Lean Methods Above the Manufacturing Floor in an Aerospace Military Program

By

Jorge F Gonzalez
M.S. Aerospace Engineering
University of Dayton, 1985

and

Thomas J Sarama
B.S. Aerospace Engineering
University of Florida, 1982

SUBMITTED TO THE ALFRED P. SLOAN SCHOOL OF MANAGEMENT
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF BUSINESS ADMINISTRATION
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 1999

Jorge F. Gonzalez & Thomas J. Sarama © 1999. All rights reserved.

The authors hereby grant to MIT permission to reproduce and to distribute publicly paper and electronic copies of this thesis document in whole or in part.

Signature of Author: _____________________________

Alfred P. Sloan School of Management
May 7, 1999

Signature of Author: _____________________________

Alfred P. Sloan School of Management
May 7, 1999

Certified by: _____________________________
Nelson P. Repenning
Assistant Professor of Management
Thesis Supervisor

Accepted by: _____________________________
Toby W. Woll
Director of Sloan Fellows Program
Lean Methods Above the Manufacturing Floor in an Aerospace Military Program

By

Jorge F Gonzalez and Thomas J Sarama
M.S. Aerospace Engineering and B.S. Aerospace Engineering
University of Dayton, 1985 and University of Florida, 1982

SUBMITTED TO THE MANAGEMENT DEPARTMENT ON MAY 7, 1999
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF BUSINESS ADMINISTRATION

ABSTRACT

Investigate the feasibility of implementing productivity improvement processes such as lean methods to the product development phase of major military aircraft programs. The study concentrated on the understanding of the current state of the industry from the point of view of the customer as well as the contractor team. The primary source of information was a number of interviews with executives from the Aerospace Industry. The major obstacles to the implementation of lean methods were discussed and the current industry implementation status was described. Using the acquired knowledge, two system dynamics causal loop models were developed to enhance the understanding of the extremely complex product development process as well as a framework describing the process of incorporation of lean principles to a major program development. The first model described the macro view of a program and identified external forces acting on the product development process. The second model described a micro view of the product development cycle concentrating on activities internal to a program. Utilizing the models and the framework, possible intervention points were identified which could enhance the successful implementation and sustainment of lean methods.

The focus of the thesis was to concentrate on managing the product development cycle time as the key indicator of the overall performance of the program. The current state of the industry appears to experience longer and longer development cycles, which leads to financial and political strain. Results show that application of lean methods to activities off the manufacturing floor is feasible with the premise that understanding of the overall system dynamics is essential to the implementation of successful measures.

Thesis Supervisor: Nelson P. Repenning
Title: Assistant Professor of Management
ACKNOWLEDGEMENTS

First and foremost, I would like to thank my wife and partner Annie, for her love and encouragement throughout my career but more significantly during this past year at MIT. It was a privilege sharing such a wonderful and challenging experience with you. To my son Andy, the center of our lives, I love you very much and thank you for adapting so well to these new surroundings.

I would like to recognize my thesis partner and dear friend Tom, for his incredible support, exceptional drive, and focused vision. Tom, you always motivate me to “push the envelope”.

I would also like to thank the United States Air Force and the Aeronautical Systems Center in Wright Patterson Air Force Base, Ohio for their sponsorship and support. I feel fortunate to have been a part of the MIT Sloan Fellows Class of 1999. We will always cherish and hope to continue the new friendships that have developed during this year.

Finally, I would like to thank my mother for her unconditional love and dedicate this work to my deceased father, Tony Gonzalez. Dad you are my hero, my role model, and the best engineer I’ve ever met. Three sons and three MIT graduates, not bad Dad!

Jorge F. Gonzalez
Massachusetts Institute of Technology
May 7, 1999
ACKNOWLEDGEMENTS

First I would like to thank my wife and partner Maylene, for her love and unyielding support throughout my career which was never more expressed than during this past year at MIT. This year brought many emotional highs and lows that we experienced as a family and as always, Maylene was the anchor of the family to which I say thank you. To my children, Robert and Suzanna, I thank you beyond any expression for your commitment and explorative insight in tackling this year. You are my reason for striving to get up every day and are the main contributor of my being. I thank you beyond any expression and love you very much.

I would like to recognize my thesis partner and dear friend Jorge, whom without I would have had so much less of an experience throughout my year at MIT. We have been together in a professional relationship and a friendship for many years but this year (1999) was made special because of my dear friend. I know this friendship has grown and will continue to grow in our future lives. I thank you and I am excited in looking forward to the coming years.

I would also like to thank Lockheed Martin Corporation for sponsoring me to attend MIT for this year. What an experience this was. I am looking forward to returning and contributing to a great corporation. I will carry away from this year new friends as well as great experiences and hope to continue those relationships in the future.

Sincerely, this year has changed my family and me for the better, I thank the Sloan Fellows class of 1999 for an endearing year, and I hope the future holds great successes for all. Thanks again to Jorge!

Thomas J. Sarama
Massachusetts Institute of Technology
May 7, 1999
TABLE OF CONTENTS

ABSTRACT.................................................................................................................. 2

ACKNOWLEDGEMENTS............................................................................................ 3

ACKNOWLEDGEMENTS............................................................................................ 4

INTRODUCTION........................................................................................................... 9

FIGURE 1 SIMPLE CONCEPTUAL MODEL................................................................. 11

CURRENT STATE – ENVIRONMENT AND INDUSTRY.............................................. 18

ENVIRONMENT.......................................................................................................... 18

FIGURE 2 OPINION ON MILITARY SPENDING LEVELS........................................... 19

FIGURE 3 DOD BUDGET (1992 TO 1999)................................................................. 20

FIGURE 4 DOD BUDGET IN % ................................................................................. 21

FIGURE 5 PRODUCT DEVELOPMENT SCHEDULE PERFORMANCE............... 22

FIGURE 6 PRODUCT DEVELOPMENT COST PERFORMANCE............................. 23

INDUSTRY.................................................................................................................... 23

WHY LEAN?............................................................................................................... 26

DATA FROM INTERVIEWS......................................................................................... 29

1) Vice President of Engineering, Contractor A: ...................................................... 29

2) Vice President of a Program, Contractor A:......................................................... 30

3) Director of Lean (Program), Contractor A.......................................................... 31

4) Lean Executive Director, Company A.................................................................... 32
DISCUSSION OF ISSUES......................................................................................... 41

1) Short vs. Long Term Focus ........................................................................ 42
2) Funding Pressures .................................................................................. 44
3) Culture .................................................................................................. 47
4) Employee Support .................................................................................. 51
5) Trust ...................................................................................................... 54
6) Government Influence .......................................................................... 58
7) Ownership ............................................................................................. 61
8) Compatibility with Business Systems ................................................... 64
9) Implementation ...................................................................................... 66

