information
  - Incomplete Information
  - Ambiguous Information
  - Inaccurate Information
  - Tolerance Exceeded
  - Poor Configuration Management

## Justifying Lean Strategies in Product Development

In January of 1995, at approximately the midpoint of the 3-year first phase of the LAI effort, an Air Force-MIT team was formed to visit LAI member companies. The primary purpose of the visits was to make an informal assessment of the progress being made by companies in adopting lean principles and to gather input from industry on government-imposed barriers to becoming lean. The team also tried to assess the impact of lean implementation on the companies and to identify "candidate" lean practices that could be considered for further research and study by LAI focus groups.

It is important to note that the principles of lean were being embraced by the aircraft industry prior to the initiation of LAI. The team looked for evidence of implementation of lean as well as any special influence that LAI was having. The team was composed of researchers from MIT, acquisition executives from the Air Force's Aeronautical Systems Center, as well as executives and technical experts from the Air Force Manufacturing Technology Directorate.[18]. With the goal of visiting all member companies in LAI Phase I, the team has visited a total of 16 companies (20 major facilities) since January 1995. The companies represent a major cross-section of the basic types of businesses participating in the military aircraft sector of the industrial base--- aircraft prime contractors, major structures subcontractors, airborne electronics

[18] The list of participants is provided as Appendix 2 of Kessler, W., Brian Kosmal, and Earll Murman (1997). Lean Aircraft Initiative: Making a Difference-Report on Site Visits,Round I & II. Cambridge, MA, MIT..

suppliers (several of which also produced tactical munitions), producers of complex electro-mechanical subsystems and engine suppliers

The product development area is rich in opportunities for improvement. The length of time it takes to develop a new product; the degree to which the product satisfies the requirements of the customer; and the ease with which new products can be produced are all areas in which most defense companies can make dramatic improvements when compared to the most successful commercial companies.

Benefits - At virtually every company, dramatic benefits are being achieved through implementation of lean product development practices and more are anticipated. Here are samples of the best results from various companies:

• Cycle time reductions

-new product introduction -- down 30%

-producibility changes -- down 75%

-production lead-time -- down 65%

-radar development-- concept to operational in 24 months

-new technology inserted 2 years ahead of original schedule

• Engineering post-release change rate

-down 96%

-down 75%

-reduced by 2/3' s in 4 years

-down by a factor of 10

• ease of assembly

- 5700 parts in new product vs. 10,000 in past designs

- 25% larger product but 33% fewer parts

- parts down 37%/interconnects down 70%

- parts reduced 44%---costs dropped 58%---64% less assy. labor

• First article inspection results

- 72% passed vs 35% on previous product

- 90% first time pass rate on new product

Integrated Product/Process Development (IPPD) - Leading companies in the commercial sector are using Integrated Product/Process Development approaches to become leaner in product development, and so was every LAI-member company visited. At some companies, IPPD was being zealously applied to pilot projects and at others it was well established and being widely used. In addition, each company was using some variant of the Integrated Product Team (IPT) as a basic mechanism for implementing IPPD. Entire programs are being run under an IPT-based structure, and at some companies, making those IPTs more effective has become the primary function of most of the other elements of the company.[19]

The success of lean on the consortium members is also discussed in a number of articles published in recent years about LAI. Two examples that provide a good overview of the LAI success story are:

- (Baker 1998)
- (Kandebo 1997)

## References for Module I:


Anderson, D. M. (1997). Agile Product Development for Mass Customization. Chicago, Irwin Professional Publishing.

Baker, S. (1998). "The Journey Toward Lean." Program Manager(March/April 1998).

Browning, T. (1996). Systematic IPT Integration in Lean Product Development. Technology and Policy and Aeronautics and Astronautics. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/browning.pdf

*Integrated Product Development (IPD) is a crucial aspect of the lean paradigm. The drive towards IPD includes an impetus to organize around Integrated Product Teams (IPTs). The use of IPTs has brought with it many issues, including those at the IPT interfaces. Program integration (of a cross-functional, upstream/downstream nature) can exist at three levels: (1) within the IPTs, (2) between the IPTs in system level teams, and (3) between the IPTs and system level teams in the program at large. This work focuses on the second and third levels, the realm of IPT interdependence, and categorizes several Integrative Mechanisms (IMs) to facilitate interteam integration. IMs are strategies and tools for effectively coordinating actions across teams within a program. To provide a variety of contexts for investigation in the defense aircraft industry, the thesis includes five case studies of development programs of varying size from each of several sectors. Each is analyzed for its use of IMs. To give a systematic basis for designing the design process, the application of the Design Structure Matrix (DSM) to model program organization based on information flow is considered in one case. DSM-based approaches to interface management have been used in the automotive and other industries. They can help a systems engineer/manager systematize the interface management process, both at a product level and at an interteam level. This facilitates decisions as to the correct utilization of IMs. These studies provide the basis for lean principles of program integration, which include designing a program for integration.*

Browning, T. (1997). Summary Report: Systematic IPT Integration in Lean Development Programs. Cambridge, MA, MIT.


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[19] Kessler, W., Brian Kosmal, and Earll Murman (1997). Lean Aircraft Initiative: Making a Difference-Report on Site Visits,Round I & II. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/RP970119Browning.pdf

*This document provides a summary report of the M.I.T. masters thesis Systematic IPT Integration in Lean Development Programs by Tyson R. Browning. Integrated product development (IPD) has been established as a salient aspect of the lean enterprise paradigm. The drive towards IPD includes an impetus to organize around integrated product teams (IPTs), cross-functional groups responsible for developing a particular element of a system product. The use of IPTs has brought with it many issues, including those at the IPT interfaces. The goal of this research is to provide insight into the integration of multiple IPTs in programs.*

Clark, K. a. T. F. (1991). Product Development Performance. Boston, MA, Harvard Business School Press.

Cusumano, M. a. K. N. (1998). Thinking Beyond Lean. New York, NY, The Free Press.

Gansler, J. (1989). Affording Defense. Cambridge, MA, MIT Press.

Kandebo, S. (1997). Lean Initiative Spurs Industry Transformation. Aviation Week & Space Technology.

Kessler, W., Brian Kosmal, and Earll Murman (1997). Lean Aircraft Initiative: Making a Difference-Report on Site Visits,Round I & II. Cambridge, MA, MIT.

*A joint MIT and USAF team visited five military aircraft companies to assess the progress being made in implementing lean practices and to identify actions the government could take in accelerating lean implementation. This report highlights important progress being made by these five LAI participating companies and identifies candidate best practices. Each company had undergone a significant shrinkage in its business base over the past few years. Most have eliminated floor space and equipment and have experienced major personnel reductions. The companies' leadership were clearly convinced that their company's future was linked to their ability to deliver quality products at affordable cost. The companies which had commercial business as the largest part of their business appeared to be moving faster towards lean than those which do not. Companies that appeared to be most advanced employed an entrepreneurial approach.*

Klein, J. a. G. I. S. (1995). Lean Aircraft Initiative Organization & Human Resources (O&HR) Survey Feedback: Integrated Product Teams. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/95_03.pdf

*The purpose of the LAI O&HR survey of IPTs was 1) to establish a baseline of defense aerospace industry practices, and 2) to determine whether factors that lead to the effectiveness of IPTs in other industries are applicable to the defense aerospace industry. This white paper first summarizes the current practices relative to IPTs within the* *defense aerospace industry, then presents an effectiveness analysis which suggests that appropriate organizational policies and practices vary with the types of products that teams develop. The analysis is based on 594 respondents who were representatives of 63 IPTs; two-thirds of the IPTs were from companies, one-third from either Air Force product centers (APCs) or logistics centers (ALCs). The survey was administered during the first quarter of 1993.*

LAI (1998). The Lean Enterprise Model. Cambridge, MA, Massachusetts Institute of Technology.

LAI (1999). Benefits of Implementing Lean Practices and the Impact of the Lean Aerospace Initiative in the Defense Aerospace Industry and Government Agencies. Cambridge, MA, Massachusetts Institute of Technology.

http://lean.mit.edu/public/pubnews/WH_bens.pdf

*Although the primary intent of the LAI Consortium is to reduce the cost and cycle time for military aerospace products, a valuable side benefit is impacting academia which represents the source of future talent and knowledge for the field. MIT cites seven ways that the LAI is impacting its institution:*

- *Some 50 graduate students have undertaken research. 11 graduates havebeen hired by consortium members and 6 by consulting groups.*
- *At any time, 13-18 faculty are engaged, most of whom knew little about leanpractices before LAI*
- *Engineering and Management School collaboration, a linkage sadly lacking in most US universities, is being positively impacted at MIT*
- *MIT faculty and students are gaining first hand knowledge of "real world" priorities through participating in focus teams and workshops*
- *MIT degree programs and curriculum are benefiting directly from the LAI ∑ The LAI is serving as a new model for collaborative research with academia, industry and government working on interdisciplinary problems*
- *The LAI is affording MIT an opportunity to make a recognized impact on a intellectual area of national importance*

LAI, M. P. D. T. (1998). Identifying the Value Stream in Product Development. Cambridge, MA, Massachusetts Institute of Technology.

*This paper captures the thoughts of the faculty, students, and staff of the MIT Lean Aerospace Initiative. Its contents were developed in May, June and July of 1998, primarily in a series of afternoon workshops. It is the first step in an LAI exercise, that will include industry, government, and expert input, to identify the Value Stream in Product Development. This work will both help to focus LAI Product Development research, and contribute to progress towards Lean Product Development. This document is intended to be a beginning point for discussions; it is NOT a final product.*

*The objective of this work is to apply the concepts of "value" and "value stream", familiar concepts in the production world, to product development. The first essential step on the path to Lean PD requires identification of the value stream. As noted in Womack and Jones's Lean Thinking: "Just as activities that can't be measured can't be properly managed, the activities necessary to create, order and produce a specific product which can't be precisely identified, analyzed, and linked together cannot be challenged, improved, and, eventually, perfected."*

Lee, D. a. A. T. (1996). Identification and Use of Key Characteristics in the Product Development Process. ASME Design Theory and Methodology Conference, Irvine, CA.

McManus, H. (1999). Lean Engineering. Cambridge, MA, Massachusetts Institute of Technology.

*This is a presentation that briefly outlines the discussions and work conducted by the product development team on the nature of lean as it applies to product development. This includes concepts like value, value stream and describes some methods to apply these within product development.*

Rosson, R. (1994). Self-Directed Work Teams at Texas Instruments Defense Systems & Electronics Group. Management. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/rosson.pdf

*Lean production is rapidly replacing conventional mass production at manufacturing companies in the US and throughout the world. Human resources practices play a critical role in any company's program to develop and institutionalize lean methods on the shop floor. One approach that has been successful at many companies involves organizing production workers into self-directed work teams. Teams of between five and fifteen workers take responsibility for an integrated, customer-driven production process. Team members cross train in many of the tasks within the defined process and gradually expand their capabilities to include administrative and support roles. As the team matures, it slowly becomes increasingly autonomous, until it functions with minimal supervision. Texas Instruments Defense Systems and Electronics Group (TI DSEG) has pioneered the concept of self-directed work teams. This thesis presents a case study and analysis of two particular teams at TI DSEG: the Switch Filter/Beam Former Team and the Diamond Point Turning Team. Both teams have achieved a high-level of maturity in terms of their degree of autonomy and the sophistication of their activities. The objectives in studying these two teams are to highlight the key factors that contributed to their success, to uncover the pitfalls and roadblocks they encountered along the way, and to document the organizational structures and operating procedures that support the self-directed team concept.*

Susman, G. a. I. P. (1995). Follow-up Study: Lean Aircraft Initiative: Product Development Team Effectiveness. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/95_06.pdf

*This study seeks to relate team management practices to team success as measured by the extent to which the team goals are met. The importance of particular team varies by project phase. In an earlier study, team leader strength was significantly related to project success. The current study helps to identify factors which influence team leader strength.*

Ulrich, K. a. S. E. (1995). Product Design and Development. New York, NY, McGraw-Hill, Inc.

Warmkessel, J. (1998). Introduction to the Product Value Stream. Cambridge, MA.
*October 1998 Plenary Presentation*

Wheelright, S. a. K. C. (1992). Revolutionizing Product Development. New York, NY, The Free Press.

Womack, J. a. D. T. J. (1996). Lean Thinking. New York, NY, Simon & Schuster.

# MODULE II: IDENTIFY THE IMPACTS OF LEAN ORGANIZATIONAL CHANGES TO PRODUCT DEVELOPMENT

## Table of Contents



## Module II Introduction

At the start of each module, it is important to understand how each relates to the overall goal of the project and also how each relates to concepts of Lean. Module II represents the second in a series of six self-standing texts aimed at releasing research uncovered through the Lean Aerospace Initiative in the field of lean product development. This module focuses on the organizational aspects of lean product development. Lean is not simply an application of best practices and tools. It requires far more in terms of cultural and organizational growth. Perspectives on teams, functions, and responsibilities must change and align themselves with the practices and goals of lean.

The first section of this module discusses the benefits (and necessity) of an integrated approach to product development, Integrated Product and Process Development, in the production of complex systems. The second defines specifics of particular engineering paradigm of collaboration across functions, Concurrent Engineering. The final section discusses the major mechanism for achieving integrated development, the Integrated Product Team (IPT).

## Integrated Product and Process Development

Often the size and growth of a company dictates the organization. Many entrepreneurial ventures start as collaborative efforts of technical specialists and business managers focusing on a single product, a situation that makes the entire company a single multifunctional team. Larger organizations dealing with multiple stable products are more often based around more functional boundaries. These functional organizations have some fundamental flaws that can result in miscommunication, decrease in system productivity and in the worst case product failure. Through increasing specialization, functions become closer and more focused and isolate themselves from the rest of the total system. In doing so they have taken steps to sub-optimize the process, but may have in fact decreased the overall system productivity.

IPD synthesizes functional disciplines to concurrently develop all necessary processes to produce an effective and efficient product that satisfies customer's needs. Perhaps the key characteristic of IPD is its cross-functional nature. In the context of IPD, integration means bringing together representatives from all affected downstream functions (such as manufacturing and product support), functional support groups, customers, and suppliers to provide input during the design phase of a program, when the cost of change is relatively low. Issues remain as to the optimal means of achieving this early assimilation of knowledge that spans the product life cycle. At its core, however, IPD involves revising a program's task, budget, and schedule profiles to reduce cost and cycle time by leveraging the interfaces, both component and organizational, within the total system.[20]

### *Integrative Mechanisms*

IMs are strategies and tools for effectively coordinating actions across teams and groups within a program. As catalysts, they facilitate information flow across communication barriers, such as a company or program's organizational structure, incentive systems, location, leadership styles, cultural differences, and management traditions.[21]

Some of the Integrative Mechanisms uncovered through LAI research are listed in Table 2.

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[20] Browning, T. (1996). Systematic IPT Integration in Lean Product Development. Technology and Policy and Aeronautics and Astronautics. Cambridge, MA, MIT.

[21] Morelli, M. a. S. E. (1993). Evaluating ommunications in Product Development Organizations. Cambridge, MA, Massachusetts Institute of Technology.

| |
|---|
| 1. Systems engineering and interface organization |
| 2. Improved information and communications technologies |
| 3. Training |
| 4. Co-location |
| 5. "Town meetings" |
| 6. Manager mediation |
| 7. Participant mediation |
| 8. Interface "management" groups |
| 9. Interface contracts and scorecards |

**Table 2: Integrative Mechanisms (IMs)**

### *Integrated Product Teams*

Integrated Product Teams (IPTs) are one of the key aspects of Integrated Product and Process Development. The primary purpose is to exploit the strengths of the various disciplines of the team. They are also organized to breakdown the "functional silos" that exist in stovepipe organizations.[22] Through the integration of the various disciplines necessary to develop a product, the product should be met with more success in terms of product performance, schedule and cost.[23]

An IPT: as defined by, must meet four criteria:

- Finite mission to develop a product or process(or a component of a larger system)
- Cross-functional membership, with a core group of team members who follow the product through the various product development stages
- Defined and measurable performance outcomes
- Single team leader[24]

[22] Pomponi, R. (1997). The Organization of Integrated Product Teams(Literature Review). Cambridge, MA, MIT.

[23] An extensive Literature review of IPTs can be found in Pomponi, R. (1997). The Organization of Integrated Product Teams(Literature Review). Cambridge, MA, MIT..

[24] Klein, J. (1995). Integrators, not Generalists Needed: A Case Study of IPD Teams at Textron Defense Systems. Cambridge, MA, MIT.

### *Case Studies on IPD Effectiveness*

LAI has done a good deal in integrating the theory of IPT effectiveness with that of real quantifiable and observable results. This section provides insight into four DoD aircraft programs experiences with Integrated Product Teams and Integrated Product Development overall. The four programs on which the case study data was taken are the B2, C17, F22, and F/A 18.[25]

#### Benefits

To observe the impacts of the IPT, Hernandez first used rework cycles as a measure of effectiveness and baselined the current state against the nominal rework cycles that exist in the aerospace industry.

Pugh Roberts Associates have done considerable work in defining and understanding the rework cycle in many industries. Figure 4 illustrates the results that were obtained from their analysis of rework and quality. This information is based on over 60 large development programs. The Pugh-Roberts data gives an industry benchmark for the number of rework cycles relative to typical quality. Their data indicates that aerospace projects experience a range of between 4 and 10 rework cycles for quality ranging between 0.05 and 0.25%.

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[25] More detailed analysis of these case studies can be found in Hernandez, C. (1995). Challenges and Benefits to the Implementation of Integrated Product Teams on Large Military Procurements. Managment. Cambridge, MA, MIT.

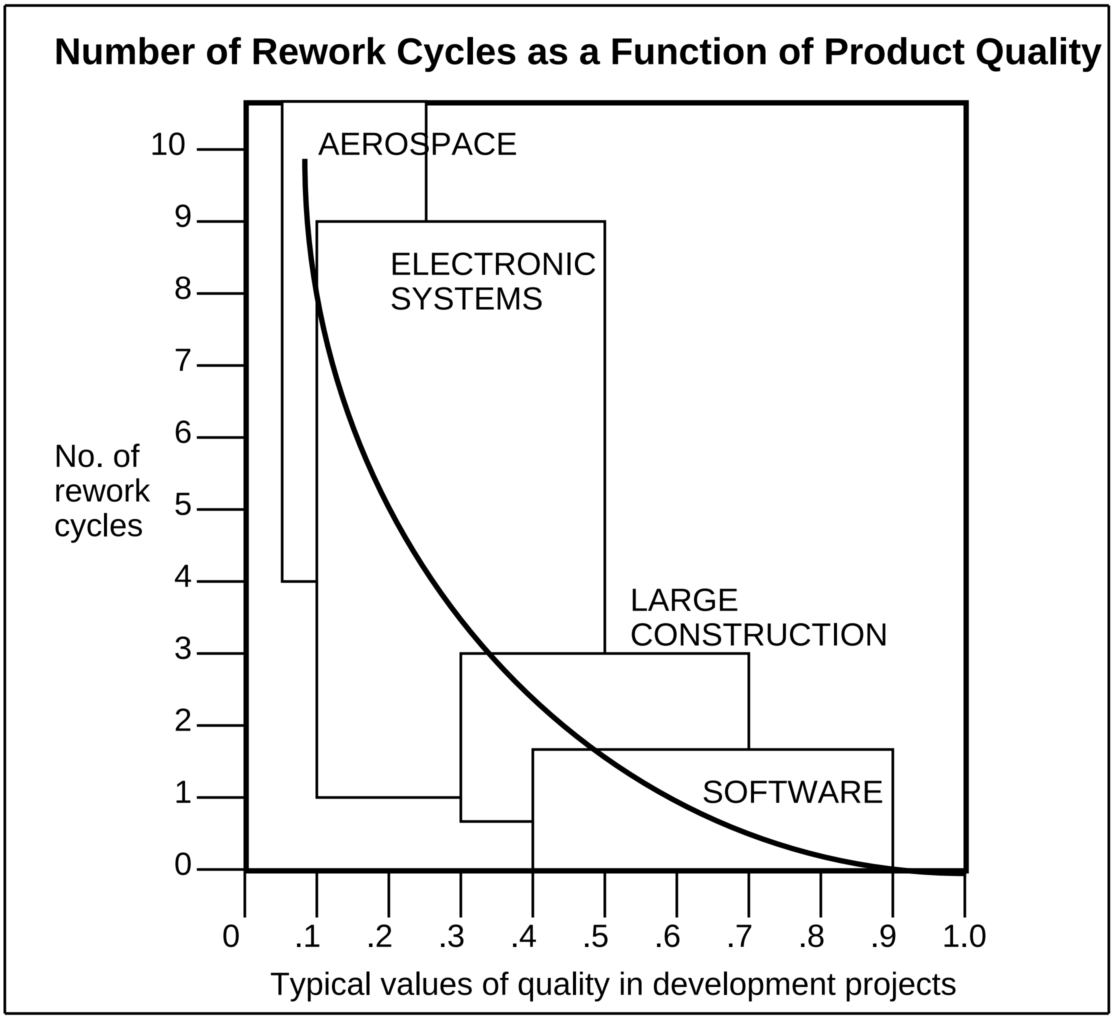


**Figure 4**

Figure 5 illustrates the two curves generated from information from the B2 program. One curve is the cumulative number of engineering drawings released. The second is the cumulative number of changes to any released drawing. From the data there has been 4.44 engineering changes per initial drawing release resulting in a 4.44 rework cycles.

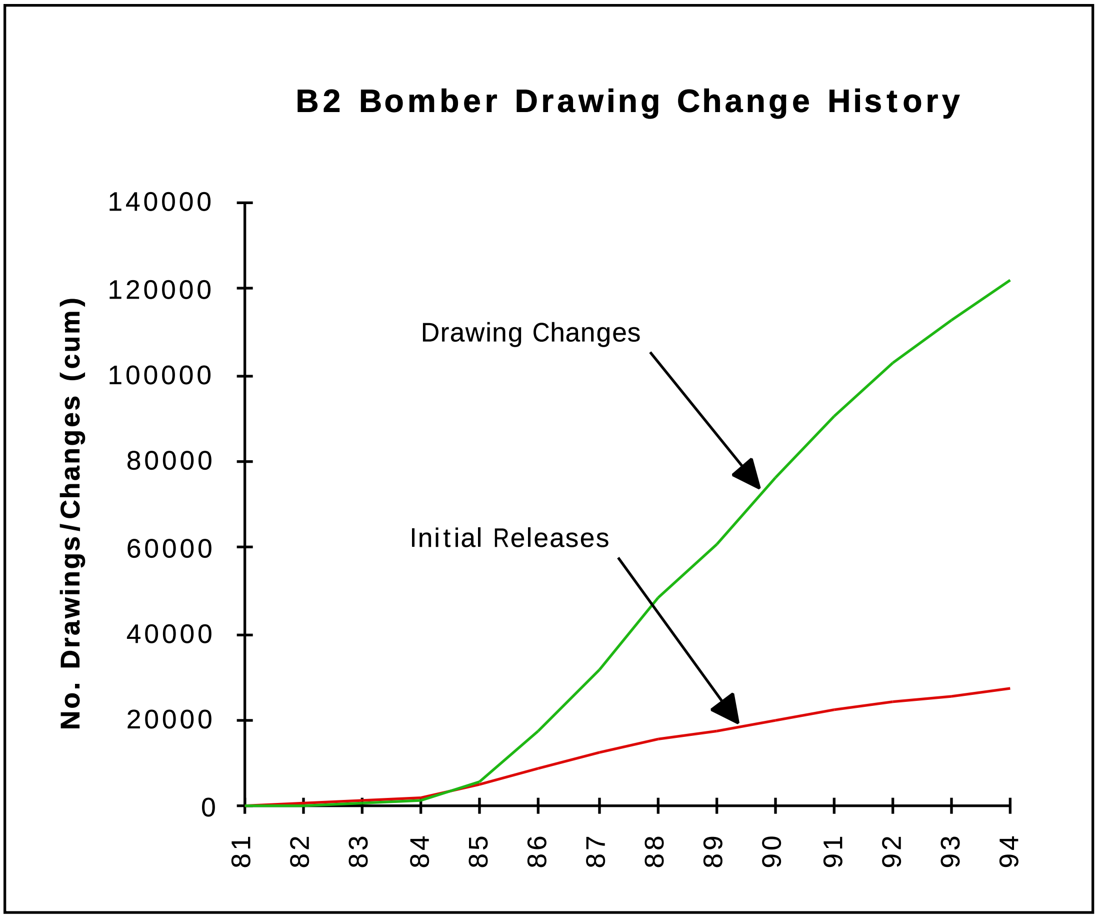


**Figure 5**

Data was also collected on rework from the F/A-18 E/F program and is presented in Figure 6. The data shown in these two figures is based on a model (The F/A-18 E/F Program Dynamics Model) that Dr. J. J. Mc Ilroy and Pugh-Roberts developed for the F/A-18 E/F Program. The model is based on the concept of "Systems Dynamics" pioneered at MIT[26], using the rework cycle as a key element. The model is calibrated[27] quarterly with actual data, such that today, it is estimated to fall in to the 95-99% confidence range for forecasting accuracy.[28]

For the F/A-18 Program the number of changes after initial release varies by major component of the aircraft. In Figure 6 the number of rework cycles expected for these two structures IPTs is about 3 and 2. As of this calibration, for all teams on the F/A-18 E/F Program, the expected number of rework cycles was between 2.5 and 3.0 rework cycles.

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[26] For further detail on Systems Dynamics see: Forester, J. W., Industrial Dynamics, MIT Press, Cambridge, MA. 1961.

[27] Since this is an ongoing project with future calibrations to be performed, it is possible that the forecasted numbers could change. However, based on the programs performance to date, it is not expected that this change would be significant.

[28] Mc Ilroy, J. J., "Program Dynamics Model Change Activity Forecasts", Draft Working Paper dated 9/21/94.

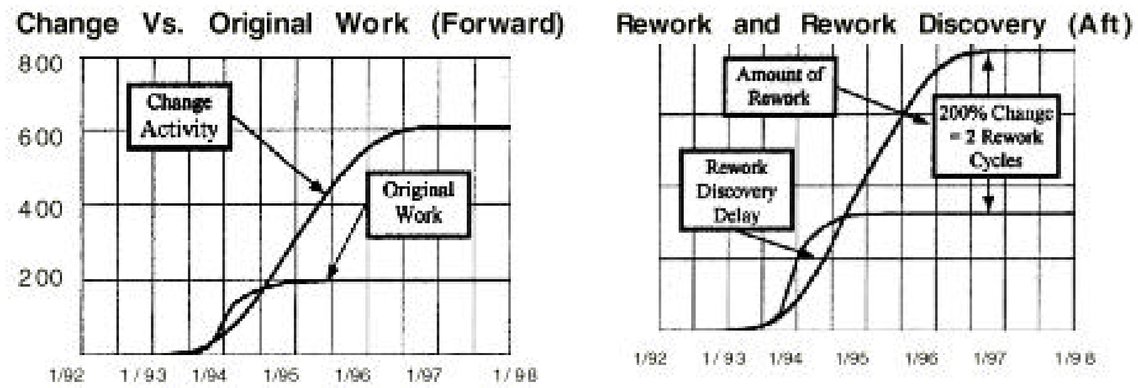


**Figure 6: F/A-18 E/F Program Dynamics Results**

To summarize the rework data; B2 at 4.44 (all teams), F/A-18 E/F at 2.0 (forecast for structures teams), and the Boeing 777 at less than 2.0. This puts the 777 and the F/A-18E/F Programs outside the "aerospace box", as defined by the Pugh Roberts data, and the B2 Program very near the bottom of the box in Figure 4. All of these programs have had a version of IPT used in their development. The F/A-18 E/F Program explicitly embraced it from the beginning. The B2 program had "design build teams" in its very early days, prior to the concept of IPT, the 777 Program used design build teams as well.

## Barriers

Identified barriers to the Integrated Product Team effectiveness were also found in the above case studies. The main barriers found were training, team budget control, and the need for balance between team and functions. As an example of the work that has been done on the barriers, Figure 7 demonstrates one researchers conclusions on the topics of training that should be covered for the various types of teams.[29]

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[29] An in depth analysis of the four case studies and the benefits and barriers of IPD can be found in Hernandez, C. (1995). Challenges and Benefits to the Implementation of Integrated Product Teams on Large Military Procurements. Managment. Cambridge, MA, MIT..

| Team Type | Training |
|---|---|
| NETWORKED | Problem solving<br>Conflict resolution<br>Inter-Group resolution<br>Information management systems |
| PARALLEL | Above-Plus:<br>Specific organizational unique skills in processes for problem solving or process improvement<br>Business and economic education |
| PROJECT | Above-Plus:<br>Special training to allow participants an appreciation for the broad background/experience of the team's membership<br>Scheduling and budgeting |
| WORK | Task trianing<br>Social interaction skills<br>Cross task training<br>Business knowledge<br>Team building activities<br>Conflict resolution<br>Problem solving<br>Group interaction skills<br>Information management systems skills<br>Quality analysis or statistical process control<br>Business and economic education<br>Train managers on how to interface with self managed teams |

**Figure 7: Team Type and Training**

## Concurrent Engineering

Concurrent Engineering and Integrated Product Development are differentiated in this text, but there is truthfully little difference in the two philosophies, as noted by Smith.[30] Smith defines concurrent engineering in terms of four principles:

- An increased role for manufacturing process design in product design decisions;
- Formation of cross-functional teams to jointly develop new products and processes;
- A focus on the customer throughout the development process; and

Womack and Jones further characterize cross-functional, concurrent engineering and design as lean product development. They note that an ideal design process would operate much like a single-piece flow in a manufacturing system. Such an analogy suggests that in a lean development process, a new product design would move continuously from concept to production, without stopping due to bureaucratic needs

[30] Smith, R. (1997). "the Historical Roots of Concurrent Engineering Fundamentals." IEEE Transactions on Engineering Management **44**(No 1)., p 67-68.

and without backflow to correct mistakes.[31] A functional organization, with its strict separation of engineering specialties, often requires such backflow and rework. By allowing for direct communication between specialties, however, concurrent engineering moves closer to this continuous flow model. A product design no longer needs to be passed around to several independent engineering departments, but is instead worked upon by multiple engineers within the same team.

### *Set-Based Concurrent Engineering*

An engineering approach that has been researched in LAI is the concept of set-based concurrent engineering (SBCE). SBCE advances the concept of concurrent engineering to allow decisions to be delayed and design options to remain open until it is absolutely necessary to select a point solution.

Sobek summarizes the definition of set-based concurrent engineering (SBCE) as engineers and product designers "reasoning, developing, and communicating about sets of solutions in parallel and relatively independently".[32] This definition is best understood by analyzing it one piece at a time. The first component of SBCE is to develop sets of designs, i.e., groups of design alternatives, for a given design problem. Rather than trying to identify one solution, engineers should instead develop a variety of design options, and then gradually eliminate alternatives, until only one option remains. This is depicted graphically in Figure 8.[33]

Figure 8 illustrates five stages of SBCE. (1) Three specialties, or functional groups, are illustrated within the design space (which contains all possible solutions) for a product development problem. (2) First, the specialties expand the number of options that they consider, establishing a small region of overlap between their design solutions. (3) They work together to expand this region of overlap, increasing the number of solutions which will satisfy all of the product's requirements. (4) The specialties then begin to eliminate options, and the region of overlap shrinks. (5) The solution space then is narrowed until only one design remains, that design being the final solution.[34]

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[31] Womack, J. a. D. T. J. (1996). Lean Thinking. New York, NY, Simon & Schuster. p 119.

[32] Sobek, D. (1997). Principles that Shape Product Development Systems: A Toyota-Chrysler Comparison. Industrial and Operations Engineering. Ann Arbor, MI, University of Michigan.

[33] Bernstein, J. (1998). Design Methods in the Aerospace Industry: Looking for Evidence of Set-Based Practices. Technology and Policy Program. Cambridge, MA, MIT.

[34] Bernstein, J. (1998). Design Methods in the Aerospace Industry: Looking for Evidence of Set-Based Practices. Technology and Policy Program. Cambridge, MA, MIT.

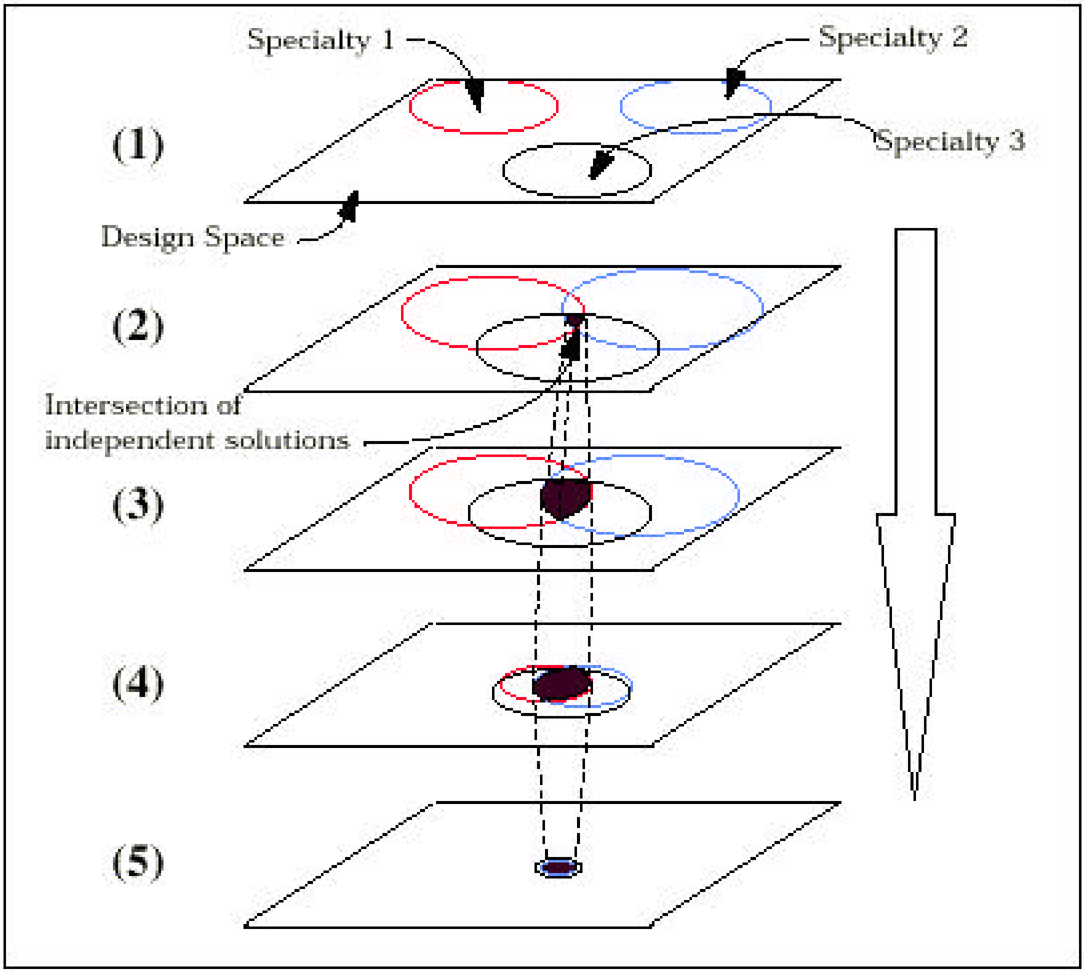


**Figure 8: Set-Based Concurrent Engineering[35]**

## Working with Organization Cultures

Using the framework developed by Shein,[36] two researchers characterized the impacts of acquisition reform on two large programs within the DoD. Although, the two program were both military, it is likely that the conclusions could be extended to a large organization undergoing fundamental improvement initiatives.

Culture is defined by Shein as "A pattern of shared basic assumptions that the group learned as it solved its problems of external adaptations and internal integration, that has worked well enough to be considered valid, therefore, to be taught to new members as a correct way to perceive, think, and feel in relation to those problems."[37] Using this

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[35] Bernstein, J. (1998). Design Methods in the Aerospace Industry: Looking for Evidence of Set-Based Practices. Technology and Policy Program. Cambridge, MA, MIT.

[36] Shein, E. (1992). Organizational Culture and Leadership, Josey-Bass Publishers.

[37] Doane, D. (1997). Cultural Analysis Case Study: Implementation of Acquisition Reform within the Department of Defense. Cambridge, MA, MIT.

definition, the two researchers were able to asses cultural change and effectiveness of the acquisition reform approach to inducing change.[38]

## References for Module II:

Ancona, D. (1999). Stretching the Rubber Band: the Impact of Expanding the Role of Product Developement Teams in Different Directions. Cambridge, MA, MIT.

Ancona, D. (1999). The Timing of Change in Product Development Teams. Cambridge, MA, MIT.

Bell, D., Dan Vermeer, and Tao Liang (1999). Innovation through Distributed Expertise in Action. Cambridge, MA, MIT.

Bell, D., Stephen Gilbert, and Lisa Abrams (1999). On the Job Distance Learning for Engineers. Cambridge, MA, MIT.

Bernstein, J. (1998). Design Methods in the Aerospace Industry: Looking for Evidence of Set-Based Practices. Technology and Policy Program. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THBernstein.pdf

*A new paradigm in engineering design, known as set-based concurrent engineering (SBCE), has been proposed which seems to offer advantages over more traditional techniques. This research, therefore, had three goals: 1) to develop a clear understanding of the definition of SBCE and to contrast that definition with other theories, 2) to assess the "set-basedness" of the aerospace industry, and 3) based on the assessment, to propose a model for implementing SBCE within an aerospace development project. While set-based concurrent engineering consists of a wide variety of design techniques, the basic notions can be stated in two principles: 1) engineers should consider a large number of design alternatives, i.e., sets of designs, which are gradually narrowed to a final design, and 2) in a multidisciplinary environment, engineering specialists should independently review a design from their own perspectives, generate sets of possible solutions, and then look for regions of overlap between those sets to develop an integrated final solution.*

Browning, T. (1996). Systematic IPT Integration in Lean Product Development. Technology and Policy and Aeronautics and Astronautics. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/browning.pdf

*Integrated Product Development (IPD) is a crucial aspect of the lean paradigm. The drive towards IPD includes an impetus to organize around Integrated Product Teams (IPTs). The use of IPTs has brought with it many issues, including those at the IPT*

[38] Doane, D. (1997). Cultural Analysis Case Study: Implementation of Acquisition Reform within the Department of Defense. Cambridge, MA, MIT.

*interfaces. Program integration (of a cross-functional, upstream/downstream nature) can exist at three levels: (1) within the IPTs, (2) between the IPTs in system level teams, and (3) between the IPTs and system level teams in the program at large. This work focuses on the second and third levels, the realm of IPT interdependence, and categorizes several Integrative Mechanisms (IMs) to facilitate interteam integration. IMs are strategies and tools for effectively coordinating actions across teams within a program. To provide a variety of contexts for investigation in the defense aircraft industry, the thesis includes five case studies of development programs of varying size from each of several sectors. Each is analyzed for its use of IMs. To give a systematic basis for designing the design process, the application of the Design Structure Matrix (DSM) to model program organization based on information flow is considered in one case. DSM-based approaches to interface management have been used in the automotive and other industries. They can help a systems engineer/manager systematize the interface management process, both at a product level and at an interteam level. This facilitates decisions as to the correct utilization of IMs. These studies provide the basis for lean principles of program integration, which include designing a program for integration.*

Browning, T. (1997). Summary Report: Systematic IPT Integration in Lean Development Programs. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/RP970119Browning.pdf

*This document provides a summary report of the M.I.T. masters thesis Systematic IPT Integration in Lean Development Programs by Tyson R. Browning. Integrated product development (IPD) has been established as a salient aspect of the lean enterprise paradigm. The drive towards IPD includes an impetus to organize around integrated product teams (IPTs), cross-functional groups responsible for developing a particular element of a system product. The use of IPTs has brought with it many issues, including those at the IPT interfaces. The goal of this research is to provide insight into the integration of multiple IPTs in programs.*

Carlile, P. a. C. O. (1999). Communities of Practice as Axes in the Creation and Distribution of New Knowledge in Product Development. Cambridge, MA, MIT.