FRAME WORK.................................................................................................. 69

FIGURE 6 PLAN FOR LEAN IMPLEMENTATION .............................................. 70

DEFINE REQUIREMENT .............................................................................. 70
BENCHMARK OUTSIDE AND INSIDE INDUSTRY ........................................ 71
DEFINE AVAILABLE TOOLS ....................................................................... 72
IDENTIFY RESOURCES OF EXPERTS ....................................................... 72
DEFINE EXPECTATIONS ............................................................................. 73
INTRODUCTION

In this thesis we study the application of “Lean Methods” to a military product development program and focus on the activities that occur “off the manufacturing floor”. The discussion will focus on the elapsed time required for the activities from the inception of the contract award to fabrication of the first article known from here on out as the Program’s “Cycle Time”. The ultimate benefits of a successful application of lean methods (to be defined) will be more product value for the investment and a shorter time span for completion of the product development cycle. The focus of the thesis will be on the forces, internal and external to the program, leading to an extension of the product development cycle time. Before we jump in, we need to provide some background on how the focus was derived and what structure this process of analysis is going to take.

Historically in military aerospace programs the cost to the taxpayer is more than the original contract value. the value of the system is less than expected and the time to delivery is typically longer than expected. When a program does meet a challenging cost, schedule, or value attribute, they are held up as the exception not the norm. Basically, meeting expectations just isn’t common throughout the history of military programs. Why? These programs are not for the weary. Without exception they are developing new advanced technology wrought with technical and financial risk. They all typically receive plenty of scrutiny due to the large sums of money associated with these programs. This scrutiny at times leads to overemphasis on controlling one
of the key performance parameters such as cost, schedule or value leading to further erosion of the other two parameters. The focus of the programs tends to be working toward seeking a cost for a capability instead of achieving a price for a system. This implies that the technical advancement of the system is the key focus and the cost and schedule are the result of such focus. As we worked through this thought process it was very evident that reducing the product development cycle time or identifying the forces that are contributing to the growth of product development cycle time was the path we wanted to pursue. The old saying that "time is money" is vividly illustrated on these programs because of their size. Extending the program schedule for any of these large programs is therefore cost prohibitive. Throughout this paper the focus will be on providing the best value for the investment in an environment of military programs. This should lead to a philosophy of balancing cost, schedule, and value.

To generate more thoughts let's go through a small "systems thinking" exercise that will help illustrate the value in focusing on cycle time (Figure 1). This figure illustrates a very simple model on the interactions of some program variables (this is not intended to encompass the entire system). For reasons of completeness let's work through the definitions as illustrate a better understanding of the model.

(01) **Funding Stability** - This is an exterior force (other examples are political support, or existing platforms life cycle costs) that can influence the program's funding stream
(02) **Program Cycle Time** - Elapsed time required for the activities from the inception of the contract award to fabrication of the first article

(03) **Cost of Program** - Total cost of the product development program

(04) **Design Iterations** - Number of design iterations

(05) **Performance Criteria Gap** - The results of the comparison of the analytical performance of the existing design iteration and the contracted performance criteria (desired performance)

---

**FIGURE 1 SIMPLE CONCEPTUAL MODEL**
Now lets trace some dynamics of the system and the net effects on cycle time and subsequently program costs. Examining loop No. B (following the direction of the arrows) with Design Iterations and the Performance Criteria Gap indicate an interaction of more design iterations (illustrated with the minus sign for Performance Criteria Gap) will reduce the gap between the design's analytical performance and the contracted performance criteria. This is very logical in that, as the design matures (i.e. iterated), the smaller the difference between design performance and the contracted performance (i.e. smaller performance criteria gap). If there is an unacceptable performance criteria gap (negative mismatch), another iteration of the design will be required (illustrated with the plus sign for Design Iterations) which again captures reality. Now if this loop continues in succession the number of design iterations grow, and the analytical performance moves closer to the contracted performance criteria. The system is characterized by a goal-seeking behavior and subsequently the cycle time increases, as described in the next loop labeled No. R.

Next, examining loop No. R (again following the arrows) which contains the variables Design Iterations and Program Cycle Time, it illustrates the dynamic relationship of the two variables indicating that Design Iterations (illustrated with the plus sign on Program Cycle Time) will increase cycle time. This also is what is experienced in reality; iterative design practices will increase cycle time. Sometimes this is difficult to understand at the program level but if one thinks of a design sequence of a basic part, the same phenomenon takes place. Iterations keep the design in an incomplete state thus the design cycle time continues to increase. Any designer will
argue that iterations are necessary for the maturation of the design. A mature design is the most “right” design. The next interaction is an illustration of design team behavior (engineers can always improve the product), that is when the Program Cycle Time is lengthened (illustrated with the positive sign on Design Iterations) more design iterations will occur. This also illustrates reality, indicating the internal behavior of design teams. There is always some feature that can be worked on to increase the local “technical value” to the system if given additional time.

Two more interactions need to be discussed before we can look at the whole system. Exterior forces, such as Funding Stability Risks can negatively impact programs. As an illustration, lets identify an increased funding stability risk where it actually interrupts the flow of funding for a program, negatively impacting Program Cycle Time, meaning increased cycle time (again illustrated with the plus sign). This also illustrates that if funding is reduced due to external forces programs extend schedules. The second interaction to observe is tied to the Cost of Program variable and the interaction with the Program Cycle Time. As the cycle time increases the Cost of the Program increases (again illustrated by the plus sign). This also illustrates reality, where an extension of the program schedule inevitably increases the program cost.

When we look at this very simple model and envision the system in a dynamic state it illustrates that if the program cycle time increases, there will be negative impacts to costs. These pressures increasing program cycle time come from the dynamic interactions of design iterations and contracted performance criteria as well as the dynamic interactions of external forces to the
program such as funding stability. This simple systems model can indicate where to pursue "drilling down" to find the primary pressures to cost and schedule on programs. Understanding a process using system analysis allows a level of understanding that managers are typically incapable of formulating due to the complexity and breadth of the process. Therefore a systems view enables the manager to formulate interventions into the system which could alleviate those pressures by implementing tools such as Lean Methods.

This process is based on "System Thinking for Business Policy Making". System thinking is viewing the total system that must be analyzed to methodically understand the interactions of the components, which make up the system. This view allows the realization that there are feedback responses from actions and behavior of components within the system that must be understood for the system to operate as desired. Our ideas are motivated by the premise that we need to understand the system as a whole as described by John Sterman and Peter Senge in the following quotations.