Charles, C. (1997). Open-Book Management Goes Beyong the Bottom Line. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THCharles.pdf

*This thesis encompasses sharing business data and its power to affect behaviors in the organization's culture, employee decision-making, trust between employer and employee, and impact to the bottom line data. This thesis will attempt to answer questions such as: why implement Open-Book Management, how does sharing information impact an organization's culture, how do implementation processes occur within these varied businesses, how does a business determine what information should be shared, and is there an impact to the bottom line.*

Cunningham, T. (1998). Chains of Function Delivery: A Role for Product Architecture in Concept Design. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/cunningham.pdf

*This research intends to improve three areas of team performance in concept design: the team's understanding and recognition of the product architecture, the team's ability to document integration issues and risks, and the team's ability to judge whether a product concept is worthy of further pursuit. Many of the high-impact decisions made in concept design revolve around integration issues: how the product's physical elements work together to deliver the performance characteristics, or functions. The product architecture, a singularly important characteristic of the product, is in great part determined by the mapping of the product's functions to the physical elements that deliver those functions.*

Cutcher-Gershenfeld, J. (1997). Lessons from Implementing Cross Functional Teams. Cambridge, MA, MIT.

Cutcher-Gershenfeld, J. a. J. K. a. R. P. (1998). "Lean Aircraft Initiative Implementation Workshop: Implementing Cross-Functional Teams in an IPPD Environment".

http://lean.mit.edu/private/documents/publications/RP98_01jcg.pdf

*There is an emerging consensus in the Aerospace sector around the importance of Integrated Product and Process Development (IPPD). This is a rejection of the old model, where different engineering disciplines and different functional groups each focused only on their own part in the development, manufacture and deployment of new products. Instead, nearly every new program is now established around a set of Integrated Product Teams (IPTs). These teams may include people involved in concurrent activities or they may involve representatives of upstream and downstream activities. Either way, the integrated team structure enables critical forms of coordination by the people doing the work - not just senior leaders.*

Doane, D. (1997). Cultural Analysis Case Study: Implementation of Acquisition Reform within the Department of Defense. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THDoane.pdf

*Over the past 20 years, the DOD has attempted to reform their acquisition policies but has failed to address the significance of culture in the implementation of reform. This thesis focuses on the impact and importance of culture on implementing and sustaining long-term change efforts. Edgar H. Schein's framework for analyzing culture within the organization is the model for the analysis focusing on the essential elements; mission and strategy, goals, means, measurement, and correction. Using case study analysis, the primary research focused on a large Navy and Air Force procurement under the new Acquisition Reform philosophy. The organizational structure of the program, roles, responsibilities, accountability, incentives and motivations of all levels within the Department of Defense workforce is defined and analyzed. The results of the analysis will*

*be integrated into Schein's framework to identify common themes that exist across the services and the specific organizations.*

Driscoll, D. (1996). Organization Changes Case Study--Sikorsky. Cambridge, MA, MIT.

Driscoll, D. (1996). Organizational and Cultural Transformation to Achieve Lean Manufacturing in the Aerospace Inductry. Cambridge, MA, MIT.

*This is a study of the operational and cultural aspects of change in a manufacturing environment. It reviews the key principles for achieving leanness and provides an overview of the Lean Enterprise Model (LEM), looking at how the practices of this model can be used to guide the development of the lean enterprise. It overviews the need for a systems approach to enterprise design and looks at the reasons why balance is necessary between people, organizations, and technology. The main portion of the thesis is a case study of the organizational and cultural transformation underway at an American aerospace company. The case study looks specifically at organizational learning and cultural change. It examines the reasons why changes were initiated, the methods used to prepare the organization for change, organizational strategies behind the transformation, and the effectiveness of management support, communication, and training. Finally, the thesis evaluates the extent to which the organizational and cultural transformation underway at this company follows the latest theories and models for developing a lean enterprise. It provides an objective assessment of ongoing activities and offers some suggestions for improvements.*

Flowers, W. a. P. L. (1999). Web-Based and Multimedia Communication Tools in Product Development Groups. Cambridge, MA, MIT.

Hauser, J., Jose Silva, and Dave Godes (1999). A Contingent Theory of How Individuals within Organizations Share Product-Development-Process Expertise. Cambridge, MA, MIT.

Hernandez, C. (1995). Challenges and Benefits to the Implementation of Integrated Product Teams on Large Military Procurements. Managment. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/hernan.pdf

*Tens of millions of dollars will be spent by the United States Air Force and Navy over the next several years on the development and production of our country's top military weapon systems. The most senior leadership of these government agencies have committed their organizations to proceed with this development using a concept of management known as Integrated Product Development (IPD) using Integrated Product Teams (IPT). Essentially, the majority of the US aerospace community is moving towards this new concept of management. Since this concept comes from the commercial industry, the underlying factors of the way commercial industry does business versus aerospace, need to be explored to ensure that a model of IPD/IPT is developed which is optimized*

*for the US aerospace industry. This thesis looks at this issue for four ongoing major aircraft developments: B-2 Bomber, C-17 Transport, F/A-18 E/F Fighter, and F-22 Fighter. These four programs are reviewed and contrasted to commercial business practices to bring out structural differences that may act as barriers to IPT Implementation. Several areas were identified that impede its implementation. These areas include: training, team budget control, and the need for balance between teams and functions. In addition, details of how benefits can be derived from the IPT concept are discussed. Current methods being used to measure these benefits are presented.*

Klein, J. (1994). A Case Study of Self-Directed Work Teams at Boeing Defense and Space Group.

http://lean.mit.edu/private/documents/publications/94_02.pdf

*Boeing Defense & Space Group - Corinth (BD&SG-C) is a self-directed team based, unionized facility in the defense and commercial aircraft industry. The plant was a greenfield start-up in 1987. Due to the nature of the defense business environment, the facility has weathered a changing product mix and surges and plateaus in its employment. The case illustrates the applicability of self-directed work systems in the defense aircraft industry and will identify lessons learned in the start-up and maintenance of such systems, including how experience in developing a labor-management partnership can be carried over to developing a partnership between DoD contractors and their defense contract administrators.*

Klein, J. (1995). Integrators, not Generalists Needed: A Case Study of IPD Teams at Textron Defense Systems. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/94_01.pdf

*The creation of cross-functional teams to breakdown functional silos has led to a call for more multi-disciplinary knowledge workers. Many knowledge workers, however, fear that they will lose their expertise as they become multi-disciplinary generalists. This case study describes the evolution of one organization which replaced its traditional functional structure with cross-functional horizontal teams. The case illustrates the need to retain technical experts who also possess integrative knowledge across multiple functions. This, in turn, poses a number of human resource challenges, such as, selection, training, rewards, and team leadership.*

Klein, J., Joel Ctcher-Gershenfeld and Betty Barrett (1997). Implementation Workshop: High Performance Work Organizations. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/RP970234_Klein.pdf

*A report on findings from the first Lean Aircraft Initiative (LAI) Implementation Workshop held on February 5-6, 1997. The report is not a "cookbook" or a "how to" manual. Rather, it is a summary of the first phase in a learning process. It is designed to codify lessons learned, facilitate diffusion among people not at the session, and set the stage for further learning about implementation.*

Klein, J. a. G. I. S. (1995). Lean Aircraft Initiative Organization & Human Resources (O&HR) Survey Feedback: Integrated Product Teams. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/95_03.pdf

*The purpose of the LAI O&HR survey of IPTs was 1) to establish a baseline of defense aerospace industry practices, and 2) to determine whether factors that lead to the effectiveness of IPTs in other industries are applicable to the defense aerospace industry. This white paper first summarizes the current practices relative to IPTs within the defense aerospace industry, then presents an effectiveness analysis which suggests that appropriate organizational policies and practices vary with the types of products that teams develop. The analysis is based on 594 respondents who were representatives of 63 IPTs; two-thirds of the IPTs were from companies, one-third from either Air Force product centers (APCs) or logistics centers (ALCs). The survey was administered during the first quarter of 1993.*

Morelli, M. a. S. E. (1993). Evaluating ommunications in Product Development Organizations. Cambridge, MA, Massachusetts Institute of Technology.

Pinelli, T., R. Barclay, J. Kennedy, A. Bishop (1997). Knowledge Diffusion in the U.S. Aeropspace Industry. Greenwich, CT, Ablex Publishing Corporation.

Pomponi, R. (1997). The Organization of Integrated Product Teams(Literature Review). Cambridge, MA, MIT.

Pomponi, R. (1998). Organizational Structures for Technology Transition (Dissertation Summary). Cambridge, MA, MIT.

Pomponi, R. (1998). Organizational Structures for Technology Transition: Rethinking Information Flow in the Integrated Product Team. Technology, Management and Policy. Cammbridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THPomponi0698.pdf

*Integrated product and process development (IPPD) is an organizational approach designed to facilitate the creation of new products by making a single team responsible for all development activities from concept design through production. While the introduction of IPPD in the manufacturing sector has generated considerable improvements in product performance, cost, and cycle time, the focused nature of its team-based approach may also lead to greater isolation between programs. One area where this fragmentation is of greatest concern for the achievement of company-wide strategic goals is in the introduction of new manufacturing technology. Since manufacturing processes are often applicable to multiple product lines, organizational mechanisms are needed to coordinate the strategic implementation of technology across the organization. The dissertation examines how organizational structure affects the implementation of new technology within an IPPD environment, focusing on information flow among integrated product teams (IPTs).*

Roberts, E. (1999). Using Technology Alliances to Establish Leadership in Emerging Technologies: Comparitive Industry Cases. Cambridge, MA, MIT.

Rosson, R. (1994). Self-Directed Work Teams at Texas Instruments Defense Systems & Electronics Group. Management. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/rosson.pdf

*Lean production is rapidly replacing conventional mass production at manufacturing companies in the US and throughout the world. Human resources practices play a critical role in any company's program to develop and institutionalize lean methods on the shop floor. One approach that has been successful at many companies involves organizing production workers into self-directed work teams. Teams of between five and fifteen workers take responsibility for an integrated, customer-driven production process. Team members cross train in many of the tasks within the defined process and gradually expand their capabilities to include administrative and support roles. As the team matures, it slowly becomes increasingly autonomous, until it functions with minimal supervision. Texas Instruments Defense Systems and Electronics Group (TI DSEG) has pioneered the concept of self-directed work teams. This thesis presents a case study and analysis of two particular teams at TI DSEG: the Switch Filter/Beam Former Team and the Diamond Point Turning Team. Both teams have achieved a high-level of maturity in terms of their degree of autonomy and the sophistication of their activities. The objectives in studying these two teams are to highlight the key factors that contributed to their success, to uncover the pitfalls and roadblocks they encountered along the way, and to document the organizational structures and operating procedures that support the self-directed team concept.*

Shein, E. (1992). Organizational Culture and Leadership, Josey-Bass Publishers.

Slaghter, S. a. C. S. (1999). Product Development Across Firm Boundaries: Problems of Cooperation and Coordination in Large Complex Systems. Cambridge, MA, MIT.

Smith, R. (1997). "the Historical Roots of Concurrent Engineering Fundamentals." IEEE Transactions on Engineering Management **44**(No 1).

Sobek, D. (1997). Principles that Shape Product Development Systems: A Toyota-Chrysler Comparison. Industrial and Operations Engineering. Ann Arbor, MI, University of Michigan.

Sorenson, E. (1995). Self-Directed Work Teams at an Aerospace Company. Management. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/sorenson.pdf

*Self-Directed Work Teams (SDWTs) are logical extensions of the Socio-Technical Systems (STS) approach to organizational design. STSs seek to balance the business environment, technical aspects of the firm, and the social aspects of the worker to achieve optimality. SDTWs, if operating effectively, strive to achieve this balance evolving as the technical, social or business conditions change. SDWTs have not absolutely proven themselves to be a better organizational form in rigorous controlled experiments, but this may have been due to uncontrolled environmental factors. Anectodal evidence, such as the example presented here, is positive, but it is clouded by uncontrolled technological innovation introduced at the same time the SDWTs were introduced. The introduction of SDWTs to a medium-sized aerospace company at a "Mature Plant" and a "Satellite Plant" was studied. Both plants contrast each other in a variety of ways: union/non-union, older/younger plants, near corporate headquarters/satellite, focused factory/multiple products-multiple processes. The results for the Satellite Plant have been extremely positive. The Mature Plant, just having started the transition to SDWTs, has yet to realize the benefits. The introduction of the SDWTs were enabled by the existence of manufacturing cells, team training, the backing of the labor union (which represented the employees of the Mature Plant), and the identification and elimination of blockers in the management ranks.*

Tavassoli, N. a. R. H. (1999). Integrating Individuals' Problem Solving Styles in Product Development Teams. Cambridge, MA, MIT.

Womack, J. a. D. T. J. (1996). Lean Thinking. New York, NY, Simon & Schuster.

# MODULE III: CREATE A CLEAR CONNECTION BETWEEN THE "PROCESSES" OF PRODUCT DEVELOPMENT AND LEAN

## Table of Contents



## Module III Introduction

Each module begins with an explanation of how each relates to the overall goal of the project and also how it relates to concepts of Lean. Module III is the third in a series of six self-standing texts aimed at releasing research uncovered through the Lean Aerospace Initiative in the field of lean product development. This module takes a stage-by-stage view on the application of lean principles to product development process.

There are three sections that each discuss the different applications of lean found in each. The first, product definition, includes the customer needs and requirements generation. The second, product architecture development, includes topics of modularity and set based approaches to architecture development. The final section, product/process design, addresses the detailed design and the building and testing of prototypes.

# Lean in Product Definition

Product Definition in this context is meant to contain requirements generation and resource prioritization. It is the phase of product development where the need is identified through marketing and applied to a product to satisfy that need.

## *Requirements Generation*

Requirements generation is one of the most influential steps of development with regards to eventual success of a program. The significance of this fact is important to comprehend in terms of requirements generation: an estimated 85 percent of a weapon's total life-cycle costs are committed before a weapon system enters full-scale development.[39] In addition, the problems that occur during requirements generation are the most expensive to fix if not caught quickly, as they require the most rework and waste.

### Keys to effective requirements generation

From 10 site visit interviews at aerospace companies and government offices, Walton suggests that effective requirements generation can often be attributed to three things: 1) well trained competent people, 2) structured, tailorable process, and 3) management support for the requirements process.

#### People

Requirements generation is a creative process that requires people who understand the customer, the end goal, and the process in which they work. Teams using varieties of input from different perspectives has also been cited as an important key to maximizing the potential of the people involved. The requirements process is probably the most social aspect of developing and delivering a new product. It is the process point at which knowledge from the customer has to be transferred to the developer. This is generally done through both documentation and communication on both sides. The people involved have to understand the process that their organization uses and the results it can achieve. They must also convey information to the customer effectively, as well as have the ability to ask the right questions to secure the customer needs.

##### Individuals

Having the right individuals was a major theme to interviewers comments on effective requirements generation. As much as M&S and other tools can help with the requirements process, it still takes a specially trained person to deal with generating requirements. At most sites visited requirements training was provided and the people generally felt satisfied with the level of training that was given. On the job training appeared to be the most effective training.

##### Teams

Teams have been cited at many sites for their benefit to the requirements process. On one program, teams were maintained at the contractor site for two years and then

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[39] Gansler, J. (1989). Affording Defense. Cambridge, MA, MIT Press.

stopped, the requirements manager saw a clear downturn in requirements generation. The teams were broken up to "fight fires" as often occurs, and the stability of the requirements team was lost. The program observed significant impacts to the level of control and stability that had existed when the team was in place.

Another example of team impacts to requirements development can be found at the Product Design Center at JPL. The Product Design Center has made strides to combine both the intellect and ability of individuals and the problem solving power of the team. The design center set up allows for quick iteration of concepts and tradeoffs. The PDC can service both Pre-Phase A and Phase A/B NASA programs through providing an integrated environment in which complex tradeoffs can take place. In this environment highly knowledgeable and creative people with the right tools can work cooperatively on each iteration. This eliminates the handoffs of information among functions that can cause timing delays as well as information being misunderstood. The center is still in its early years, but opinions of the center at JPL are very positive. In addition, other locations like the Aerospace Corporation in El Segundo, CA are creating their own design center based on the JPL model because of the perceived benefits.

### Process

Providing a guideline to the requirements generation process is a necessary step to achieving more effective requirements. The process differs from organization to organization, but retain much of the same process steps. Tailoring to individual programs is encouraged, but straying from the structure is not. The process is the key to obtaining a level of stability across the organization. A common language in terms of the process becomes very important in an area where all aspects of the process have little physical meaning.  The process serves as a roadmap, but does not prescribe requirements. It lays a framework from which interpretation and adaptation to each program can be achieved. From interviews conducted at one site visit, program officials were quite happy with the modifiable system that was made available to them. The process people at this same site very comfortable with the process and the way it was being used, but still stressed that a formal understanding of the full process should be obtained before any tailoring can take place. They also stressed the dangers of straying away from the plan as a whole. The process people stressed the utility of the requirements map to any program and that there should be no size or funding limitations, just tailoring of the process to accommodate those differences.

### Management Support

Time is an essential characteristic of effective requirements generation. The product of the requirements process is not as physical as that from design or manufacturing, and therefore is often not treated with the level of management support that is necessary to achieve good requirements for the program. The process is one that requires a great deal of communication, interaction and cooperation with the customer as well as other stakeholders. This process of eliciting customer needs can be a time consuming task and without the necessary time, the requirements will suffer. Once the customer needs are obtained, they have to be validated against what is possible to be achieved. This often takes a great deal of time as well and extensive use of M&S to validate the needs as both technologically feasible, but the cost and schedule feasibility as well.

Another aspect of management support that becomes key to effective requirements generation is the ability to say "no" to requirements changes. Management must have an understanding of what minimal requirements changes should be accepted and which should be rejected for the good of the program. It was discovered from numerous site visit interviews that successful requirements generation had management that understood the impact of requirements changes and were not afraid to say "no" to customer requests for requirements changes.[40]

#### Software Requirements Generation

Developing software is more than just writing code. The complexity associated with developing modern military and commercial aircraft has created a need for a new framework for analyzing development processes. Identifying the value stream is an important step in defining the scope of the project and, subsequently, process improvements to reduce cost and shorten end-to-end cycle time.

Compared to other steps in the software development process, the requirement derivation process is still maturing and being defined. There is evidence that shows that the stakeholders are finding ways to effectively define software requirements. However, there is still room for improvement. Interviews with the software developer, end users, and customers found that they all felt the 26-month requirement derivation process could be shortened and the approximately 16% cost of rework could be lowered.[41]

## Lean in Product Architecture Development

Product Architecture is the name given to the method through which functions are assigned to physical elements and the interactions among those elements are defined. Architectures exist in a range between integral, where all components are custom to the product, and modular, where components are the same across sub-systems and programs and have common interfaces for easier component replacement.[42]

### *Modular Architectures*

Modularity incorporates separate components into a single system, where each component is produced in a "block." The blocks are combined in various ways to satisfy different functional needs. Components that are present in all product variants are called essential blocks and play a major part in the realization of economies of scale. Such component sharing across product variants, otherwise known as commonality, allows development costs and capital expenses to be amortized across a greater number of units and drives more-efficient production through higher volumes.

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[40] For further reading, an extensive literature review on requirements generation is provided in Walton, M. (1999). Identifying the Impact of Modeling and Simulation on the Generation of System Level Requirements. Aeronautics and Astronautics. Cambridge, MA, MIT**:** 135..

[41] Ippolito is focusing on the software requirements process. This research is still underway, but recently a paper has been released with preliminary findings. Ippolito, B. (1999). Establishing Requirements: A Step in the Software Development Value Stream. International Conference on Systems Engineering, Las Vegas, NV.

[42] Cunningham, T. (1998). Chains of Function Delivery: A Role for Product Architecture in Concept Design. Cambridge, MA, MIT.

Modularity admits a certain tradeoff between the need to take advantage of economies of scale through standardization and the desire to provide the customer with a product tailored to his needs. It seems logical that all customers' needs could be met with a sufficient number of different components, combined in different ways to create almost infinite variety, but the manufacturing process to achieve such variety becomes increasingly close to pure craft, and the benefits of economies of scale are not realized. The challenge of modularity is defining a set number of standard components that combine to satisfy the needs of the greatest number of customers.

## Modularity Types

Modularity is divided into six different types as shown in Figure 9 all of which can be combined in a single complex system: component-sharing, component-swapping, fabricate-to-fit, mix modularity, bus modularity, and sectional modularity.