"System thinking is the ability to see the world as a complex system, in which we understand that you can’t do just one thing, everything is connected to everything else".

John Sterman, "Introduction to System Dynamics for Business Policy"
“System thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static snapshots.”

Peter Senge, “The Fifth Discipline”

To better understand the current state of the industry, we decided to interview executives of major Aerospace Companies and Government officials and obtain data related to the implementation of lean principles to product development activities off the manufacturing floor. Ultimately combining System Thinking analysis and Lean Methods with the data collected we will try to make some observations on possible ways that the program cycle in a military product development program might be controlled to help execute the program more efficiently.

We have mentioned “Lean Methods” and the applications of those methods but have not discussed in what context lean will be discussed in the analysis. Webster’s Dictionary defines “Lean” as:

“Containing little or no fat; lacking richness, sufficiency, or productiveness....deficient in an essential or important quality or ingredient.”

Renowned authors James P. Womack and Daniel T. Jones in their book “Lean Thinking” said about the same topic:
"Lean thinking provides a way to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively. In short, lean thinking is lean because it provides a way to do more and more with less and less—less human effort, less equipment, less time, and less space—while coming closer and closer to providing customers with exactly what they want."

Lean has been prospering in applications on the manufacturing floor within the aerospace industry since the early 1990s. The Companies have adopted the methodology as a "must have" versus a competitive advantage. The application of work cells, flow, pull, flexibility, product families, value stream, mapping, etc are all being applied to some degree and in some manor in all of the aerospace manufacturing facilities across the U.S. There are many documented successes proudly discussed showing 99% cycle time reductions, high cost savings, and fewer people doing more. There is also enthusiasm because there is so much more that can be accomplished! If you walk into these facilities and mention "lean", the very first place you will be taken is the manufacturing floor. All discussion will be directed to manufacturing metrics, which are beautifully displayed within the working areas. The employees are knowledgeable with the terminology of lean and can dutifully show anyone where and how these techniques are being applied. Interestingly though, when you venture off the manufacturing floor, there is a remarkable difference on views about lean, how to apply it and how far companies have incorporated the concept in the way they do business.
It is interesting to ponder the reasons why lean methods haven’t taken hold within the community that resides off the manufacturing floor in major aerospace firms. Applying lean to processes off the manufacturing floor will require addressing additional challenges from the ones encountered on the manufacturing floor. This paper will pursue the differences as well as the similarities and give some indication how widespread lean methods have been applied to activities off the floor.

The significance of this observation, that lean has yet to transcend in earnest from the manufacturing floor, is that 70% to 80% of the costs associated with large product development programs within the aerospace industry are spent off the manufacturing floor. Based on this distribution, it stands to reason that analysis of the forces working with and against these companies in obtaining the same energy and focus seen on the manufacturing floor in applying lean is essential.
CURRENT STATE – ENVIRONMENT AND INDUSTRY

ENVIRONMENT

The end of the Cold War has resulted in increased social pressure to reduce the Defense Spending Budget. Recent opinion polls indicate that the general public does not support increased military spending. A CNN/USA Today poll showed that 55% of the people were oppose to increased defense spending. Only one third of the people polled said that defense spending is a “high priority” for available funds, compared to 80% supporting deficit reduction and over 60% in favor of tax-cuts. Figure 2 illustrates the change in public opinion towards increased military spending from the high approval rating during the Reagan years (1980’s). Based in great part to decreasing public support, President Clinton’s FY 1999 defense budget and the FY 1999-2003 Future Years Defense Program (FYDP) seek to ensure America’s security and sustain the nation’s vital global leadership role without increasing the fund allocation.

The President’s FY 1999 budget requested $257.3 billion in budget authority and $252.6 billion in outlays for the Department of Defense (DOD). The budget that was requested by the DOD for FY 1999 is, in real terms, about 40 percent below its level in FY 1985, the peak year for inflation-adjusted defense budget authority since the Korean War.
FIGURE 2 OPINION ON MILITARY SPENDING LEVELS

In 1992 the portion of the defense budget, adjusted for inflation, allocated for Research, Development, Test, and Evaluation (RDT&E) which are funds available for product development programs, was $41.7 billion dollars compared to FY99 amount of $36.1 billion dollars. As a share of America’s gross domestic product, DOD outlays are expected to fall to 3.0 percent in FY 1999, well below average levels during the past five decades (see Figure 3). The percent of Federal taxes allocated to the Department of Defense has reduced from a Wartime high of 51.4% in 1955 to a low of 16.2% 1996 (see Figure 4). This is also significantly lower than the 25% averaged during the Reagan defense buildup years. For a long term capital intensive industry, adjusting to this large reduction in cash flow has been difficult to say the least.
FIGURE 3 DOD BUDGET (1992 TO 1999)

When comparing product development program cost from the 1960's to today, it shows an order of magnitude difference in development cost for state of the art military aircraft. This increase in cost coupled with decreasing funds have resulted in higher percent of available funds allocated to an specific program and less program starts per unit of time. As a result, the industry has experienced unprecedented consolidation and the few remaining major contractors have been forced in some cases to "teaming" arrangements with their most feared competitor.
Shrinking spending and reduction in program starts have also affected a key resource, people. The new potential aerospace engineering talent pool is shifting to “other” industries such as automotive and entertainment. The existing talent pool is migrating to other industries with better growth potential. Those who stay, have significant less exposure to different programs in their careers creating a situation were sustainment of broad technical knowledge is a challenge. The realities of shrinking budgets have been a major catalyst for change. Product development cost and schedule performance or lack thereof, is also a common problem experienced by the Defense industry. Many reasons drive this situation. Reviewing the available information shows that of 166 development systems available in the Defense System Database, only 29% met the original schedule estimates and all experienced some level of cost growth. The programs that performed
to schedule showed significant cost performance deterioration. Figure 5 shows the schedule performance of eight recent military programs and in only one occasion was the program completed on time but that particular program experienced a 49% cost growth (see Figure 6).