*Component sharing*, is also called commonality and will be discussed at length in a later section. It involves using the same component across multiple products.

*Component swapping* creates variety by pairing different components with a basic product, creating as many varieties as there are components. An example of this type of modularity would be the choice of several radios in a particular car model.

*Fabricate-to-fit modularity* assumes that one or more of the components is variable within practical limits. The aircraft fuselage is an example from the aerospace industry, which can be stretched to accommodate more passengers and create new models.

Mix modularity entails combining different components to create something new, for example paint.

Bus modularity is comprised of a common structure that can attach a number of different components. Standard interfaces can be matched with any selection of components, which can be varied in both number and location on the bus. Again, an aircraft fuselage can function as a bus with standard interfaces, to which subsystems like avionics and propulsion can be attached.

*Sectional modularity* comprises a collection of components that can be configured in arbitrary ways, as long as they are connected at standard interfaces. Lego building blocks are the quintessential example of this type of modularity.

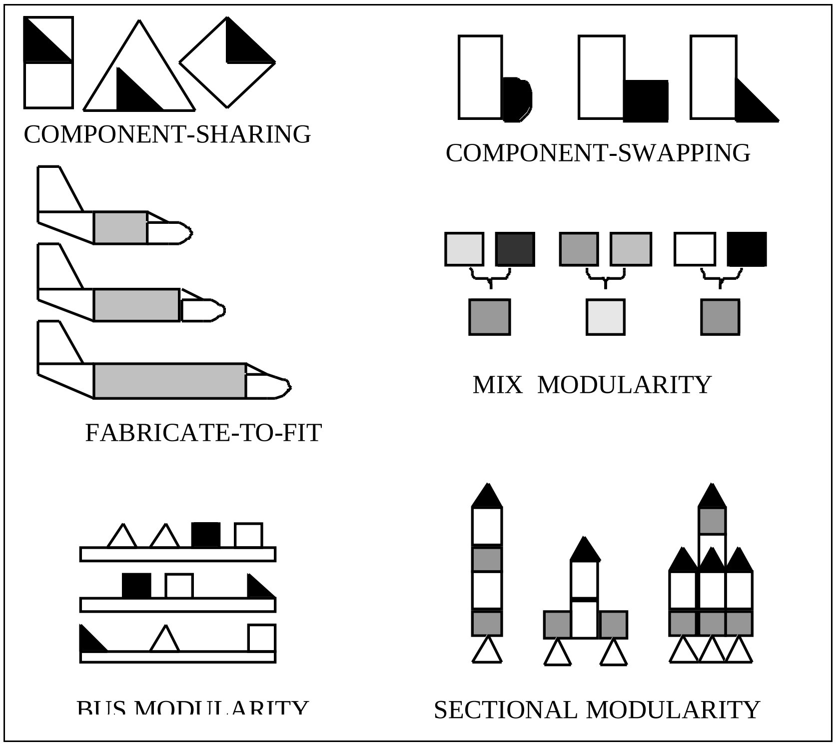


**Figure 9: Types of Modularity**[43]

## Benefits and Disadvantages to Modular Design

Once a modular course of action is established, the design advantages are many. First, if a system contains technologies that are changing rapidly, such as electronics or computer-related components, modularity enables these components to be upgraded regularly to keep pace with the state-of-the-art. Dividing a product into components and interfaces allows the manufacturer to accommodate different rates of change without affecting the entire design. Second, a product with well-defined interfaces and subsystems can borrow heavily from previous products or other product lines. Also, by definition of modularity, the concept enables designers to break the problem into smaller, simpler, parts. Breaking the problem into modules from the beginning defines clear boundaries and sets up standard interfaces. It is also a natural human tendency to break processes down by function. Next, with several portions of the system being designed in parallel, design teams can share or reuse components from other designs, and development time can be decreased. Another benefit of modularity is that it enables engineers to focus more directly on their own module, often leading to a more effective design solution. Finally, this design technique creates expertise within the company in particular areas of specialization.

Nothing is obtained for free, however, and modular design has several disadvantages to go along with its perceived gains. Designing for modularity is more difficult and

[43] Nuffort, M. (1998). Research Proposal for Managing Subsystem Commonality in the DoD. Cambridge, MA, Massachusetts Institute of Technology.

requires more effort than designing a stand-alone system. Determining how to separate a system into modules and how these modules will interconnect is the root of the problem. Once the design is complete, however, product development is simplified by modularity. Next, with any specific design technique, the possibility exists that designers will not think to explore other methods or solutions. Such tunnel vision may detract from the overall quality of the design. Also, the use of modular design may sacrifice a certain amount of performance optimization. Performance almost always can be improved over a modular design, because the elimination of interfaces reduces weight and size. Additionally, it is sometimes difficult to integrate modules, designed by different teams, and to make them work together optimally. In fact, modularity causes the design to be less integrated, and designers must take care in defining clear inputs and outputs ahead of time. The method also may cause a certain lack of function sharing, and designs that group two or more functions together may be overlooked because of separate design teams. Finally, another possible disadvantage that arises from lack of communication between teams is the potential for redundancy. Organizational methods discussed later will address methods for dealing with these disadvantages.[44]

### *Set-Based Engineering*

Although discussed in Module II with regards to organizational impacts, set based engineering methods are described hear as they pertain to architecture development. Set-based engineering seeks large sets of options that satisfy the requirements developed in the product definition phase. There are multiple mappings of physical form to functions that are completed.

The first component of SBCE is to develop sets of designs, i.e., groups of design alternatives, for a given design problem. Rather than trying to identify one solution, engineers should instead develop a variety of design options, and then gradually eliminate alternatives, until only one option remains. Independent exploration of design sets enables several engineering specialties to consider a design problem from their own perspective (i.e., to allow each specialty to work on a sub-problem) and then to effectively re-combine those independent alternatives into an integrated final solution.[45] Set-based engineering can therefore be looked at from a product architecture standpoint as well as from a design standpoint.

## Lean in Product/Process Design

Product/process design includes the detail design (including design-for-X techniques) and the development of prototypes. Research included in this section are increasing cost awareness in design, understanding the role of data commonality, and assembly oriented design.

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[44] Nuffort, M. (1998). Research Proposal for Managing Subsystem Commonality in the DoD. Cambridge, MA, Massachusetts Institute of Technology.

[45] Bernstein, J. (1998). Design Methods in the Aerospace Industry: Looking for Evidence of Set-Based Practices. Technology and Policy Program. Cambridge, MA, MIT. provides a complete thesis devoted to set-based concurrent engineering.

### *Elements of integrated design and cost*

The least expensive way to create a low-cost product is to design it to be low at the start. This however requires upfront knowledge of manufacturing methods and costs in the design phase. To do this a method of integration of design and cost becomes necessary. Research has been conducted within LAI that addresses the benefits and problems of tighter coupling of design and cost accounting. One paper cited here points out the four elements necessary to create an integrated design and cost scheme.[46]

First, an integrated database must exist to include product information, fabrication and assembly processes, and accounting costs. This is then linked to the design system, cost modeling and validation. The design system includes the CAD modeling system, as well as the computer aided manufacturing module. The cost model may include empirical correlation of cost with design features or more advanced cost modeling schemes based on knowledge-agents. Finally, the validation of the cost models extracts data from the database and compares it to the data produced using the cost models.

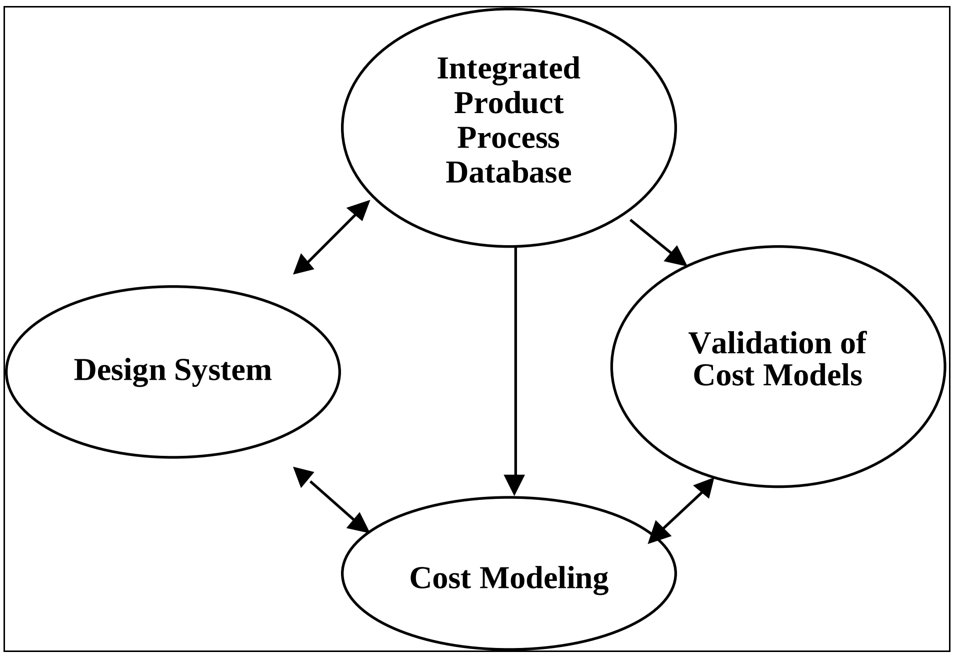


**Figure 10: Elements of Integrated Design and Cost[47]**

### *Key Characteristics*

One of the significant contributions that have been made through LAI research is in the topic of Key Characteristics. Key Characteristics (KCs) are "product features, manufacturing processes, and assembly characteristics that significantly affect a

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[46] Hoult et al have two papers on this topic: Hoult, D., and C. Lawrence Meador (1995). Methods of Integration Design and Cost Information to Achieve Enhanced Manufacturing Cost/Performance Trade-Offs. Cambridge, MA, MIT. and Hoult, D., C. Lawrence Meador, John Deyst, and Maresi Berry-Dennis (1995). Cost Awareness in Design: The Role of Data Commonality. Cambridge, MA, MIT..

[47] Hoult, D., and C. Lawrence Meador (1995). Methods of Integration Design and Cost Information to Achieve Enhanced Manufacturing Cost/Performance Trade-Offs. Cambridge, MA, MIT.

product's performance, function, fit, and form."[48] Ertan provided thesis research on KCs to manage variation risk in compex products. In the research, two KC identification approaches are discussed and findings from a series of benchmarking surveys are provided. In addition, the KC Maturity Model is explained as a tool for continuous improvement.[49]

## References for Module III:

Ancona, D. (1999). Stretching the Rubber Band: the Impact of Expanding the Role of Product Developement Teams in Different Directions. Cambridge, MA, MIT.

Ancona, D. (1999). The Timing of Change in Product Development Teams. Cambridge, MA, MIT.

Anderson, D. M. (1997). Agile Product Development for Mass Customization. Chicago, Irwin Professional Publishing.

Bell, D., Dan Vermeer, and Tao Liang (1999). Innovation through Distributed Expertise in Action. Cambridge, MA, MIT.

Bernstein, J. (1998). Design Methods in the Aerospace Industry: Looking for Evidence of Set-Based Practices. Technology and Policy Program. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THBernstein.pdf

*A new paradigm in engineering design, known as set-based concurrent engineering (SBCE), has been proposed which seems to offer advantages over more traditional techniques. This research, therefore, had three goals: 1) to develop a clear understanding of the definition of SBCE and to contrast that definition with other theories, 2) to assess the "set-basedness" of the aerospace industry, and 3) based on the assessment, to propose a model for implementing SBCE within an aerospace development project. While set-based concurrent engineering consists of a wide variety of design techniques, the basic notions can be stated in two principles: 1) engineers should consider a large number of design alternatives, i.e., sets of designs, which are gradually narrowed to a final design, and 2) in a multidisciplinary environment, engineering specialists should independently review a design from their own perspectives, generate sets of possible solutions, and then look for regions of overlap between those sets to develop an integrated final solution.*

[48] Lee, D. a. A. T. (1996). Identification and Use of Key Characteristics in the Product Development Process. ASME Design Theory and Methodology Conference, Irvine, CA.

[49] Ertan, B. (1998). Analysis of Key Characteristic Methods and Enablers Used in Variation Risk Management. Mechanical Engineering. Cambridge, MA, MIT.

Carlile, P. a. C. O. (1999). Communities of Practice as Axes in the Creation and Distribution of New Knowledge in Product Development. Cambridge, MA, MIT.

Clark, K. a. T. F. (1991). Product Development Performance. Boston, MA, Harvard Business School Press.

Clausing, D. a. J. K. (1999). Balancing customer-Driven Variety and Cost-Intensive Complexiy of Product Families During Development. Cambridge, MA, MIT.

Cochran, D. a. T.-S. K. (1999). The Integration of the Product Development Process with Production System Design. Cambridge, MA, MIT.

Cunningham, T. (1998). Chains of Function Delivery: A Role for Product Architecture in Concept Design. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/cunningham.pdf

*This research intends to improve three areas of team performance in concept design: the team's understanding and recognition of the product architecture, the team's ability to document integration issues and risks, and the team's ability to judge whether a product concept is worthy of further pursuit. Many of the high-impact decisions made in concept design revolve around integration issues: how the product's physical elements work together to deliver the performance characteristics, or functions. The product architecture, a singularly important characteristic of the product, is in great part determined by the mapping of the product's functions to the physical elements that deliver those functions.*

de Figueiredo, J. a. M. K. (1999). Product Development in Laser Printers. Cambridge, MA, MIT.

Ertan, B. (1998). Analysis of Key Characteristic Methods and Enablers Used in Variation Risk Management. Mechanical Engineering. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THErtan.pdf

*Many engineering organizations, including aerospace companies, are using Key Characteristics (KCs) to manage the risk of variation in complex products during design through manufacturing. Effective KC implementation improves the quality of the product, reduces manufacturing variation, and reduces cost of design and manufacturing. The KC Maturity Model, which identifies twenty-two supporting practices for achieving optimal KC implementation, can be used by both high and low volume companies as a self-assessment tool. This assessment can identify strengths and weaknesses in KC Practices.*

Ertan, B. (1998). Key Characteristics Maturity Model. Cambridge, MA, MIT.

Fine, C. (1998). Three Dimensional Concurrent Engineering: Clockspeed-based Principles for Process and Supply Chain Development. Cambridge, MA, MIT.

Fine, C. a. S. N. (1999). Sourcing by Design in the Context of Three Dimensional Concurrent Engineering: Product Architecture and the Supply Chain. Cambridge, MA, MIT.

Frey, D., Nicholas Hirshi, and Martin Jared (1999). Product Architecture and Its Role in Robust Design. Cambridge, MA, MIT.

Gansler, J. (1989). Affording Defense. Cambridge, MA, MIT Press.

Hoult, D., C. Lawrence Meador, John Deyst, and Maresi Berry-Dennis (1995). Cost Awareness in Design: The Role of Data Commonality. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/95-08.pdf

*Management of information holds a promise of providing significant improvements in both the effectiveness and efficiency of developing complex products. Determining actual management implementations that deliver on this promise has often proven elusive. Work in conjunction with the Lean Aircraft Initiative at MIT has revealed a straightforward use of Information Technology that portends significant cost reductions. By integrating previously separate types of data involved in the process of product development, engineers and designers can make decisions that will significantly reduce ultimate costs. Since the results presented are not specific to particular technologies or manufacturing processes, the conclusions are broadly applicable.*

Hoult, D., and C. Lawrence Meador (1995). Methods of Integration Design and Cost Information to Achieve Enhanced Manufacturing Cost/Performance Trade-Offs. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/hoult.pdf

*This paper addresses problems which arise when large organizations attempt a tight integration of design and cost while developing complex products. Topics include the sources of cost and design data, the arrangement of the databases, and the interfaces required. It also discusses the management methods required to develop and implement Design/Cost Database Commonality.*

Hsu, T.-C. (1999). Causes and Impacts of Class One Engineering Changes: An Exploratory Study Based on Three Defense Acquisition Programs. Aeronautics and Astronautics and Technology and Policy Program. Cambridge, MA, Massachusetts Institute of Technology.

http://lean.mit.edu/private/documents/theses/TH_Hsu.pdf

*Past studies on engineering changes have focused on products other than defense aerospace products, and have concentrated primarily on the design-manufacturing interface within single companies. Thus, engineering changes in the context of US defense aerospace product development - where the user community, the acquisition community, and the contractors share the responsibility for developing a product - remain largely unexplored. This research focused on three defense aircraft acquisition program case studies, referred to hereafter as Programs A, B, and C. The primary goal of these studies was to develop a better understanding of the causes and impacts of Class I engineering changes in the US defense aerospace product development context. Class I engineering changes, simply referred to as engineering changes below, are those that fundamentally modify the form, fit, and/or function of a product such that the results before and after the engineering changes are different, and are visible to all communities involved with developing the product. In addition, this research sought to identify ways in which contractors and customers may help to reduce the number of undesirable engineering changes.*

Ippolito, B. (1999). Establishing Requirements: A Step in the Software Development Value Stream. International Conference on Systems Engineering, Las Vegas, NV.

Lee, D. a. A. T. (1996). Identification and Use of Key Characteristics in the Product Development Process. ASME Design Theory and Methodology Conference, Irvine, CA.

Mantrpragada, R. (1998). Assembly Oriented Design. Mechanical Engineering. Cambridge, MA, MIT.

*Most complex assemblies consist of many individual sub-assemblies and parts that are designed and made by different suppliers at different locations. Fit-up problems are often discovered during final assembly when trying to put these parts and sub-assemblies together. Finding the source of these fit-up problems is a very difficult and time-consuming task, and most of the time the exact causes cannot be identified. Early anticipation and avoidance of these problems can have a huge impact in reducing the product development time, cost, and production fit-up problems, and can improve final product quality.*

Menendez, J. (1997). Building Software Factories in the Aerospace Industry. Aeronautics and Astronautics. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THMenendez.pdf

*The defense aerospace industry is currently in a phase of shrinking procurement budgets brought on by the end of the Cold War and pressures to reduce the national deficit and balance the Federal budget. Consequently, the Department of Defense has shifted its product development emphasis from system performance to system affordability. Simultaneously, software has become increasingly important for implementing functionality in new systems and sometimes dominates total product development costs. The challenge for industry is to implement new processes and technologies that will*

*allow the reliable, repeatable development of high quality software at reduced cost. One emerging practice capable of meeting this challenge is the software factory.*

Nuffort, M. (1998). Literature Review for Concepts Leading to Enhancing Subsystem Commonality. Cambridge, MA, Massachusetts Institute of Technology.

*Defense aerospace acquisition differs from commercial consumerism in almost all respects. In general, defense aerospace systems are procured in relatively small quantities, with high variety, at a high cost. It is often difficult to achieve reductions in cost through the economies of scale that reduce costs in commercial products. Increasing production volumes or decreasing variety may not be an acceptable option to the military customer, who is limited to a set allocation of funds and dependent on mission specificity. Higher production volumes also will translate to higher operational costs, even though the aircraft unit cost may be reduced significantly. Procuring more units of a system than needed to meet the services' requirements may result in concentrated capability in a specific area, and consequently, deficient capability in another arena and lower overall mission preparedness. Defense contractors must find another means of reducing costs.*

*A second method to reduce program acquisition cost is to reduce variety by designing and manufacturing a single platform or a few standard designs to meet the needs of all the services. Again, this method endeavors to take advantage of economies of scale, but it runs the risk of not meeting the unique operational needs of each service. A system designed for several customers usually results in extra features or unwanted capability being delivered to one user, while another user is forced to compromise a certain amount of operational capability. This approach to cutting costs also may result in dissatisfied customers.*

*One potential solution to the problem of satisfying all customers' performance needs, while at the same time reducing program cost, is the modern concept of "mass customization." The approach applies a single process to produce a basic platform, around which many variations of features are available. By creating standard interfaces across platforms, multiple subsystems form a vast array of different products. Such a modular architecture creates the opportunity to take advantage of broad-based commonality between platforms, thus enjoying economies of scale without sacrificing variety. The intent of this review is to investigate the effects, both positive and negative, of more extensive use of common subsystems across multiple defense aerospace projects and to examine the implementation of a strategy to manage subsystem commonality in the industry.*

Nuffort, M. (1998). Research Proposal for Managing Subsystem Commonality in the DoD. Cambridge, MA, Massachusetts Institute of Technology.