![Product Development Program Schedule Performance](image)

**FIGURE 5 PRODUCT DEVELOPMENT SCHEDULE PERFORMANCE**

In summary, the current environment in the defense industry can be best described by diminishing resources (fewer dollars and decreasing skilled workforce), poor program performance (cost and schedule), and decreasing public support. All these factors prescribe the need for change.
FIGURE 6 PRODUCT DEVELOPMENT COST PERFORMANCE

INDUSTRY

The Department of Defense and the remaining Defense Contractors are pursuing innovative processes in an attempt to improve efficiencies and product yields. The current industry has five major companies, all profitable, with large backlog for future business. All of them are experiencing shrinking markets, and are pursuing increased diversification into commercial markets. Addressing the need for improving efficiency, all the contractors have recognized the need for incorporation of lean practices on the manufacturing floor. This is not perceived to be a competitive advantage but a reaction to market demands.
A vehicle for improvement, demanded by the environment, is the Lean Aircraft Initiative (LAI). LAI is an effort by the military establishment and the Aerospace Community to improve the communication across industry to increase efficiency in design, development and manufacturing of these complex weapon systems. With the assistance of LAI, all companies have recognized the need to incorporate lean practices into the total enterprise. Implementation of LEAN has started in all the major Aerospace contractors but the available program data has yet to show any measurable operating profit effects. Implementation of lean methods to the design and development effort (i.e. “off the floor”) is perceived to be a significantly more challenging endeavor since it involves complex functional interfaces and requires streamlining of thought processes as oppose to steps in an assembly process.
METHODOLOGY

The methodology that we utilized was fairly straightforward. We decided to interview a total of eleven officials within the aerospace industry including two private contractors and Government officials to obtain their point of view on the state of the industry and the potential for application of lean principles off the manufacturing floor. The interviews surfaced issues that have been in part some of the frustrations the authors have experienced in trying to implement new programs in the productivity improvement game during the last 16 years. Based on the data collected from the interviews and the personal experiences of the authors, the methodology proceeded as follows:

- Develop a set of key factors (or variables) that could drive the product development cycle
- Identify, discuss, and provide an industry status on key issues surfaced
- Develop a generic framework for possible implementation of lean principles
- Develop a systems dynamic model capturing the key relationships between all the “external” variables that could affect the product development cycle
- Develop a systems dynamics model capturing the key relationships between all the “internal” variables that could affect the product development cycle
- Identify potential interventions and opportunities for implementation of lean principles which might counterbalance factors driving the product development cycle
WHY LEAN?

Interestingly, as the interviews went on it was apparent that the same gross problems that triggered the quality programs like TQM in the 1970's and 1980's continue to be an issue in the aerospace industry. The main difference for lean implementation versus the other quality programs is that the local results are very immediate in nature. The changes that occur from applying this methodology are visible at the local process level and are very fundamental to the employees “common sense” thought process in which “my job” is easier from the effort of change. This characteristic may be the sustaining force behind this methodology if the company’s executives allow time for “group learning” that is required for continuous improvement.

Why Lean Thinking and why was the initial application originated on the manufacturing floor? The methodology is appealing to the employees because of the simple nature of the concepts, the methodology attacks waste, its very intuitive and results in making the job functions easier and less frustrating. The visible nature in the results such as fewer stairs to walk up and down all day or eliminating the idle time spent waiting for the right parts and tools to complete a job are very real to the employee. Also, there is a strong focus on processes, which is the fundamental building block in achieving a result. Under the existing product efficiency programs, the processes focus on the “how to” of a transformation from raw material to a final part. This process view was one of the actual physical transformations consisting of all that was happening to the material during the transformation. What this left out was the processes the individual employee had to go through to support these transformations or the movement of personnel and
material through the "system" to gain the final result. Many days one would look out over the manufacturing floor and see the employees working very hard while the program's performance continue to deteriorate in reference to delivery schedules or program costs. The answer to this puzzle is concentrating on the whole process of people, material movement, paper movement etc. including the actual processes of material transformation. Lean provides the ability to look at each incremental step in detail and helps identify the value adding activities within. This is a powerful capability but also provides huge implementation challenges. So, there are two real answers to why lean methodology? The first is that the fundamental concept is intuitive and provides quick visible results, which ultimately provides more value to the enterprise. The second is that the employees experience the changes. Their job activities change in a way that simplifies their everyday burden, which leads to a more favorable working environment.

As the evolution of lean manifested itself and was captured by James P. Womack and Daniel T. Jones in their books "The Machine That Changed the World" and "Lean Thinking" the thrust was applied to physical movement or transformation of "things". This concept was formulated from the approach pioneered by the "Toyota Production" system which was focused on the manufacturing floor. The process analysis, work cells, pull, flow etc was very visible in the manufacturing and operations worlds. "You could see the waste" and apply mapping techniques to identify value streams that mapped tangible items such as parts and paper. This was a natural fit for the methodology within the manufacturing and production world. Also, the experts that became part of the evolving transition into industry were very much focused on the manufacturing
floor. (Issues will be discussed on whether an expert is required but all companies that were interviewed used outside experts to initiate lean methods on the manufacturing floor). In production programs, which are where the genesis of the methodology was created, the majority of the money is spent on the manufacturing floor supporting the original focus. In contrast, product development programs largest expenditures are off the manufacturing floor. With this focus, the companies put a great deal of effort in trying to be successful and did not move in earnest off the manufacturing floor. The total enterprise view, as mentioned in “Lean Thinking”, is just now being addressed with focus for the companies that were interviewed. The broadening of the application brings with it new issues of implementation that will be discussed after we summarize the interviews.
DATA FROM INTERVIEWS

We started our investigation by interviewing senior government and contractor officials to compile qualitative information related to the incorporation of lean methodologies off the floor. The executives interviewed, in general felt optimistic about the application of lean principles off the manufacturing floor. Their primary concerns were sustainability and resource allocation. It is fair to say that the companies interviewed are not in a financial crisis although the external pressures demanding change are significant. In fact, the majority of the executives interviewed expressed a sense of urgency related to the long-term profitability of their company. The three companies interviewed (including the Government) will be identified as Company A, Company B, and Company C. We will provide a summary of the key points of interest discussed by each of the interviewees. The information compiled by the answers was used to help identify the key variables that were considered for inclusion in the system dynamics models and to help define the proposed framework both of which will be discussed latter in this paper.

1) Vice President of Engineering, Contractor A:

The VP of Engineering from Contractor A voiced strong support for the application of lean with a strong connection for efficiency improvements and cost reductions. To that extent he felt the need to focus on value stream mapping to help identify and eliminate waste. As a general rule he saw no strong linkage between organizational structure and successful application of lean principles but felt that Integrated Product Teams could help in the communication and
implementation. Also, he recognized the need to adjust the organizational structure, as required, as the implementation of lean methods evolves. He believes that company/corporate commitment is essential to the overall success of the lean initiative but at this stage, most of the lean initiatives are expected to pay for themselves. As far as implementation, he supports introduction of outside contractor experts to drive the implementation process and the required training in lean methods. He felt pretty strongly that training (up grading skill level) was an essential ingredient to the overall success of productivity improvement across the total enterprise. From the customer interface standpoint, he stated that the customer should review the acquisition policy for monetary compensation associated with improved performance as an incentive for implementation of lean initiatives. Related to the implementation methodology, he stated that each function/program organization should be empowered to tailor the lean implementation plan for engineering with a consistent tool set. The general focus of his perspective on lean is a vehicle for cost reduction, cycle time and quality improvements that should result in more efficient enterprise. He mentioned several factors that could affect the success of lean including long Vs short-term financial goal conflicts (will the cost savings pay for itself), funding for training, functional organizations and legacy cultures, and employee’s trust and cooperation.

2) Vice President of a Program, Contractor A:

The VP of this program strongly supports and stated he considers that his program is a leader in incorporation of lean principles across the enterprise. He felt that a Lean supplier base was essential to efficient value change management since a significant percent of the overall cost of the
program is related to sub contractor costs. He also felt that the customer should provide financial incentives for the application of lean principles by offering increased profit margin and was willing to do the same within the supplier value chain. In his opinion, the customer was providing a strong push and was a catalyst in driving implementation of lean methods, without the financial incentives. He further elaborated incentives that were viewed by the program, as negative did not motivate application of productivity improvement methods. He stated that “negative incentives” typically reinforced the wrong behavior. This behavior typically focused on short term cost reductions such as reduced training and investments. He felt that organizational structure was an important enabler to lean principles and offered that technology such as integrate business systems and information technology could be used as leverage to maximize efficiency of lean principles. He also felt that a strong company/corporate backing was very important. In his opinion, one method to gain company/corporate backing was through the introduction of “Pilot projects” to be used as a vehicle to demonstrate the efficiency of lean tools. He also voiced some concerns, which include goals that conflict (technical vs. cost and schedule performance), political pressures (exterior forces) driving the wrong behaviors and the overall industry culture.

3) Director of Lean (Program), Contractor A

The Director of Lean for a Program, from contractor A, stated that most of the effort associated with lean was focused on the manufacturing floor even though off the floor expenditures were over 60% of the total expenditures for the EMD phase. He also felt that direct funding was not made available to support implementation of lean initiatives even on the production floor. As the
others, he felt strongly that training was an essential piece of the puzzle and supported outside expert’s help. In his current position, he felt that the cost/schedule performance focus that was being applied by the customer was a positive catalyst for change. Although he felt that more could be done on the customers side to help streamline the program management processes, focusing on the interface. Overall his assessment was that the company was committed to change and that a cultural change was required for sustained success. From an organizational point of view he stated that organizational structure did matter and in fact he believes that the current organization has to many levels. On the subject of metrics and incentives, his position is that team performance metrics were required and that customer and internal incentives for improvement should be concentrated around team performance. From a longer-term point of view, he suggested that the companies should leverage their position in order to influence formal academic curriculum change in colleges to include teaching of lean principles. He prescribed patience and felt that a minimum of 2 to 3 years of focused lean applications was required before entering the sustainment mode of lean.

4) **Lean Executive Director, Company A**

The executive director of lean from company A stated that outside experts were essential to validate and support technically the implementation of lean methods. Also, to help prevent internal conflict and provide a source for the allocation of potential fallout. Consultants are less concerned about consequences of their recommendations and changes of this magnitude tend to be better received if initiated from the outside. The consultants have less at stake, compared to an
executive, which could compromise his/her career if the recommendations are perceived to be a failure.

Further, he believes in oversight by an independent lean committee as an enforcing and integration agent during the first few years of implementation. He felt that it was essential to pursue support from top-level management across the enterprise in order to sustain change. He also commented on the importance of investing in education (skills upgrading) and in technical tools such as improved information systems. The organizational structure should be compatible with lean principles such as the use of product teams. Also, the functional organizations should align with the value stream and with the customer interface. Suppliers should be considered an integral part of the value stream. Acquisition reform is breaking down barriers that can assist in the development of lean organizations but it's not providing performance incentives for investment. He believes that sharing of the benefits if lean methods "pay-off" should be a part of the acquisition strategy. The customer has a vested interest in pushing for lean initiatives but the cultural heritage of the relationship might foster some lack of trust. Change is a fragile process and sustainment a challenge, in his opinion it would take between 3 to 5 years to start seeing significant benefits from lean and continued support for sustainment to pursue perfection.

5) Vice President of Lean, Company A

The VP of Lean for Company A identified a few necessary factors that, in his opinion were essential to the success of lean. These factors included commitment from senior management, alignment of the organizational structure with the value stream of the product, and support from
critical interfaces such as the customer as well as suppliers. He felt that a crisis or threat of survival was a powerful motivator but investment in continued improvement was essential to long term survival. He voiced a few concerns including gaining “buy-in” from middle management which in his opinion could easily deter progress if they perceived that the changes affected them directly. He used an interesting term for this behavior, “the frozen middle”. He explained that without commitment from middle management communications and change were not effective since the workers and the top managers were not working to the same implementation plans. In the area of metrics, he felt they were important for continued support and believed the company should focus on cycle time and quality in terms of cost savings as the key discriminator to implement lean activities.

6) Director of Engineering, Company C

The Director of Engineering from Company C felt that it was essential for the customer to concentrate on leaning out their processes. These processes provide guidance to contractors on how to “obtain” certification. Corporate commitment is a must. He feels the customer’s role in product development should focus more on ensuring operational safety. In order to embrace a new paradigm, he believes the company will have to be in a crisis mode (threat to survival). He stressed that organization structure does not matter as much, however, it needs clear ownership and definition. He was also concerned about functional/matrix organizations and product development office interface.
7) **Executive Director, Company C**

The Executive Director for Company C stated that he supports lean principles as one way of coping with restructuring and decreasing employee levels and protecting employee “balance” leading to reducing on the job frustration. He was concerned about many external factors such as: short term profit focus from the contractor’s point of view, training priority, conflicting interests between customer and contractor, the annual budget cycle and threat from ever changing political environment.

He voiced that the customer’s technical involvement in product development was similar to implementing an “insurance” policy and was not certain how lean principles would affect this relationship. He felt strongly that “visible” corporate commitment was essential to the success of lean applications.

8) **Vice President of Engineering, Company B**

The VP of Engineering from Company B voiced strong support of lean “off the floor” measures. He believes in strong customer relations and felt that their success was related to “understanding what the customer wants”. He feels Company B’s current initiatives are driving for constant improvement. Company B is totally committed to paying for training (skills upgrade) for all employees even in different career fields as long as there is some application to the business. He feels a crisis will have to happen in order to have a significant employee reduction since “fear” can be a strong motivator. He felt that improving the customer interface was important to the success of lean application. Their strategy is not to use lean terminology in the organization since he was
concerned with “flavor of the week” syndrome. Currently above the floor implementation is lagging behind the production floor commitment. On the subject of metrics, he felt that they were good tools to set goals, focusing on lean initiatives affecting the product development cycle time and cost containment. He believes in normal flow of lean applications not linked to specific cost savings goals and supports cross-pollination of lean methods within his organization. His company is more focused on traditional cost saving strategies such as value engineering.