*The cost of state-of-the-art weapons of defense has increased steadily over the past number of decades, while the overall defense budget in the United States has been shrinking with similar consistency. If the United States is to retain its technological advantage, the Defense Department must find ways to procure new weapon systems more quickly and at lower cost than present methods. The commercial world, driven by intense competition and fluctuating economies, is constantly in search of methods to reduce cost and cycle time, thus gaining an advantage over competitors. One such*

*method employed by industry is the use of platform-based design and design reuse to increase the amount of commonality between platforms, thereby decreasing engineering time and capital outlay. For example, world auto companies have been increasing their use of common subsystems and platform sharing across different vehicle programs to drive down costs in the highly competitive environment that has characterized the industry in this decade. This research seeks to examine the possibility of utilizing these commercial practices, namely increased subsystem commonality and platform-based design, to decrease cost and cycle time for weapon system procurement in the defense aerospace industry.*

Otto, K. a. E. Z. (1999). Product Family Architecture Decisions Using Function-Variety Structures. Cambridge, MA, MIT.

Otto, K. a. J. Y. (1999). Market Driven Product Architecture Definition. Cambridge, MA, MIT.

Pomponi, R. (1997). The Organization of Integrated Product Teams(Literature Review). Cambridge, MA, MIT.

Walton, M. (1999). Identifying the Impact of Modeling and Simulation on the Generation of System Level Requirements. Aeronautics and Astronautics. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/TH_Walton.pdf

*Requirements generation is an influential time in the evolution of the program. It allocates 70% of the life-cycle cost of a program and is responsible for a large percentage of the system errors and cost overruns. This project lays the framework of the current state of requirements generation and then focuses on the use of modeling and simulation within the process. It is shown that although modeling and simulation tools are being used extensively in requirements generation in many programs throughout the DoD, their effectiveness is largely undocumented and areas of high leverage are unknown. Research results also indicate that the more effective use of M&S within requirements generation could be achieved with increased tool interoperability and easier tool validation and verification. Finally, the ability to perform more iteration early and M&S use as a boundary object for communication are set forth as the two main benefits of M&S.*

Whitney, D. a. P. R. (1999). A Methodology for Platform Reduction. Cambridge, MA, MIT.

# MODULE IV: APPLYING LEAN THINKING TO PROGRAM PLANNING AND EXECUTION

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## Module IV Introduction

Each module begins with an explanation of how each relates to the overall goal of the project and also how it relates to concepts of Lean. Module IV is the fourth in a series of six self-standing texts aimed at releasing research uncovered through the Lean Aerospace Initiative in the field of lean product development. This module takes a close look at the application of lean in program planning and execution.

The first section discusses interesting research in what can best be described as program management. This includes topics of managing risk and people. The next section explores some of the research in LAI on technology investment and insertion. The third section puts forth a piece of the supply chain research that has been done through LAI. Finally, lean information management is discussed.

## Program Management

In this section, two topics that are often attributed to program management will be addressed. Other sections of the text could fall under the heading of program management as well, such as metrics, but were placed elsewhere for sake of a better fit. There has been no comprehensive research done through LAI that focuses on program management and perhaps that would be a fruitful topic.

### *Managing Risk*[50]

The ability to manage risk well is one of the sought after ability in leadership, and the tools and information that can help in the process are equally sought after. Successful companies and successful individuals take risks. The taking of risks however doesn't dictate success. Instead, the ability to calculate the resulting benefit of the risk and the consequences of the risks themselves allows for more effective risk taking that relies less on luck and qualitative judgment and more on statistical probabilities and true quantitative assessment. One researcher illustrated the tie of risk management to that of product development on the whole:

> *From one perspective, product development is a process of uncertainty reduction and risk management. Markets and customers are studied to derive product design and pricing criteria and a product introduction window of opportunity; designs are developed to meet these goals; and development projects are managed and controlled to keep cost and schedule within acceptable limits. Each of these steps contains uncertainty and therefore risk. Bettering our understanding of the sources of risk in the product development process is fundamental to improving it.*[51]

Research conducted through LAI has identified six types of product development risk: product performance risk, technology risk, development cost risk, schedule risk, market risk, and business risk, as illustrated below.

***Performance risk*** Uncertainty in the ability of a design to meet desired quality criteria (along any one or more dimensions of merit, including price and timing) and the consequences thereof

***Schedule risk*** Uncertainty in the ability of a project to develop an acceptable design (i.e., to sufficiently reduce performance risk) within a span of time and the consequences thereof

***Development cost risk*** Uncertainty in the ability of a project to develop an acceptable design (i.e., to sufficiently reduce performance risk) within a given budget and the consequences thereof

***Technology risk*** A subset of performance risk: uncertainty in capability of technology to provide performance benefits (within cost and/or schedule expectations) and the consequences thereof

***Market risk*** Uncertainty in the anticipated utility or value to the market of the chosen "design to" specifications (including price and timing) and the consequences thereof
***Business risk*** Uncertainty in political, economic, labor, societal, or other factors in the business environment and the consequences thereof

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[50] A majority of this section has been taken from Browning, T. (1998). Modeling and Analyzing Cost, Schedule, and Performance in Complex System Product Development. Technology, Management and Policy. Cambridge, MA, MIT.

[51] Browning, T. (1998). Modeling and Analyzing Cost, Schedule, and Performance in Complex System Product Development. Technology, Management and Policy. Cambridge, MA, MIT.

Browning went on to put forth a model for representing some of these dimensions of risk through a derived Design Structure Matrix Approach. Th approach allows for probabalistic estimation of three dimensions of risk: cost, schedule, and performance. A sample of the model is presented in Figure 11.

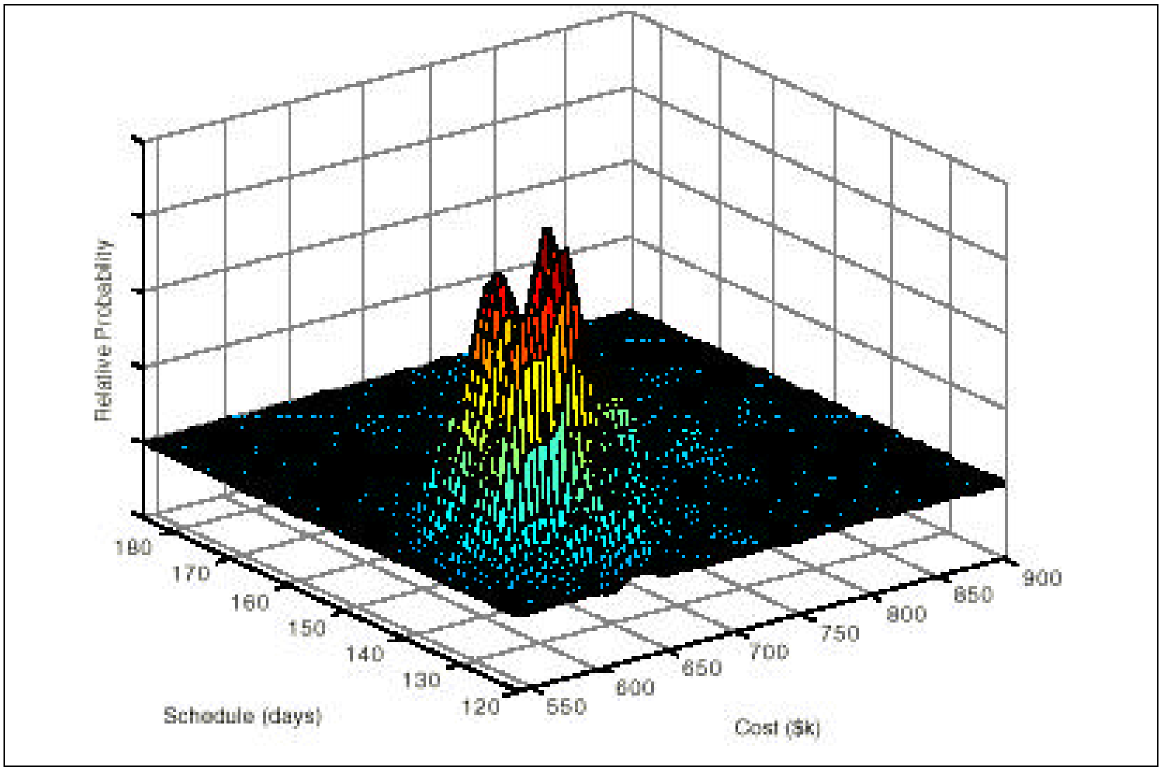


**Figure 11: Multi-Dimensional Risk Modeled**[52]

### *Managing Information*

Information Management is becoming more and more important at companies and organizations as the amount of information necessary to succeed increases dramatically. The main topic that will be covered in this section is open book management and internal organizational information sharing.

Open Book Management is defined in the following statement:

> It is possible to create a work environment in which each employee can make an impact on the company's profitability. Such an approach has been taken by a few leading edge companies with dramatically successful results. Their success stems from creating a partnership with all employees. This partnership is developed through the application of a combination of proven and innovative

[52] Complete explanation of the model can be found in Browning, T. (1998). Modeling and Analyzing Cost, Schedule, and Performance in Complex System Product Development. Technology, Management and Policy. Cambridge, MA, MIT., as well as results applied to case study data.

human resources initiatives that are based on trust and sharing and free from the concept of exploitation [53]

Thus it becomes clear that ideals of OBM fit very nicely with the empowerment ideals of lean.  Charles and Negron went on to illustrate a model definition of Open Book Management as it exists on four dimensions, as shown in Figure 12.[54]

- degree of employee involvement or empowerment
- types of information shared
- risk/reward or incentive system
- business scorecard

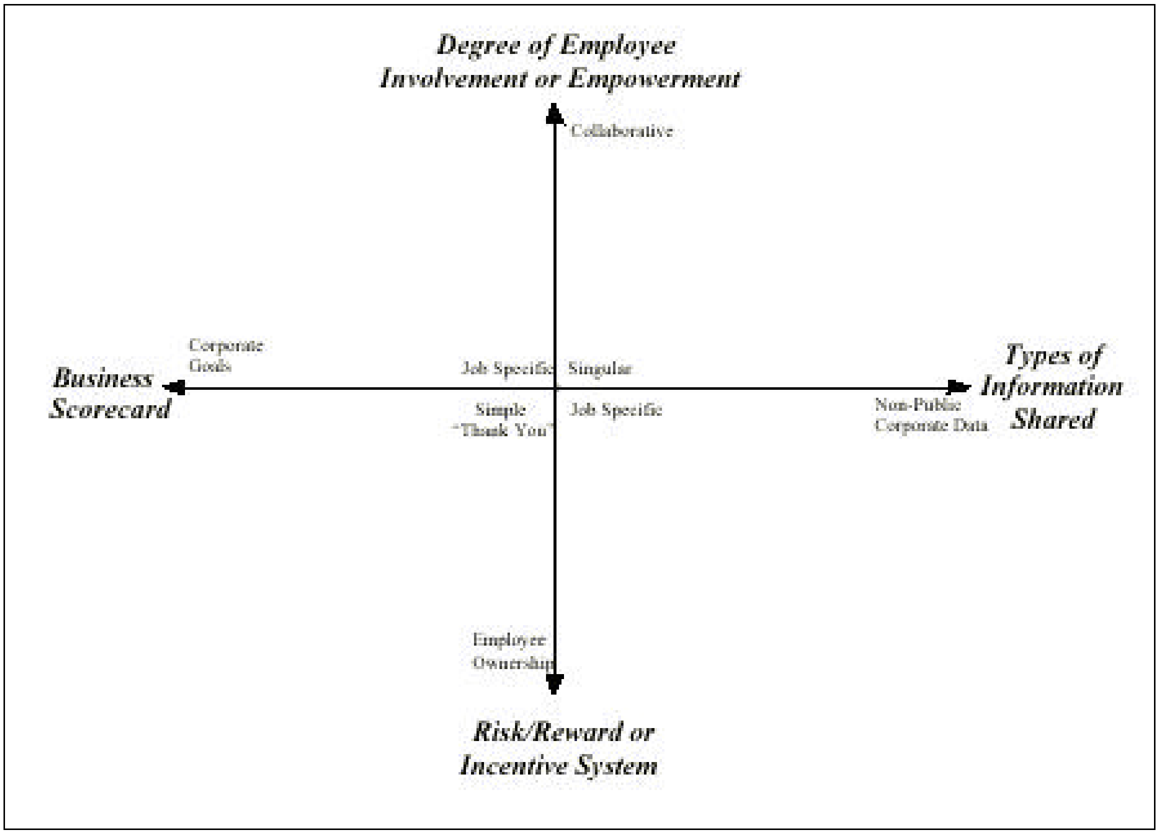


**Figure 12: Open Book Management Model**

The upper vertical axis describes the degree of employee involvement (empowerment) in various decisions that are made throughout organizations. This can range from individual decision-making to a collaborative or team-based effort.

The horizontal axis to the right represents the type of information required to be shared to effectively make quality, informed decisions. This can range from information specifically related to one's job to corporate data that has not been publicly disclosed.

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[53] McCoy, T. (1996). Creating an Open Book Organization: Where Employees Think and Act Like Business Partners. New York, NY, Amacon. p. 2

[54] Charles, C. (1997). Open-Book Management Goes Beyong the Bottom Line. Cambridge, MA, MIT.

The horizontal axis to the left identifies achievement of critical measurement items, such as business goals and objectives. This business scorecard assesses the attainment of previously specified goals that can range from individual job-specific to corporate objectives.

The lower vertical axis in Figure 12 represents the incentive system that can include both pay at risk and a profit sharing payment.

The team went on in their research to conduct two case studies, one at Springfield Remanufacturing Corporation (SRC), and the other at GM's Saturn. Their applied model to these two case studies is displayed in Figure 13.

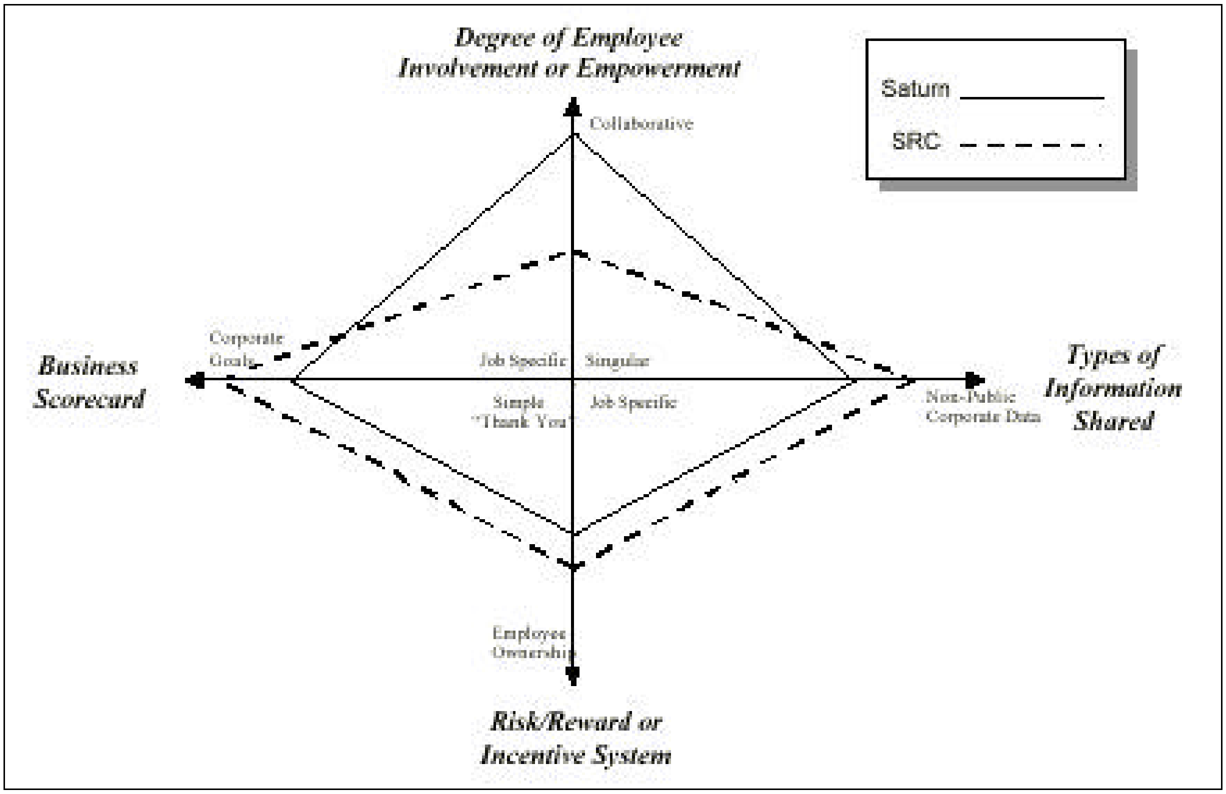


**Figure 13: Case Studies of OBM**[55]

## Technology Insertion and Investment

Technology insertion and investment is of great concern to virtually all industries, but the aerospace industry presents some unique problems with new technology because its lengthy cycle times and risk avoidance. One LAI researcher evaluated the current NASA best practices in place for technology investment decisions; evaluated the application of Real Options to the technology selection policy; and made

[55] For complete text on case studies and further information, refer to Charles, C. (1997). Open-Book Management Goes Beyong the Bottom Line. Cambridge, MA, MIT.

recommendations for the strategic management of the NASA portfolio and publicly funded R&D in general.[56]

The key insight of this research is that a decision process can be established to fill the current vacuum and improve budget allocation, but that real options has two weaknesses that are particularly pronounced when applied to this sector. The first is the reliance on expert opinions for probabilities. The second is the necessity to place an absolute monetary value on outcomes.[57]

## Integrating the Supply Chain

Integrating the supply chain into product development decisions is essential to achieving lean in any organization or program. Significant research has been ongoing through LAI in the area of supplier relations and integrating the supply chain. One example of such research is Cambell's research on *Managing the Defense Industry Transition to Performance-Based Practices and Supply Chain Integration.* In the thesis, he looks at integration of the supply chain from a military program standpoint and the challenges that face the integration of commercial industry and military programs through the supply chain, but also points out the benefits that can result from these relationships.[58]

## References for Module IV:

Browning, T. (1997). An Introduction to the Use of Design Structure Matrices for Systems Engineering, Project Management and Organizational Planning. Cambridge, MA, MIT.

Browning, T. (1998). Modeling and Analyzing Cost, Schedule, and Performance in Complex System Product Development. Technology, Management and Policy. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THbrowning.pdf

*In the future, it is unlikely that complex system products will compete solely on the basis of technical performance. What will differentiate such systems and their developers is the ability to balance all the dimensions of product performance, including product pricing and timing (which are functions inclusive of development cost and cycle time). Furthermore, this balance must be congruent with customers' perceptions of value. Once this value is ascertained or approximated, complex system developers will require the capability to adjust the design process to meet these expectations. The required amount and sophistication of project planning, control, information, and flexibility is unprecedented. The primary goal of this work is a method to help managers integrate*

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[56] Lackner, D. (1999). Strategic Technology Investment in Research and Development. Technology Policy Program. Cambridge, MA, Massachusetts Institute of Technology.

[57] For more information on option theory and the assessment of NASA's technology investment strategy see Lackner, D. (1999). Strategic Technology Investment in Research and Development. Technology Policy Program. Cambridge, MA, Massachusetts Institute of Technology..

[58] Cambell, E. (1998). Managing the Defense Industry Transition to Performance-Based Practices and Supply Chain Integration. Sloan School of Management. Cambridge, MA, MIT..

*process and design information in a way that supports making decisions that yield products congruent with customer desires and strategic business goals.*

Browning, T. (1998). UCAV VSS Process Report. Cambridge, MA, MIT.