9) **Program Manager, Company B**

He is a strong believer in the Integrated Product Development Process and supports providing authority and responsibility to the teams. He also believes that strong customer relations are essential and trusts that the customer will continue to streamline their processes. Key to customer relations is to manage risk and gain customer trust. Organizational restructuring, elimination of work and the resulting improved productivity can lead to reducing staff or more commercial work (value creation). He is a strong believer in technical excellence and “getting the job done” focusing on the fundamentals. He is sensitive to employee’s needs and the required support of the employees for productivity improvement programs to be successful; he feels the company must take care of their people. He thought that acquisition policy should include incentives to motivate productivity improvement programs. Suppliers are key to value chain management which can lead to efficient long-term contracts. To succeed, the company must disconnect lean from specific short-term financial returns and allow necessary time for change to take hold.
10) Vice President, Company B

Strong believer in “People Factor” and managing change by ensuring people buy-in to the change. Company incentives are important and feel that they should be allowed to retain some profits and reinvest the rest (incentive contracts) if productivity improves. Strong customer relations are essential. He also is a strong supporter of employee training. Supports new paradigm in product acquisition based on price in lieu of costs (post product development reform). Believes a mutual trust is essential for customer/private contractor relationships. He is concerned with the differences in cultures off the production floor versus on the production floor and due to these differences, questions if lean methods are transferable to off the production floor. He also believes a financial crisis is required for effective change to occur across the enterprise.

11) Chief Engineer, Major Program, Company C

A financial crisis is a key agent for change since employees have resistance for change due to fear of the unknown and are comfortable “doing what they do”. He feels that the customer plays a role of “honest broker” and part time technical support and can provide a wealth of experience in some specific cases. Acquisition reform is focused on providing good processes as oppose to reviewing contractor work (Oversight vs. Insight). This means more self-governance from the private contractor. The program should push for “End State” contracting and further reduction of detailed performance specifications. “End State” contracting is based on mission description in lieu of performance requirements. He believes in up-front and honest relations with “customer”, and stakeholders. The new paradigm is that affordability is very important and is open to provide
industry incentives to motivate companies to get lean but is not convinced that it would yield a great pay-off.

In his opinion, the Industry suffers the “captive audience syndrome”, which is that cost equals sales. This contractor mental model works against the incorporation of lean principles. Competitive markets could provide further incentives to reduce cost. He believes that controlling cycle time is essential to reducing the development cycle. Engineering manufacturing development (EMD) to production contract transition is not a big motivator since the contractor believes this transition is automatic. That phenomenon might affect motivation and investments during EMD. Programs on edge of cancellation go into survival mode and try to justify existence and abandon long-term strategies. Motivation and training are absolutely critical to get the employees pointing in the same direction. Changes in organizational structure can also provide morale compensation with teaming which could lead to job satisfaction. The industry should focus on the entire element of the team for compensation. He is concerned about time lag between initiatives and the bottom line and believes good metrics are critical. Customer role is to provide some insurance for risk management. Exterior perceived threat is necessary for program support. Corporate commitment is essential since new initiatives typically require a “strong champion” for success. The companies should focus on lean applications in EMD and not only in the production phase.
Based on the results of the interviews we developed a matrix to try to rate essential factors discussed in all the interviews. The factors are related to the successful implementation of lean off the floor concepts. Table 1 shows key variables that will be included in the models with the goal of identifying some potential leverage points for introduction of lean concepts above the floor.

From the interview data and the subjective data in Table 1 we started the process of developing a framework and causal loop models in order to help define feedback loops, which can be used to track and adjust behaviors as necessary. Some of the strong points, which were common in most of the interviews, like training, customer interface, incentives and compensation are extremely complex and vulnerable during hard times. If a program is having financial difficulties, in many instances, training is cut, incentives are eliminated or not viable, financial compensation is frozen and as a result, the interface with the customer becomes strained. This behavior correlates with the complex conflict between short-term goals and long term objectives. The interviews were extremely helpful for us to capture many different points of view about the state of the industry and the benefits and obstacles of incorporation of lean methods off the manufacturing floor.
<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corporate Commitment</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Organizational Structure</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Customer Interface</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Training</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Contract Incentives</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Managing Exterior Forces</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Crisis/Catalyst</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Outside Experts</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>-</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Culture Change</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Long Term View Required</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
DISCUSSION OF ISSUES

The following is a summary of the issues as seen from the executives interviewed in the implementation of lean methods applied off the manufacturing floor.

- Conflict between short term results (financial) and long term investments
- Sufficient funding levels to implement at a pace to provide short-term results while maintaining project commitments
- Changing of a culture
- Lean terminology illustrates the benefit of less doing more and could create employee concern for job security
- Trust of employees toward upper management
- Conflict between Government contracts and continuous productivity improvements
- Is the Government support necessary for the contractor to be successful
- Who owns the responsibility of implementation
- The business systems are not capable of tracking the financial gains that are being made at the detail level
- Pace of implementation for cross functional interfaces
- Implementation policy i.e. what restrictions should be applied to focus teams

The following will have a structure for the review of these issues which will be made up of the statement of the issue, discussion on the characteristics of the issue, actual implementation plans to address the issue, and additional observations if different from the companies implementation plans.
1) SHORT VS. LONG TERM FOCUS

Issue: The challenge of short-term financial results and the effect on long-term investment for lean method application is a question that is at the core of sustainability.

Discussion: This is not a commitment issue from the executives as much as a simple financial statement question. What is the return on investment and in what time frame does that return start to materialize? There are high expectations set by the successes experienced on the manufacturing floor as well as from what has been documented by many reports on the success of lean. The real issue that needs to be addressed is, does the company believe in the methodology enough to agree that this is a necessity to compete and not a competitive advantage? If that realization occurs, the focus needs to transition from how much and how fast, to what is the most efficient way to implement while focusing on learning and the breadth of implementation. The return on investment will follow.

An interesting phenomenon, that will be addressed in more detail when the models are presented, is that if the entire system is not taken into consideration, the process elements that are not “leaned out” may dominate the other processes and the total return will be minimized or not achieved. This can lead to disappointment, less focus (investment) and less enthusiasm, which could put lean in the category of the “fad of the decade”, sending one more mixed message to the employees whom become less and less interested in productivity enhancing programs. The companies need to understand that financial goals of investment and return are necessary but must
be addressed with the knowledge of the enormity of this application which is to process change in operating systems and cultural norms which will take time to become institutionalized.

**Company’s implementation:** The consensus from the interviews was that a five-year plan, populated with successes, was seen to be necessary before consistent bottom line savings would be achieved (recognize that the push for perfection is a primary goal of lean and continuous improvement is the only way to pursue perfection). This is in an environment where the company’s business activities will sustain growth for the immediate future years. The implementation strategy though differs. Company A’s strategy was to monitor the investment by providing financial guidelines for the evaluation of the individual projects focusing on the predicted cost savings and limiting the projects to the ones meeting that criteria. This allowed the return on the investment to be monitored as the projects were completed and to focus limited available manpower on the most valuable projects. Company B’s strategy was to apply general implementation guidelines focused on the “how to” concentrating on the employees learning by doing. The focus was on the spreading of the methodology and encouraging the managers to focus on productivity metrics and less focus on the return of investment. The theory being that the gaining of experience in working all kinds of projects will institutionalize the thought processes faster and hence initiate cultural change.

The estimate of the five years also expresses the unknowns that the companies are being presented with when they start venturing off the manufacturing floor. There is great complexity
in trying to define an overall strategy and coordination scheme that will assure continued successes. Once defined, the strategy must be managed continuously to maintain commitment to lean.

Observations: There is a balance that must be maintained with the funding available to accomplish all the activities each of the companies must deliver to be successful. Each one believes and is committed to the necessity of lean practices applied to the total enterprise to remain competitive. The strategy that must be chosen is the one that disseminates the operating processes of lean to the masses the quickest while balancing the restrictions given by the necessity to continue to meet commitments. Then continue to apply managerial pressures in practicing those processes in the everyday activities of all the employees (focus on the productivity metrics). If the return on the investment becomes more important than the implementation in the early years, there is a real risk of lean quickly following the many productivity programs of the past. The company must determine what is expected and realize “what it will take” in reference to financial investment to accomplish the expectations. There may be alternate strategies required (like a strong growth strategy) that will require emphasis over improving productivity. The key is to recognize what is the strategy!

2) Funding Pressures

Issue: Providing sufficient funding levels to implement lean at a pace to provide short-term results while maintaining commitments for existing projects.
Discussion: One of the strengths of lean is the participation of the employees who are actually involved in the day to day activities of the programs. These employees define the projects that need to be addressed and participate in the practices to define solutions. One of the tools used in lean is an “event” in which participating employees come together and work on a specific process or areas defining waste and providing solutions to eliminate waste. These “events” are allocated no more than five days to accomplish their mission. To have a successful “event”, pre-event preparation is required by all the participants who are committed to existing assignments with near term schedule milestones. The tendency of the manager and the employee is to focus on the existing assignment’s scheduled milestones and let the preparation for the “event” to be neglected. This promotes poor participation and negates employee learning.

The time spent in participating in an “event” and in preparation for the “event” also applies pressure on the funding levels for a specific team or department. This pressure is related back to the short-term view for financial success. The teams or departments are encouraged to participate in lean practices while they are to maintain their existing funding levels, which are allocated for the program work they are assigned. The management rational is if the team is successful, their should be more funding available to fuel more investment into lean practices from the savings achieved by the earlier successes (short term return view). This rational is an attempt to focus the team’s or department’s activities on larger cost saving items and therefore short term returns. Once again this promotes poor participation and negates learning for the employees. The issue
contributes to two limiting issues. Learning that is necessary to change culture and the continued sustainment of the initiative.

**Company’s implementation:** Both companies are implementing lean in parallel with the existing program commitments within the individual programs. Both have created support personnel trained in product improvement tools to support the lean implementation. They are implementing training programs and have identified stretch goals that will require productivity improvements within the product development cycle. Both feel the pressure of trying to maintain existing commitments and deliver in the implementation of lean. For both companies they must have great short-term return to be able to meet the goals that have been set.

**Observations:** The management of the teams or departments must be able to provide planned time in their everyday program scheduling for the participation in lean “events”. They must develop an atmosphere that is supportive and beneficial to participate in the practice of lean implementation. The Focus must be employees learning by participating. They must feel equally that their obligation is to both their existing program commitments as well as the practices of lean. If an environment can be developed to promote participation and learning the change in culture, aggregate savings will out pace expectations. Management does not easily accept this because the short-term performance will not be what is indeed, thought to be required, to maintain control of the lean implementation process.
The management process of funding participation only through existing program funding profiles puts sustainability, the pace of expansion, and ultimately the success of the effort at risks. This practice develops a feeling at the manager level that this is just another assignment that is stacked on the other one hundred tasks that must be accomplished. This obviously does not fuel participation and learning. At the managers’ level, “commitment” means providing the resources to accomplish the tasks. If initial resource allocation is not experienced, the early successes required for successful implementation will not occur. Participation of the employees will never get an opportunity to fuel future investment from the earlier successes. Implementation will be discussed later in the paper but management must recognize the scope of investment needs to grow into the process of actual participation and not just in training and support structure. Learning by participation is a powerful tool that will make the journey successful. Once again this focus is really about the overall strategy and what is the high profile focus. There is little chance that there is available money to spend at a pace that is desired. Therefore, all commitments must be balanced. This balance must be derived from the strategy and thoroughly communicated to the employees so as to remove the “choice” factor on what commitment shall get the attention.

3) CULTURE

Issue: Changing of cultures is one of the larger challenges of the military aerospace industry.

Discussion: In the Webster’s Dictionary, culture is defined as “the integrated pattern of human knowledge, belief, and behavior that depends upon man’s capacity for learning and transmitting
knowledge to succeeding generations”. The Aerospace industry is a highly technical industry that is viewed by the ultimate customers, passengers, pilots, governments and airlines, as an industry that builds extremely complex systems that deliver the mission success that they require. This environment leads to an aura over the industry as being different than any other. Complex, highly technical, expensive, short quantity run production lines, exciting, risky, valuable, needed, unique, costly, inefficient, etc., are common adjectives associated with the industry. The industry’s “special” categorization by the customer is part of the deep-rooted cultural history that has been part of every employee from the executives, managers, and secretaries to the factory personnel. The behavior that results from this culture is to develop the most advanced designs, advanced manufacturing processes, sophisticated point of usage machines, and expensive high performance products which have become a historic measure of the success in the industry. It is both authors’ point of view that the industry had to be “special” to create the unbelievable technically advanced products that the public has become very comfortable with in a very short period of time, though the market environment has now changed. The customers are more familiar with the technology, the airplane is as common as beanie babies (maybe even more than certain ones), competition is in the market place, the cold war is over, and government funding is scarce. Cost reduction and cost control is rapidly becoming the rallying cry of the industry.