Cambell, E. (1998). Managing the Defense Industry Transition to Performance-Based Practices and Supply Chain Integration. Sloan School of Management. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THCampbell.pdf

*With the end of the Cold-War, the U.S. defense aerospace industry has been going through a historic process of change and adaptation in the 1990s due to a number of significant structural shifts, including changes in national security threats and sharp reductions in defense spending In the wake of these drastic structural changes, and in an effort to achieve greater affordability of weapon systems, the DoD has implemented a number of initiatives, including industrial base pilot programs to develop and test new technologies and business practices, such as the Military Products from Commercial Lines (MPCL) Industrial Base Pilot (IBP) program. This thesis focuses on the MPCL IBP experience, which has successfully demonstrated the ability of a military contractor to produce military electronics hardware through a commercial product line, with a "win-win" outcome for all participants. This thesis documents the "Lessons Learned" from the MPCL IBP case study to shed light on the broader set of challenges and opportunities in managing the transition of the defense aerospace industry to performance-based non-governmental or commercial practices, with particular emphasis on supply chain integration.*

Carlile, P. a. W. L. (1999). Risk Management as Knowledge Management in Product and Process Development: Designing and Implementing Complex Product and Production Technologies. Cambridge, MA, MIT.

Charles, C. (1997). Open-Book Management Goes Beyong the Bottom Line. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THCharles.pdf

*This thesis encompasses sharing business data and its power to affect behaviors in the organization's culture, employee decision-making, trust between employer and employee, and impact to the bottom line data. This thesis will attempt to answer questions such as: why implement Open-Book Management, how does sharing information impact an organization's culture, how do implementation processes occur within these varied businesses, how does a business determine what information should be shared, and is there an impact to the bottom line.*

Clausing, D., Nelson Repenning, and John Hull (1999). Modeling Product Portfolio Evolution. Cambridge, MA, MIT.

Cusumano, M. a. A. G. (1999). Rapid and Flexible Strategic Planning and Product Development: An Analysis of PC and Internet Software Producers. Cambridge, MA, MIT.

Cusumano, M. a. K. N. (1998). Thinking Beyond Lean. New York, NY, The Free Press.

Eppinger, S. a. M. S. (1999). Controlling the Execution of Complex Product Development Projects. Cambridge, MA, MIT.

Garbo, S. (1997). A Technology Development and Business Strategy: A Changing Environment Impacts Practices. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THGarbo.pdf

*Many high technology US manufacturing industries, and especially the aerospace industry are facing unparalleled world-wide competition in a new, faster-paced, cost-conscious, global marketplace. The process of new technology development, and its earliest introduction into product production programs, is undergoing major changes in almost all US firms as they restructure for this new global business environment. These forces of change were studied relative to their impact on how technology planning is accomplished and its interaction with company business plans. Manufacturing industries were selected and historically reviewed. An industry background was created to list major business and strategy trends known to be occurring. Independently, selective industry interviews were performed to collect complementary data on current practices and changes ongoing. A literature survey was performed to summarize major academic theories regarding planning for needed technology development, and its required interaction with firm strategic (business) planning. Results were assessed relative to the adequacy of current practices to the business environment of the mid-1990's, and the changing role of technology in industry strategy.*

Hauser, J. a. A. M. (1999). Identifying the Most Effective New Product Development Metrics. Cambridge, MA, MIT.

Hou, A. (1995). Toward Lean Hardware/Software System Developement: An Evaluation of Selected Complex Electronic System Development Methodologies. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/95_01.pdf

*The development of electronic hardware and software has become a major component of major DoD systems. This report surveys a wide set of new electronic hardware/software development methods and develops a system to evaluate them, particularly for cross system integration. A possible foundation for lean hardware/software development is described.*

Hoult, D., C. Lawrence Meador, John Deyst, and Maresi Berry-Dennis (1995). Cost Awareness in Design: The Role of Data Commonality. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/95-08.pdf

*Management of information holds a promise of providing significant improvements in both the effectiveness and efficiency of developing complex products. Determining actual management implementations that deliver on this promise has often proven elusive. Work in conjunction with the Lean Aircraft Initiative at MIT has revealed a straightforward use of Information Technology that portends significant cost reductions. By integrating previously separate types of data involved in the process of product development, engineers and designers can make decisions that will significantly reduce ultimate costs. Since the results presented are not specific to particular technologies or manufacturing processes, the conclusions are broadly applicable.*

Klein, J. (1996). Labor Support Survey Summary Report. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/RP960808Klein.pdf

*One of the main cost drivers in the defense aerospace industry is overhead personnel. Traditionally, labor support ratios have been used as an efficiency measure and to control overhead levels. More recently, several organizations have used labor support ratios as a basis for outsourcing and/or downsizing decisions. As a result, the Factory Operations Focus Group attempted to benchmark how member companies stand relative to one another on labor support ratio. This report outlines the survey responses and analysis and summarizes the potential factors influencing labor support ratios.*

Lackner, D. (1999). Strategic Technology Investment in Research and Development. Technology Policy Program. Cambridge, MA, Massachusetts Institute of Technology.

http://lean.mit.edu/private/documents/theses/TH_Lackner.pdf

*NASA (National Aeronautics and Space Administration) is succumbing to pressures to operate more like a private entity than a government agency; however, modern business practices are rare in the organizational structure. NASA can install project evaluation and selection techniques like real options analysis to improve capital budgeting for technology projects.*

*This thesis evaluates the current NASA best practices in place for technology investment decisions; evaluates the application of Real Options to the technology selection policy; and makes recommendations for the strategic management of the NASA portfolio and publicly funded R&D in general.*

McCoy, T. (1996). Creating an Open Book Organization: Where Employees Think and Act Like Business Partners. New York, NY, Amacon.

McNutt, R. (1998). Reducing DoD Product Development Time: The Role of the Scedule Development Process. Technoogy, Management and Policy. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/TH_McNutt_399.pdf

*According to the Packard Commission, "Unreasonably long acquisition cycles -- ten to fifteen years for major weapon systems is a central problem from which most other acquisition Problems stem." Since the commission issued its report in 1986, the time required to develop new military systems has only grown. This research and its recommendations are intended to identify and eliminate the causes of those long development times for military systems. This report addresses a key factor in determining the development time for military projects: the project's initial schedule.*

Perrons, R. (1997). Make-Buy Decisions in the U.S. Aircraft Industry. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THPerrons.pdf

*This thesis approaches the topic of make-buy decisions in the U.S. aircraft industry in four ways. One, it offers insight into the circumstances and criteria behind make-buy decisions in the industry by examining two case studies involving commercial and defense products, respectively. The case studies focus as well on the vertical relationships among the companies examined, and how these relationships are realigned as a result of the prime's make-buy decisions. Two, this thesis proposes a framework that explains ex post how managers in the industry decide to make or buy a particular component or process, and that provides guidelines for approaching future make-buy decisions. The framework concentrates on two major factors that play key roles in the aircraft sector's make-buy judgments: the degree of technological maturity of the component or process, and the relative competitive market position of a firm with respect to the particular technology underlying the component or process. Three, this thesis recommends a make and buy strategy that large companies in the industry should consider for securing and maintaining a leading role in their respective core competencies. Four, it addresses the principal ways in which the aircraft industry's make-buy decisions may be affected by or may eventually lead to changes in the policies of the U.S. government.*

Rebentisch, E. (1996). Preliminary Observations on Program Instability. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/96_03.pdf

*This white paper reports emerging findings at the end of Phase I of the Lean Aircraft Initiative in the Policy focus group area. Its objective is to discuss high-level findings detailing: 1) the relative contribution of different factors to a program's overall instability; 2) the cost impact of program instability on acquisition programs; and 3) some strategies recommended by program managers for overcoming and/or mitigating the negative effects of program instability on their programs. Because this report comes as this research is underway, this is not meant to be a definitive document on the subject. Rather, it is anticipated that this research may potentially produce a number of reports on program instability-related topics.*

Robbins, J. (1994). Critical Examination of a Complex and Critical Major Acquisition for the Department of Defense: The Advanced Medium Range Air-to-Air Missile (AMRAM). Management. Cambridge, MA, MIT.

*In 1976, a group of United States Air Force and United States Navy fighter aircraft pilots told the acquisition professionals of the Armament Development and Test Center at Eglin Air Force Base in Florida the operational requirements for a new, lightweight air-to-air missile. They dreamed that the engineers and scientists of the US aerospace community could put an entire radar system more powerful than most aircraft radar into a 7-inch diameter and that the resulting missile would let them launch multiple missiles at multiple enemy aircraft from beyond visual range. As of March 1994, the operational forces have received over 3,000 missiles that surpass all expectations in performance and reliability. This thesis is a case study of the acquisition strategy and Government organization that the Department of Defense used to acquire the AMRAAM system. The AMRAAM program is explained and analyzed from a managerial perspective from the genesis of the operational requirements until March of 1994. Positive and negative lessons learned, as well as critical programmatic issues, are described for research and development, introduction of production competition through a leader/follower technique, pre-planned product improvements to sustain system performance well beyond the year 2010, management in the joint-service environment, and multi-national participation. The thesis concludes with alternative acquisition strategies that the Air Force has for the AMRAAM program. The road to AMRAAM's success as a program was long and difficult. Current and future Department fo Defense programs will be benchmarked against the AMRAAM accomplishments.*

Simester, D. a. C. C. (1999). Using Non-Monetary Incentives to Encourage Adoption of New Product Development Methods. Cambridge, MA, MIT.

Slaghter, S. a. C. S. (1999). Product Development Across Firm Boundaries: Problems of Cooperation and Coordination in Large Complex Systems. Cambridge, MA, MIT.

Stern, S. a. D. H. (1999). Shaping Technology Strategy: Understanding the Incentives for In-House Development Versus the External Acquisition of New Ideas. Cambridge, MA, MIT.

Stout, T. (1996). The Role of Product Development Metrics for Making Design Decisions in the Defense Aerospace Industry. Technology and Policy and Mechanical Engineering. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/stout.pdf

*In current product development activities, many companies are unable to accurately predict the success of their efforts. This leads companies into dead-end development paths and often results in output that meets the contracted requirements for the program but fails to satisfy either the internal or external customers' needs. These problems arise primarily from one or more of three common problems during the development: failure to* *focus on the proper metrics and measurements of current activities; failure to maintain a significant historical database to facilitate corporate learning; and the use of a decision-making process that often lacks the information necessary to make good decisions. This thesis identifies these problems through three case studies of product modifications and upgrade development programs in the defense aircraft industry. From these cases and existing literature, examples of both good and poor practices are presented to support the basic conclusions.*

Wallace, D., and Shaun Meredith (1999). Modeling Granularity and Information Quality. Cambridge, MA, MIT.

Whitney, D. a. Q. D. (1999). Information Flow Mapping to Aid Design of Complex Products. Cambridge, MA, MIT.

# MODULE V: UNDERSTANDING THE ENVIRONMENT AS A KEY TO EFFECTIVE PRODUCT DEVELOPMENT

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## Module V Introduction

Each module begins with an explanation of how each relates to the overall goal of the project and also how it relates to concepts of Lean. Module V is the fifth in a series of six self-standing texts aimed at releasing research uncovered through the Lean Aerospace Initiative in the field of lean product development. This module ties together some concepts that can best be described as methods to achieve an understanding of the program and project environment.

A majority of the research conducted through LAI is focused on defense aerospace programs. LAI research has shown that in military programs, the impacts felt from the changing political and social environments create a layer of complexity not found in the commercial sector that have significant impact on program success. With that being said though, there is significant information in this module that can be applied regardless of military or civil or commercial.

## Metrics in Product Development

In current product development activities, many companies are unable to accurately predict the success of their efforts. This leads companies into dead-end development paths and often results in output that meets the contracted requirements for the program but fails to satisfy either the internal or external customers' needs. These problems arise primarily from one or more of three common problems during the development: failure to focus on the proper metrics and measurements of current activities; failure to maintain a significant historical database to facilitate corporate learning; and the use of a decision-making process that often lacks the information necessary to make good decisions.[59]

Stout's thesis identifies these problems through three case studies of product modifications and upgrade development programs in the defense aircraft industry. From these cases and existing literature, examples of both good and poor practices are presented to support the basic conclusions. The research led to three very strong conclusions:

- Metrics currently used in product development within the defense aerospace industry are not accurate indicators of the success or failure of development programs;
- Historical records of past development programs are normally incomplete or the information is inaccessible; and
- Design decisions often rely upon incomplete information and lack a strong understanding of the risks inherent in the design.

## Achieving Program Stability in a Changing Environment

Research by Rebentisch, sought quantitative data on the elements that contribute to program instability and some of the steps that are most effective strategies to avoiding the instability.[60] Figure 14 illustrates the contributing factors to program stability as seen by a survey of program mangers, while Figure 15 shows the most effective strategies used by program managers to avoid the instability.

[59] Stout, T. (1996). The Role of Product Development Metrics for Making Design Decisions in the Defense Aerospace Industry. Technology and Policy and Mechanical Engineering. Cambridge, MA, MIT.

[60] For more detail into research method and further conclusions and data see Rebentisch, E. (1996). Preliminary Observations on Program Instability. Cambridge, MA, MIT..

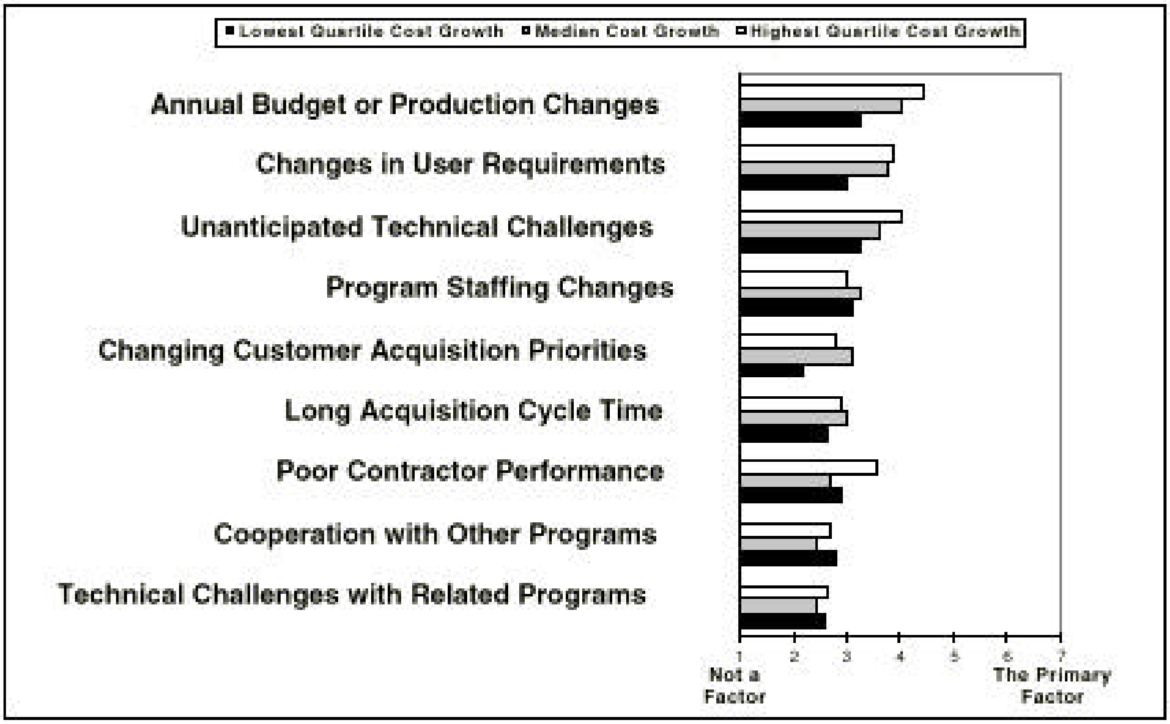


**Figure 14: Rated Causes of Program Instability[61]**

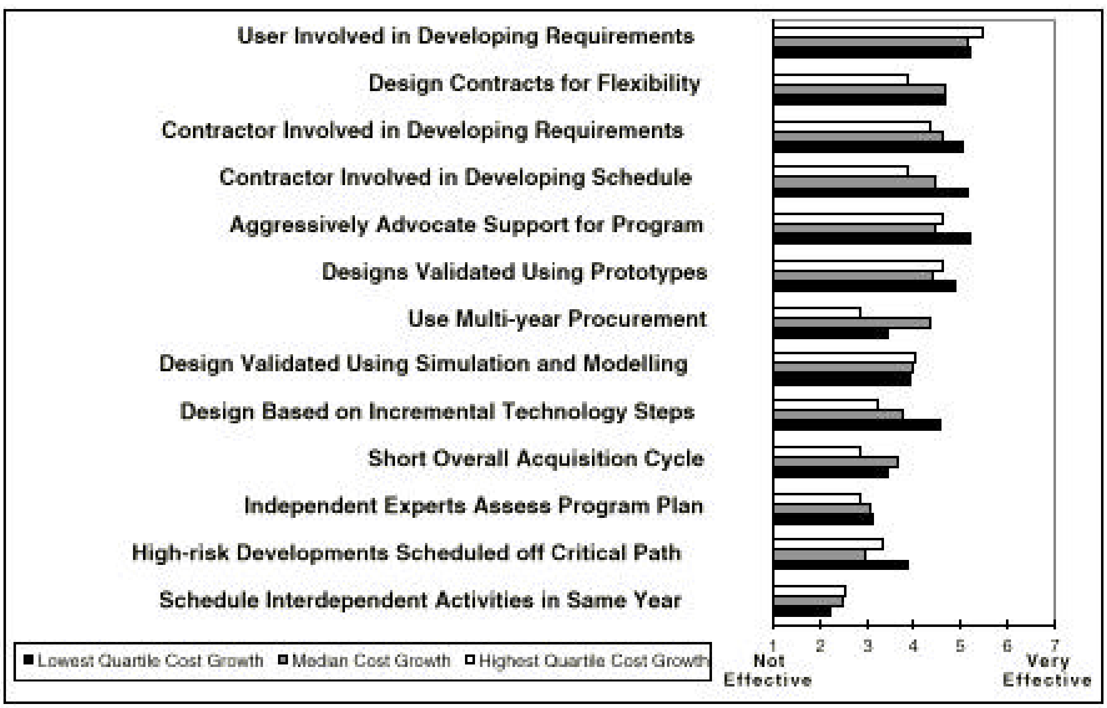


**Figure 15: Ratings of Strategies to Avoid Program Instability[62]**

[61] Rebentisch, E. (1996). Preliminary Observations on Program Instability. Cambridge, MA, MIT.

A second work related to program instability is McNutt's work in LAI was on DoD product development cycle time reduction. In it, he explored the factors of delay and improvement recommendations. His research developed the key barriers to reducing development time for military systems as the lack of importance placed on project schedules; the lack of effective schedule-based information and tools; the lack of schedule-based incentives; and the overriding impact of the funding-based limitations on defense projects.

In addition, the steps necessary to establish a focus on reducing development time are: 1) recognizing the impact of development time, 2) providing the necessary information for decision makers, 3) providing proper incentives at each organizational level, and finally providing a structure to effectively manage the set of all development projects to ensure that each project can be funded based on its development related requirements.[63]

## Program Incentives for Success

Incentive structures for contracts in the department of defense can be very complicated to develop and mange. Cowap's thesis provides a framework for government and contractor program managers to develop economic incentives in the future. Changing acquisition policies challenge program managers as they attempt to structure procurement contracts that meet government and company goals and objectives. The framework developed highlights the critical link between the management processes within a weapon system acquisition program and the establishment of economic incentives. Practices are described that help identify, quantify and foster the development of incentives.[64]

## Military Environment

The unique aspects of the military environment often cause it to be the subject of research. Areas of commercial and military interaction, military policy and culture have all been investigated in LAI related research. The following contains two examples of such research that has been conducted. The first explores the military and commercial relationship, while the second section discusses the military acquisition reform strategy.

### *Military and Commercial Interactions*

Anderson provides an interesting investigation into the use and experiences of the federal government's experience with commercial. Using research information gathered from 23 current defense acquisition programs that used commercial procurement practices successfully, the thesis identifies specific practices in use, documents lessons learned from practice implementation, and investigates five core

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[62] Rebentisch, E. (1996). Preliminary Observations on Program Instability. Cambridge, MA, MIT.

[63] McNutt, R. (1998). Reducing DoD Product Development Time: The Role of the Scedule Development Process. Technoogy, Management and Policy. Cambridge, MA, MIT.

[64] Cowap, S. (1998). Economic Incentives in Aerospace Weapon System Procurement. Technology and Policy and Aeronautics and Astronautics. Cambridge, MA, MIT.

hypotheses regarding the direct impact of the practices on acquisition costs, acquisition schedule, quality, life cycle support, and life cycle costs.[65]

### *Acquisition Reform*

Acquisition reform is department of defense ongoing improvement initiative aimed at curtailing the ever increasing cost and schedule of defense acquisitions. Research within LAI has focused on this change initiative and what kind of impact it has had on the overall aerospace industry. (Doane 1997) (Sapolsky 1994) both explored the conditions of acquisition reform. Doane research looked at the influence of acquisition reform on culture, while the Sapolsky report concentrated on developing a detailed history on acquisition reform and recurring themes of reform in the department of defense.

## References for Module V:

Anderson, M. (1997). A Study of the Federal Government's Experiences with Commercial. Cambridge, MA, MIT.

*The continual decline in our country's defense budget has severely impacted both government and the defense industry. To cope, the government has increasingly relied on the use of commercial procurement practices, a central tenet of federal acquisition reform. This thesis examines the impact of new commercial procurement practices from the perspective of the average defense acquisition manager. Using research information gathered from 23 current defense acquisition programs which used commercial procurement practices successfully, the thesis identifies specific practices in use, documents lessons learned from practice implementation, and investigates five core hypotheses regarding the direct impact of the practices on acquisition costs, acquisition schedule, quality, life cycle support, and life cycle costs.*

Bakkila, M. (1996). A System Dynamics Analysis of the Interaction Between the U.S. Government and the Defense Aerospace Industry. Aeronautics and Astronautics. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THBakkila.pdf

*The defense aerospace industry is experiencing a dramatic decrease in product orders due to the downsizing of the U.S. military. Industry leaders have recognized a need to reduce both the cost and cycle time of defense aircraft design, development, and production while maintaining product performance, quality, and corporate profitability. As a result, several aerospace companies, the Department of Defense, and researchers at the Massachusetts Institute of Technology have formed a consortium - the Lean Aircraft Initiative (LAI). The LAI goal is to identify the path for implementation of "best" practices into the aerospace industry and the government departments with which they interact. This thesis investigates the interaction of the government and the defense aerospace industry during the military procurement cycle. This interaction is demonstrated by analyzing the defense procurement system and the industry product*

[65] Anderson, M. (1997). A Study of the Federal Government's Experiences with Commercial. Cambridge, MA, MIT.

*development process using system dynamics principles. The resulting System Dynamics model identifies and seeks to quantify the interaction between the two organizations. The model interactions are calibrated against a recent military development project and the effects of variables on project performance and investigated through sensitivity analysis.*

Cowap, S. (1998). Economic Incentives in Aerospace Weapon System Procurement. Technology and Policy and Aeronautics and Astronautics. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THCowap.pdf

*In the last several years, policy makers have attempted to make changes in the defense acquisition system to allow for a structure that provides for the selection and budgeting of the most cost-effective weapons. Senior Department of Defense officials are attempting to shift away from regulation and oversight and towards economic incentives for the procurement of higher quality and lower cost weapon systems. This thesis provides a framework for the establishment of incentives within an aerospace weapon system program. The objective of this thesis is to provide a framework for government and contractor program managers to develop economic incentives in the future. Changing acquisition policies challenge program managers as they attempt to structure procurement contracts that meet government and company goals and objectives. The framework developed highlights the critical link between the management processes within a weapon system acquisition program and the establishment of economic incentives.*

Cutcher-Gershenfeld, J. a. D. B. a. t. L. I. I. (1999). “Lean Aircraft Initiative Implementation Workshop #3: Customer and Supplier Integration Across the Supply Chain.” .

http://lean.mit.edu/private/documents/publications/RP99_01_38.pdf

*The integration of customers and suppliers along the supply chain involves a fundamental transformation of the way business is conducted in the Aerospace industry. Lean Aerospace Initiative (LAI) members, as well as representatives from their supplier base, had the opportunity to examine this challenge and the dynamics of implementing system-wide change during the third implementation workshop sponsored by LAI, February 12-13, 1998 in Palm Beach Gardens, Florida.*

Doane, D. (1997). Cultural Analysis Case Study: Implementation of Acquisition Reform within the Department of Defense. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THDoane.pdf

*Over the past 20 years, the DOD has attempted to reform their acquisition policies but has failed to address the significance of culture in the implementation of reform. This thesis focuses on the impact and importance of culture on implementing and sustaining long-term change efforts. Edgar H. Schein's framework for analyzing culture within the organization is the model for the analysis focusing on the essential elements; mission and strategy, goals, means, measurement, and correction. Using case study analysis, the primary research focused on a large Navy and Air Force procurement under the new Acquisition Reform philosophy. The organizational structure of the program, roles,* *responsibilities, accountability, incentives and motivations of all levels within the Department of Defense workforce is defined and analyzed. The results of the analysis will be integrated into Schein's framework to identify common themes that exist across the services and the specific organizations.*

Driscoll, D. (1996). Organizational and Cultural Transformation to Achieve Lean Manufacturing in the Aerospace Inductry. Cambridge, MA, MIT.

*This is a study of the operational and cultural aspects of change in a manufacturing environment. It reviews the key principles for achieving leanness and provides an overview of the Lean Enterprise Model (LEM), looking at how the practices of this model can be used to guide the development of the lean enterprise. It overviews the need for a systems approach to enterprise design and looks at the reasons why balance is necessary between people, organizations, and technology. The main portion of the thesis is a case study of the organizational and cultural transformation underway at an American aerospace company. The case study looks specifically at organizational learning and cultural change. It examines the reasons why changes were initiated, the methods used to prepare the organization for change, organizational strategies behind the transformation, and the effectiveness of management support, communication, and training. Finally, the thesis evaluates the extent to which the organizational and cultural transformation underway at this company follows the latest theories and models for developing a lean enterprise. It provides an objective assessment of ongoing activities and offers some suggestions for improvements.*

Falco, J. (1998). Offsets and the Aerospace Industry. Management. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THFalco.pdf

*A field study was performed and a literature search conducted to frame and analyze the role of offsets in the aerospace industry. The subject of offsets was defined in relation to the current environment in the aerospace industry. An overview of the US aerospace industry is provided and highlights revenue and employment trends over the past few years. This study segregated the three major sections of the aerospace industry: Airframes, Engines and Missiles.*

Garbo, S. (1997). A Technology Development and Business Strategy: A Changing Environment Impacts Practices. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THGarbo.pdf

*Many high technology US manufacturing industries, and especially the aerospace industry are facing unparalleled world-wide competition in a new, faster-paced, cost-conscious, global marketplace. The process of new technology development, and its earliest introduction into product production programs, is undergoing major changes in almost all US firms as they restructure for this new global business environment. These forces of change were studied relative to their impact on how technology planning is accomplished and its interaction with company business plans. Manufacturing industries were selected and historically reviewed. An industry background was created to list* *major business and strategy trends known to be occurring. Independently, selective industry interviews were performed to collect complementary data on current practices and changes ongoing. A literature survey was performed to summarize major academic theories regarding planning for needed technology development, and its required interaction with firm strategic (business) planning. Results were assessed relative to the adequacy of current practices to the business environment of the mid-1990's, and the changing role of technology in industry strategy.*

Harris, W. (1998). Economic Incentives: C-17 Case Study. Cambridge, MA, MIT.

Henderson, R. a. J. F. (1999). Building Responsive Organizations in Swiftly Changing Environments: Product Development in Biotechnology and Pharaceuticals. Cambridge, MA, MIT.

Hoult, D., and C. Lawrence Meador (1995). Methods of Integration Design and Cost Information to Achieve Enhanced Manufacturing Cost/Performance Trade-Offs. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/hoult.pdf

*This paper addresses problems which arise when large organizations attempt a tight integration of design and cost while developing complex products. Topics include the sources of cost and design data, the arrangement of the databases, and the interfaces required. It also discusses the management methods required to develop and implement Design/Cost Database Commonality.*

Klein, J. (1994). A Case Study of Self-Directed Work Teams at Boeing Defense and Space Group.

http://lean.mit.edu/private/documents/publications/94_02.pdf

*Boeing Defense & Space Group - Corinth (BD&SG-C) is a self-directed team based, unionized facility in the defense and commercial aircraft industry. The plant was a greenfield start-up in 1987. Due to the nature of the defense business environment, the facility has weathered a changing product mix and surges and plateaus in its employment. The case illustrates the applicability of self-directed work systems in the defense aircraft industry and will identify lessons learned in the start-up and maintenance of such systems, including how experience in developing a labor-management partnership can be carried over to developing a partnership between DoD contractors and their defense contract administrators.*

Lucas, M. (1996). Supplier Management Practices of the Joint Direct Attack Munition Program. Technology and Policy and Aeronautics and Astronautics. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/lucas.pdf

*U.S. defense aerospace contractors have been in the process of reducing the supplier base and delegating greater responsibilities to key suppliers in order to remain competitive in the face of defense cutbacks. The trend towards greater outsourcing has meant that new products and modifications of existing systems are being designed, developed, and produced by first tier and lower tier suppliers. Supplier management becomes increasingly important as suppliers take on a greater role in product development. The Joint Direct Attack Munition (JDAM) program reveals changes in the model for supplier relationships in the defense aerospace industry that have been accompanied by unprecedented results. The joint Air Force and Navy program was designated a Defense Acquisition Pilot Program by the Department of Defense to implement acquisition reform -- particularly the reform measures of the Federal Acquisition Streamlining Act of 1994. Changes in decision-making, program structure, and organizational culture occurred as the result of reform measures and the product development administration of the program. The changes implemented by the Government as well as the innovative supplier management practices of the prime contractor showed progress in the general model for supplier relationships towards a more collaborative, team-oriented partnership. The JDAM program not only reveals the use of a new model for supplier relationships and management but also reveals that the underlying corporate strategies of subcontractor firms influenced the types of information exchanged within the program. Limitations in certain types of information exchanged, however, did not necessarily limit subcontractor contributions to product development and to program affordability goals. It was also revealed that the dynamics behind JDAM team formation influenced the type of innovation in development of the Guidance Control Unit. The linkages of the suppliers and the supplier designs resulted in innovations that changed the system architecture. In future programs, the Government, prime contractors, and suppliers may be able to manage the types of resulting designs and innovations by focusing on team dynamics and inter-relationships.*

McNutt, R. (1998). Reducing DoD Product Development Time: The Role of the Scedule Development Process. Technoogy, Management and Policy. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/TH_McNutt_399.pdf

*According to the Packard Commission, "Unreasonably long acquisition cycles -- ten to fifteen years for major weapon systems is a central problem from which most other acquisition Problems stem." Since the commission issued its report in 1986, the time required to develop new military systems has only grown. This research and its recommendations are intended to identify and eliminate the causes of those long development times for military systems. This report addresses a key factor in determining the development time for military projects: the project's initial schedule.*

Perrons, R. (1997). Make-Buy Decisions in the U.S. Aircraft Industry. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THPerrons.pdf

*This thesis approaches the topic of make-buy decisions in the U.S. aircraft industry in four ways. One, it offers insight into the circumstances and criteria behind make-buy decisions in the industry by examining two case studies involving commercial and*

*defense products, respectively. The case studies focus as well on the vertical relationships among the companies examined, and how these relationships are realigned as a result of the prime's make-buy decisions. Two, this thesis proposes a framework that explains ex post how managers in the industry decide to make or buy a particular component or process, and that provides guidelines for approaching future make-buy decisions. The framework concentrates on two major factors that play key roles in the aircraft sector's make-buy judgments: the degree of technological maturity of the component or process, and the relative competitive market position of a firm with respect to the particular technology underlying the component or process. Three, this thesis recommends a make and buy strategy that large companies in the industry should consider for securing and maintaining a leading role in their respective core competencies. Four, it addresses the principal ways in which the aircraft industry's make-buy decisions may be affected by or may eventually lead to changes in the policies of the U.S. government.*

Rebentisch, E. (1996). Preliminary Observations on Program Instability. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/96_03.pdf

*This white paper reports emerging findings at the end of Phase I of the Lean Aircraft Initiative in the Policy focus group area. Its objective is to discuss high-level findings detailing: 1) the relative contribution of different factors to a program's overall instability; 2) the cost impact of program instability on acquisition programs; and 3) some strategies recommended by program managers for overcoming and/or mitigating the negative effects of program instability on their programs. Because this report comes as this research is underway, this is not meant to be a definitive document on the subject. Rather, it is anticipated that this research may potentially produce a number of reports on program instability-related topics.*

Robbins, J. (1994). Critical Examination of a Complex and Critical Major Acquisition for the Department of Defense: The Advanced Medium Range Air-to-Air Missile (AMRAM). Management. Cambridge, MA, MIT.

*In 1976, a group of United States Air Force and United States Navy fighter aircraft pilots told the acquisition professionals of the Armament Development and Test Center at Eglin Air Force Base in Florida the operational requirements for a new, lightweight air-to-air missile. They dreamed that the engineers and scientists of the US aerospace community could put an entire radar system more powerful than most aircraft radar into a 7-inch diameter and that the resulting missile would let them launch multiple missiles at multiple enemy aircraft from beyond visual range. As of March 1994, the operational forces have received over 3,000 missiles that surpass all expectations in performance and reliability. This thesis is a case study of the acquisition strategy and Government organization that the Department of Defense used to acquire the AMRAAM system. The AMRAAM program is explained and analyzed from a managerial perspective from the genesis of the operational requirements until March of 1994. Positive and negative lessons learned, as well as critical programmatic issues, are described for research and development, introduction of production competition through a leader/follower technique, pre-planned product improvements to sustain system performance well beyond the year 2010, management in the joint-service environment, and multi-national* *participation. The thesis concludes with alternative acquisition strategies that the Air Force has for the AMRAAM program. The road to AMRAAM's success as a program was long and difficult. Current and future Department fo Defense programs will be benchmarked against the AMRAAM accomplishments.*

Sapolsky, H., Ethan McKinney and Eugene Gholz (1994). Acquisition Reform. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/94_03.pdf

*A review of the six most recent major acquisition reform reports, starting in 1949 with the Hoover Commissions and including McNamara's Total package Procurement, Fitzhugh Commission, the Commission on Government Procurement, the Grace Commission, and ending with the Packard Commission report in 1986. They frame the weapons acquisition process as a tradeoff between technical and political uncertainty by the program manager. Political uncertainty can be managed either by multi-year procurement or by reducing technological uncertainty and time-to-market. The reports' recommendations are devided into six areas: centralized procurement, professionalization of the acquisition corps, management improvements, changes in contracting procedures, new development strategies, and legislative/executive relations.*

Simester, D., Dina Mayzlin, and Scott Jeffrey (1999). Coordinating Internal and External Suppliers. Cambridge, MA, MIT.

Simester, D. a. C. C. (1999). Using Non-Monetary Incentives to Encourage Adoption of New Product Development Methods. Cambridge, MA, MIT.

Slaghter, S. a. C. S. (1999). Product Development Across Firm Boundaries: Problems of Cooperation and Coordination in Large Complex Systems. Cambridge, MA, MIT.

Stern, S. a. D. H. (1999). Shaping Technology Strategy: Understanding the Incentives for In-House Development Versus the External Acquisition of New Ideas. Cambridge, MA, MIT.

Stout, T. (1996). The Role of Product Development Metrics for Making Design Decisions in the Defense Aerospace Industry. Technology and Policy and Mechanical Engineering. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/stout.pdf

*In current product development activities, many companies are unable to accurately predict the success of their efforts. This leads companies into dead-end development paths and often results in output that meets the contracted requirements for the program but fails to satisfy either the internal or external customers' needs. These problems arise primarily from one or more of three common problems during the development: failure to focus on the proper metrics and measurements of current activities; failure to maintain a*

*significant historical database to facilitate corporate learning; and the use of a decision-making process that often lacks the information necessary to make good decisions. This thesis identifies these problems through three case studies of product modifications and upgrade development programs in the defense aircraft industry. From these cases and existing literature, examples of both good and poor practices are presented to support the basic conclusions.*

Walton, M. (1999). Identifying the Impact of Modeling and Simulation on the Generation of System Level Requirements. Aeronautics and Astronautics. Cambridge, MA, MIT: 135.

http://lean.mit.edu/private/documents/theses/TH_Walton.pdf

*Requirements generation is an influential time in the evolution of the program. It allocates 70% of the life-cycle cost of a program and is responsible for a large percentage of the system errors and cost overruns. This project lays the framework of the current state of requirements generation and then focuses on the use of modeling and simulation within the process. It is shown that although modeling and simulation tools are being used extensively in requirements generation in many programs throughout the DoD, their effectiveness is largely undocumented and areas of high leverage are unknown. Research results also indicate that the more effective use of M&S within requirements generation could be achieved with increased tool interoperability and easier tool validation and verification. Finally, the ability to perform more iteration early and M&S use as a boundary object for communication are set forth as the two main benefits of M&S.*

# MODULE VI: APPLICABLE TOOLS FOR LEAN PRODUCT DEVELOPMENT

## Table of Contents



## Module VI Introduction

Each module begins with an explanation of how each relates to the overall goal of the project and also how it relates to concepts of Lean. Module VI is the sixth in a series of six self-standing texts aimed at releasing research uncovered through the Lean Aerospace Initiative in the field of lean product development. This module describes some of the tools and applications that have been used evaluated in the research of the Lean Aerospace Initiative. [66]

## The Design Structure Matrix (DSM)

Browning distinguishes four dependency structure matrix (DSM)-based approaches to systems analysis. All of these techniques emphasize a simple, highly visual representation of a complex system, showing system components and their relationships. The discussion draws together four different types of DSMs, highlighting their similarities, differences, and applications. The four types are: (1) component-based or architecture DSM, useful for modeling system component relationships and facilitating appropriate architectural decomposition strategies; (2) team-based or

[66] Note: All of the work included in the references is not described in the text, so be sure to examine references for more information.

organization DSM, beneficial for designing organization structures to account for interteam information flow; (3) activity-based or schedule DSM, advantageous for modeling project schedules based on activity information dependencies; and (4) parameter-based or (low level) schedule DSM, effective for planning design decisions and activities based on physical design parameter relationships. An industrial example and hints accompany a discussion of the use of each type of matrix on application in his dissertation. This review and discussion leads to conclusions regarding the benefits and limitations of DSMs in practice and to suggestions for future research into additional applications.[67]

## System Dynamics

System dynamics modeling is a simulation technique, pioneered at MIT by Jay Forrester, used to evaluate system characteristics, interactions, and sensitivities. The tool has been found to be of great use in analyzing processes whose process components and characteristics are known and understood. Some of the areas where system dynamic modeling has been used include increased understanding of management practices, rework cycles, sustainment and population/inventory assessment, and many others. Some programs have used this technique to model their complete program for use in process decisions.

A few researchers have used system dynamics effectively to describe process interaction, rework and flow. Bakilla used system dynamics to describe interactions between the US government and the Defense Aerospace Industry.[68] Weigel used system dynamics modeling to study the spacecraft testing value stream in order to identify waste.

### *Modeling interactions of the US government and the defense aerospace industry*

This research has been directed at identifying the major interactions between the government and industry during the development phase of a military project. The increasing complexity of the military procurement system has added to the cost of military projects. Deeper levels of management, added oversight, and excessive scrutiny of expenses in a military project have resulted in a burdensome development system. Military aircraft once developed in three to five years can now require ten or more years of development to achieve designs of comparable complexity— even after normalizing to then-year technological capability.

The output of this research is a dynamic model capable of predicting project timeline behaviors based on a variety of inputs. This model will serve as a tool for project managers— both government System Program managers and contractor project managers— to track a project' s progress and evaluate the impact of changing requirements and political actions on project performance. This predictive power will allow the manager to re-baseline schedule progress after funding changes more

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[67] Browning, T. (1998). Modeling and Analyzing Cost, Schedule, and Performance in Complex System Product Development. Technology, Management and Policy. Cambridge, MA, MIT.

[68] Bakkila, M. (1996). A System Dynamics Analysis of the Interaction Between the U.S. Government and the Defense Aerospace Industry. Aeronautics and Astronautics. Cambridge, MA, MIT. Chapter 2 provides a good overview of the system dynamics process and how to create models.

accurately and in a shorter time. This tool will also give the manager a basis for requesting more funding earlier in the project by predicting cost and schedule growth in future years due to funding decreases in the current year.

### *Modeling the Testing Value Stream*

For low volume, low risk tolerant complex systems such as spacecraft, testing is essential to achieve a properly functioning system given current technical and manufacturing capabilities. Today, spacecraft testing identifies significant defects that, if they had gone unnoticed, would have caused catastrophic system failures once on orbit. Testing of spacecraft, as well as testing of other low volume low risk tolerant complex systems, is a significant portion of the total system cost. For communications spacecraft, the recurring testing alone is typically 1/3 of the total recurring system costs. Thus, there is great incentive within the spacecraft industry to reduce testing cycle time, thereby lowering costs. But what is the smart way to go about this? The answer lies in identifying value and waste in testing, and using the systems engineering process to ultimately achieve value-driven testing.

This paper overviews the spacecraft testing value stream and discusses the concepts of value and waste in the spacecraft testing process. It then presents a simplified systems dynamics model of spacecraft production and testing, and demonstrates the effects of system-level test discrepancies on the enterprise as a whole. The model brings to light a *takt time* component to spacecraft testing that has not been identified before. In addition, it also shows that the effects of discrepancies are not easily seen in the short term, but become more visible in the long term.

## Computer Aided Software Engineering (CASE)

The increasing role and complexity of avionics and software in aerospace products has provided an impetus for greater research in the area of effective software development. Menendez researched one approach to more effective software production through the use of CASE tools.

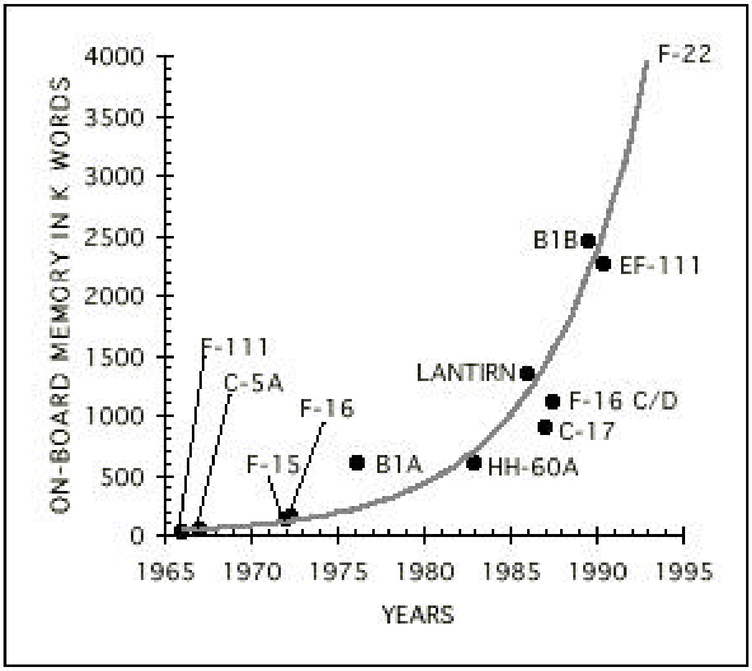


**Figure 16: Growth of Aircraft Software**[69]

Computer-Aided Software Engineering (CASE) uses tools to automate much of the software development process. Software process automation can reduce the labor requirement, significantly reduce errors introduced during implementation, and provide leverage toward the front-end stages of the process. Additionally, incorporation of CASE technologies can de-emphasize the coding and debugging tasks of implementation, and thus shift focus to requirements analysis and design. In addition, providing automated support for analysis and design can eliminate many errors that occur during the requirements stage of development. The goal of implementing CASE technology is to achieve an ideal software development process wherein requirements and design specification are directly translated into error-free software that does not require testing or maintenance.[70] Therefore eliminate all the non-value added process steps that currently exist today. Menendez compiled a list of ongoing CASE efforts at the time of the research, as presented in Table 3.

| **Company** | **Environment/Technology** |
|---|---|
| United Technologies | Pictures-to-Code |
| General Electric | Beacon |
| Integrated Systems, Inc. | MATIXx Product Family |
| McDonnell Douglas | RAPIDS |

[69] Menendez, J. (1996). The Software Factory: Integration CASE Technologies to Improve Productivity. Cambridge, MA, MIT.

[70] Menendez, J. (1996). The Software Factory: Integration CASE Technologies to Improve Productivity. Cambridge, MA, MIT.

| **Company** | **Environment/Technology** |
| --- | --- |
| NASA-JSC | Rapid Development Lab |
| Lockheed | LEAP |
| Honeywell | DSSA Toolset |
| Draper Labs | CSDL CASE System |
| Verilog | SAO + SAGA |

**Table 3: Environments and Case Technology in the Aerospace Industry**[71]

## Modeling and Simulation

Modeling and Simulation has become an essential tool in the product development process. The fidelity and performance achieved by the complex aerospace systems today are due in large part to our enhanced computer capability for design and development, specifically through modeling and simulation. It is very difficult to understand how product development could have been completed before the rise in technology where slide rules and paper and pen have been traded for personal supercomputers and virtual reality.

Within LAI, research into the impact of modeling and simulation on system level requirements generation has been carried out. The research looked at a cross-section sample of current 17 Department of Defense air and space programs. It was shown that although modeling and simulation tools are being used extensively in requirements generation in many programs throughout the DoD, their effectiveness is largely undocumented and areas of high leverage are unknown, as shown in Figure 17. Research results also indicate that the more effective use of M&S within requirements generation could be achieved with increased tool interoperability and easier tool validation and verification, as shown in Figure 18. Finally, the ability to perform more iteration early and M&S use as an information boundary object for communication are set forth as the two main benefits of M&S.[72]

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[71] Menendez, J. (1996). The Software Factory: Integration CASE Technologies to Improve Productivity. Cambridge, MA, MIT., p. 25

[72] Walton, M. (1999). Identifying the Impact of Modeling and Simulation on the Generation of System Level Requirements. Aeronautics and Astronautics. Cambridge, MA, MIT**:** 135.

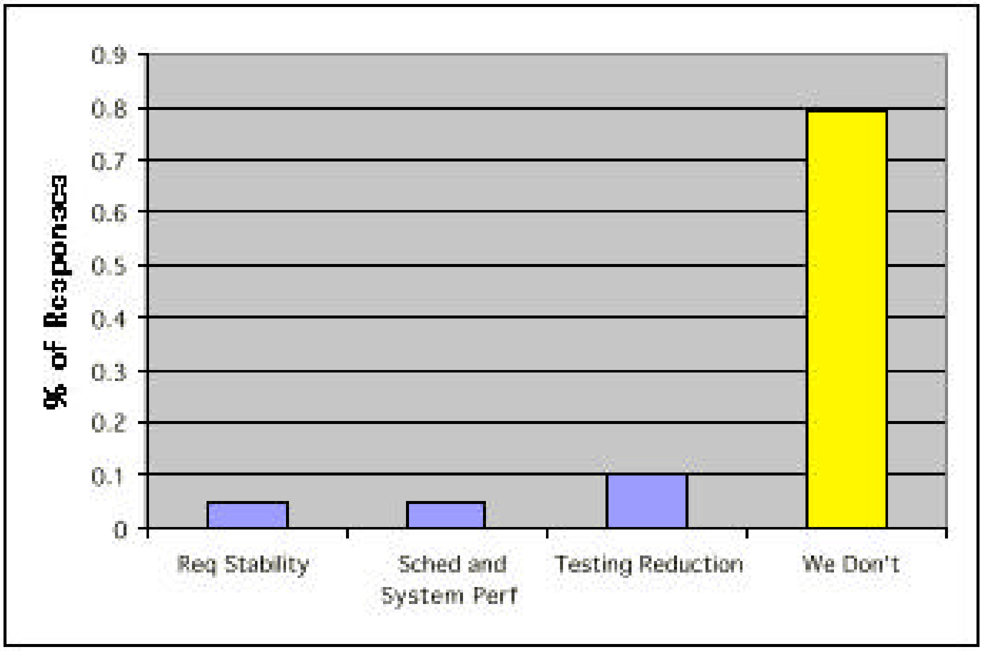


**Figure 17: How do you measure the benefits of M&S?**

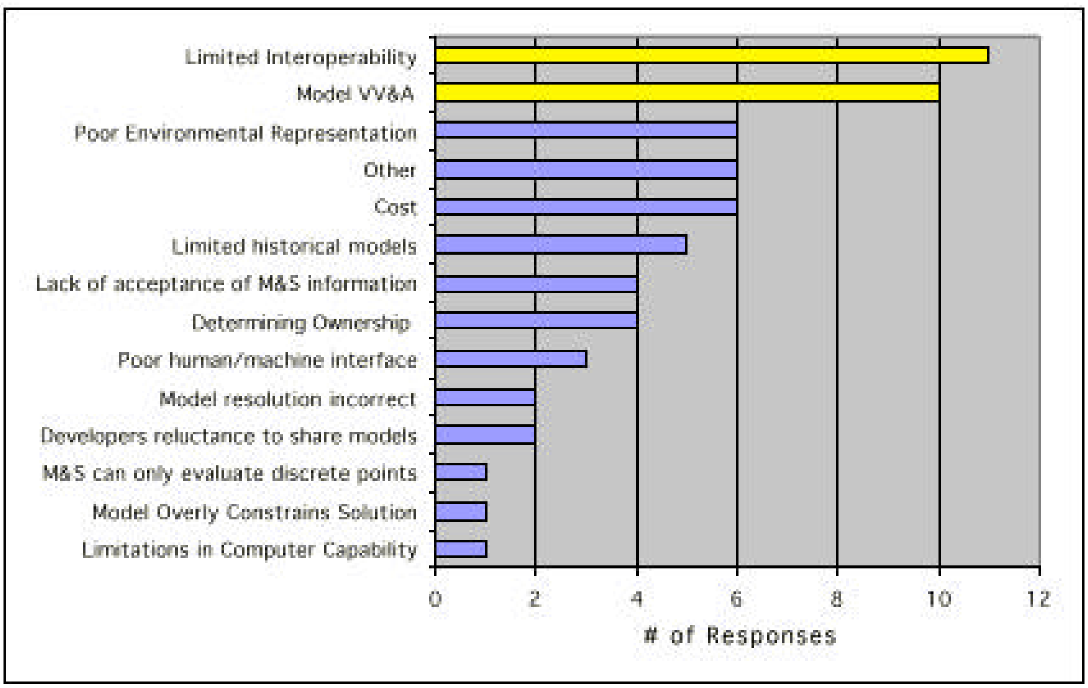


**Figure 18: Perceived barriers to M&S usage in requirements generation**

## Key Characteristic Databases

Many engineering companies use Key Characteristics (KC), including aerospace, to manage the risk of variation in complex products. Effective KC implementation improves the quality of the product, reduces manufacturing variation, and reduces cost of design and manufacturing.

Key Characteristics are product features, manufacturing processes, and assembly characteristics that significantly affect a product's performance, function, fit, and form. KC methods are tools and processes used by design and manufacturing organizations to identify the critical parameters that cannot withstand a significant amount of variation -- particularly if the variation causes a significant loss (scrap, rework, repair, or failure). KCs can be identified at a system level and flowed down to a detailed part level. KCs are also used to identify critical fabrication, sub- assembly, and assembly processes that are used to produce critical parameters. The use of KC methods can help to reduce cost in a production environment. However, if they are not identified correctly, those KCs can cost the corporation in engineering effort and manufacturing control effort.[73]

Ertan's thesis identified enablers for successful Key Characteristic implementation. Best practices in KC implementation were documented through a series of benchmark studies. These trips also helped identify the gap in the KC practices. Other benchmarking were performed during a Key Characteristics Symposium at the Massachusetts Institute of Technology in January 1997. During this symposium, 40 company representatives from 11 companies discussed KC definitions and implementation challenges. The findings from the benchmark studies and symposium were documented in the MIT Key Characteristic Maturity Model.[74]

## Process Capability Databases

Process capability data (PCD) is needed for robust design, optimal tolerance allocation, and variation simulation analysis. Process capability databases (PCDBs) have been developed in many industries and are being used by the manufacturing community to monitor quality; however, they are not being effectively utilized by design. When the PCDBs were developed, the intent was for design to use PCD for optimization and product cost minimization, but this ideal situation has not been realized.

A survey of a variety of design and manufacturing companies was circulated to determine both the state-of-the- art in PCDBs and the barriers preventing design from fully utilizing PCD. Two key barriers were identified for internal PCDBs: lack of a company-wide vision for PCD usage and poor communication between manufacturing and design. Supplier PCDBs have the additional barriers of lack of trust between suppliers and customers and time lag for data entry. Management support, training, database population, and common systems were identified as potential solutions to the identified barriers.[75]

## References for Module VI:

Bakkila, M. (1996). A System Dynamics Analysis of the Interaction Between the U.S. Government and the Defense Aerospace Industry. Aeronautics and Astronautics. Cambridge, MA, MIT.

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[73] Ertan, B. (1998). Analysis of Key Characteristic Methods and Enablers Used in Variation Risk Management. Mechanical Engineering. Cambridge, MA, MIT.

[74] Ertan, B. (1998). Analysis of Key Characteristic Methods and Enablers Used in Variation Risk Management. Mechanical Engineering. Cambridge, MA, MIT.

[75] Tata, M. a. A. T. (1999). Process Capability Database Usage in Industry: Myth vs. Reality. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THBakkila.pdf

*The defense aerospace industry is experiencing a dramatic decrease in product orders due to the downsizing of the U.S. military. Industry leaders have recognized a need to reduce both the cost and cycle time of defense aircraft design, development, and production while maintaining product performance, quality, and corporate profitability. As a result, several aerospace companies, the Department of Defense, and researchers at the Massachusetts Institute of Technology have formed a consortium - the Lean Aircraft Initiative (LAI). The LAI goal is to identify the path for implementation of "best" practices into the aerospace industry and the government departments with which they interact. This thesis investigates the interaction of the government and the defense aerospace industry during the military procurement cycle. This interaction is demonstrated by analyzing the defense procurement system and the industry product development process using system dynamics principles. The resulting System Dynamics model identifies and seeks to quantify the interaction between the two organizations. The model interactions are calibrated against a recent military development project and the effects of variables on project performance and investigated through sensitivity analysis.*

Browning, T. (1997). An Introduction to the Use of Design Structure Matrices for Systems Engineering, Project Management and Organizational Planning. Cambridge, MA, MIT.

Browning, T. (1998). Modeling and Analyzing Cost, Schedule, and Performance in Complex System Product Development. Technology, Management and Policy. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THbrowning.pdf

*In the future, it is unlikely that complex system products will compete solely on the basis of technical performance. What will differentiate such systems and their developers is the ability to balance all the dimensions of product performance, including product pricing and timing (which are functions inclusive of development cost and cycle time). Furthermore, this balance must be congruent with customers' perceptions of value. Once this value is ascertained or approximated, complex system developers will require the capability to adjust the design process to meet these expectations. The required amount and sophistication of project planning, control, information, and flexibility is unprecedented. The primary goal of this work is a method to help managers integrate process and design information in a way that supports making decisions that yield products congruent with customer desires and strategic business goals.*

Browning, T. (1998). UCAV VSS Process Report. Cambridge, MA, MIT.

Cochran, D. a. T.-S. K. (1999). The Integration of the Product Development Process with Production System Design. Cambridge, MA, MIT.

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Eppinger, S. a. J. J. (1999). Product Development Process Decomposition. Cambridge, MA, MIT.

Ertan, B. (1998). Analysis of Key Characteristic Methods and Enablers Used in Variation Risk Management. Mechanical Engineering. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THErtan.pdf

*Many engineering organizations, including aerospace companies, are using Key Characteristics (KCs) to manage the risk of variation in complex products during design through manufacturing. Effective KC implementation improves the quality of the product, reduces manufacturing variation, and reduces cost of design and manufacturing. The KC Maturity Model, which identifies twenty-two supporting practices for achieving optimal KC implementation, can be used by both high and low volume companies as a self-assessment tool. This assessment can identify strengths and weaknesses in KC Practices.*

Ertan, B. (1998). Key Characteristics Maturity Model. Cambridge, MA, MIT.

Flowers, W., Anna Thornton, Julie Yang Palaez, and Shawn Ritchie (1999). Visualizing Relationships in Large Information Databases. Cambridge, MA, MIT.

Flowers, W. a. P. L. (1999). Web-Based and Multimedia Communication Tools in Product Development Groups. Cambridge, MA, MIT.

Frey, D. a. E. J. (1999). Formulating Effective Signal-to-Noise Ratios for Products with Multiple Response Variables. Cambridge, MA, MIT.

Jackson, D. a. E. B. (1999). Evaluation of Revers Engineering Tools Applied to CTAS. Cambridge, MA, MIT.

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Menendez, J. (1996). The Software Factory: Integration CASE Technologies to Improve Productivity. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/96_02.pdf

*This report addresses the use of computer-aided software engineering (CASE) technology for the development of aircraft software. Real-time embedded software is becoming the key to implementing avionic systems functionality in all types of aircraft. Avionic systems in modern defense aircraft are highly complex. They are composed of multiple subsystems (navigation, radar, flight control, engine control, warfare systems, etc.) distributed over multiple processors throughout the aircraft. Embedded software, by implementing functionality within each subsystem and providing for overall integration, is both mission and safety critical.*

Menendez, J. (1997). Building Software Factories in the Aerospace Industry. Aeronautics and Astronautics. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/theses/THMenendez.pdf

*The defense aerospace industry is currently in a phase of shrinking procurement budgets brought on by the end of the Cold War and pressures to reduce the national deficit and balance the Federal budget. Consequently, the Department of Defense has shifted its product development emphasis from system performance to system affordability. Simultaneously, software has become increasingly important for implementing functionality in new systems and sometimes dominates total product development costs. The challenge for industry is to implement new processes and technologies that will allow the reliable, repeatable development of high quality software at reduced cost. One emerging practice capable of meeting this challenge is the software factory.*

Seering, W., William Finch, and Tze Ho Lee (1999). Concurrent Application of Information-based Tools. Cambridge, MA, MIT.

Tata, M. a. A. T. (1999). Process Capability Database Usage in Industry: Myth vs. Reality. Cambridge, MA, MIT.

http://lean.mit.edu/private/documents/publications/99-tata.pdf

*Process capability data (PCD) is needed for robust design, optimal tolerance allocation, and variation simulation analysis. Process capability databases (PCDBs) have been developed in many industries and are being used by the manufacturing community to monitor quality; however, they are not being effectively utilized by design. When the PCDBs 1 were developed, the intent was for design to use PCD for optimization and product cost minimization, but this ideal situation has not been realized.*

*A survey of a variety of design and manufacturing companies was circulated to determine both the state-of-the-art in PCDBs and the barriers preventing design from fully utilizing PCD. Two key barriers were identified for internal PCDBs: lack of a company-wide vision for PCD usage and poor communication between manufacturing and design. Supplier PCDBs have the additional barriers of lack of trust between suppliers and customers and time lag for data entry. Management support, training, database population, and common systems were identified as potential solutions to the identified barriers.*

Thornton, A. a. G. P. (1999). Key Characteristic Management Tool. Cambridge, MA, MIT.

Thornton, A. a. T. C. (1999). Variation Risk Management Practice Database. Cambridge, MA, MIT.

Wallace, D. a. J. C. (1999). Computational Stability of Model Networks. Cambridge, MA, MIT.

Walton, M. (1999). Identifying the Impact of Modeling and Simulation on the Generation of System Level Requirements. Aeronautics and Astronautics. Cambridge, MA, MIT: 135.

http://lean.mit.edu/private/documents/theses/TH_Walton.pdf

*Requirements generation is an influential time in the evolution of the program. It allocates 70% of the life-cycle cost of a program and is responsible for a large percentage of the system errors and cost overruns. This project lays the framework of the current state of requirements generation and then focuses on the use of modeling and simulation within the process. It is shown that although modeling and simulation tools are being used extensively in requirements generation in many programs throughout the DoD, their effectiveness is largely undocumented and areas of high leverage are unknown. Research results also indicate that the more effective use of M&S within requirements generation could be achieved with increased tool interoperability and easier tool validation and verification. Finally, the ability to perform more iteration early and M&S use as a boundary object for communication are set forth as the two main benefits of M&S.*

Whitney, D. a. Q. D. (1999). Information Flow Mapping to Aid Design of Complex Products. Cambridge, MA, MIT.