To change the culture, the structural environment for the employees must change. The structure, focus, and management philosophy must be redirected to service the customer’s needs. The exterior forces are demanding that change occur. Lean methods are a vehicle for that kind of
change. Lean provides focus to be better, provides more value, and is a practice that disseminates the behavior through participation. This is why there is value in creating an environment where the employees can participate and learn.

The Webster’s definition was chosen because it illustrates the challenges that are faced when attempting to change processes off the manufacturing floor. The passing of how information (notice not parts) flows through a system to obtain a risk adverse result in a highly risky environment creates a rigid structure that has serviced successfully very different market demands over the years. The difficulty of the acceptance of changing the process is that the end result still must obtain the same risk adverse result. The processes that are in motion today have been revised and proven over the years to deliver a proven methodology. The legacy of why things are done the way they are done, in some cases, has been lost. When challenged, the process owners will defend the methodology based on experience gained on other highly technical products that have been proven to be successful. These processes have been honed and revised over the years to assure the failures of the past will not be recreated in the future. How does any methodology trace “thinking” through the creative cycle to get to a final product? Can thought be traced like tangible items as parts are traced through a process? If so, will changing the process give way to less creativity? This illustrates a culture that is going to resist change. The question then arises, can lean methods be transformed from the manufacturing floor to off the manufacturing floor successfully?
Company’s implementation: The companies recognize that this is a cultural change and must implement the change through environmental structural changes. They are committed to the change and are seeing dramatic changes on the manufacturing floor. They believe they can leverage the change on the manufacturing floor experienced to off the manufacturing floor through exposure and illustrations of successes. Training is being given ultimately to all employees off the manufacturing floor in lean methods. Goals and metrics are in the process of being defined in which productivity improvements are the focus. Discussion using the terminology of eliminating waste is starting to become prevalent off the manufacturing floor.

Observation: Cultural changes in large organizations take time to be successful. There is little doubt that this is part of a cultural change throughout the enterprise. Changes will have to be accomplished across the total organization in trust, communication, training, processes, enablers for organizational learning, employee nurturing, organizational structure, dissemination of empowerment, and incorporation of systems thinking. This is not a complete presentation of the attributes and characteristics that are pieces of an organization’s change in culture but it illustrates that there is more than just product improvement training and implementation of a methodology. When viewing the entire enterprise as a system that is a working community the view broadens the focus of the strategy. A Company’s culture is the beliefs as well as the behaviors that have been passed down and reinforced by the environment. For example, if the company’s values are not changed to support the methodology, then the employees could receive a mixed message that could foster confusion and illustrate the detachment of commitment to the initiative. This is
obviously a simple example but is at the heart of the implementation strategy. The whole must support the vision. Companies embarking on this journey are using the methodology as a catalyst for a cultural change. Lean addresses behavior, thinking, environment, and processes and provides tools that will enable changes. But lean is not the total answer for cultural change. The companies need to apply the same levels of energy and focus to the other characteristics that must be addressed in parallel with the lean journey yielding a new, improved state.

When lean implementation was focused on the manufacturing floor there was a view of this methodology as a cultural change but was strictly related to the processing of the tangible products. Even though this was an immense change in the approach to the manufacturing process, it was not a cultural change for the company within itself. This is why the managers must broaden their views of the total system and the interventions that are necessary to develop a change in culture within the total enterprise.

4) EMPLOYEE SUPPORT

Issue: Lean terminology illustrates the benefit of less doing more. Acceptance of the methodology is affected by the terminology due to the association with fewer employees required to accomplish the business activities.

Discussion: The terminology of lean is very focused on elimination of wastes and creating improved efficiency, which can lead to less doing more. This has lead to more questions about the
intentions of the company in moving forward to implement lean. The acceptance of the methodology is slower because of the terminology’s inference to employment downsizing. Employees hear and read terms like eliminating waste and doing more with less, which translates to loss of jobs. The immediate response is not to participate because of this concern. This illustrates a difference in the behavior between employees that work in the manufacturing process and those who are outside the manufacturing process. There is more enthusiasm from the onset for this methodology on the manufacturing floor. There are many reasons for the enthusiasm such as participation and empowerment to change, but there is also a reduction in the physical workload that is visible and immediate after a successful project is completed. Off the manufacturing floor, it is more difficult to receive the immediate feedback because of the nature of the processes for information flow which is mostly transparent to the information user. There is an elimination of frustration and stress to a certain extent but there is little if any physical labor that is involved. Therefore, the immediate feedback for the individual employee off the manufacturing floor does not sense he or she is better off for the change, though possible reduction in employment is a risk.

Interestingly, the same behavior is not experienced in the other productivity improvement programs seen in the past. These programs were specifically focused on quality of the product whether the product was information or tangible. The end result did sometimes lead to less manpower required to accomplish the activities but was focused on a positive outcome that could be grasped and understood. Lean emphasizes the elimination of waste from processes the
employee was trained in by the company to use. The irony is that, in the process of making the company better, the employee may lose his or her job.

**Company’s implementation:** Two different paths were taken for implementation. One was to incorporate the beliefs and methods into many of their existing productivity practices using familiar terminology, which is part of their culture and operational language. The other was to stay with the lean terminology creating new processes, which incorporated the terminology outside the existing productivity language. Both paths have proven to be successful in the early stages. The company that chose to incorporate the terminology into existing programs has also had to adjust the terminology when interfacing with a partner company in joint own program or industry associations. Confusion has occurred from both sides.

**Observation:** There is a risk that incorporating the terminology within the existing productivity terminology will not provide the “this is special” view and focusing may become difficult. Also, when discussing the methodology outside of the company, which is more and more of an occurrence in multi-company programs, communication is difficult. On some programs, existing terminology would have to be translated into the lean terminology to communicate with partners and customers. Efficiency and accuracy are put at risks. Either implementation strategies will work if there is direct and constant communication from management on the goals and reasons for implementing lean. The typical employee will fuel the organizational learning and implementation of projects if information of the strategy and the vision are understood. If there are circumstances
in which employment is threatened, those situations must and should be communicated to the employees. Alternatives need to be addressed in a manner that illustrates the company’s support of the employees allowing options for re-training for entrance into another function or outside employment. Trust will be addressed below but this issue is all about trust and communication. In our opinion, honesty and disclosure is the best path to take for long term sustainment.

5) **TRUST**

**Issue:** Historically there has been an element of employee mistrust of management in aerospace companies fueled by the legacy of cyclic employee layoffs that have been part of the bust-boom economic cycle of the industry.

**Discussion:** Trust between employees and management is companies past successes and will be a large part of successes in the future. Implementing a methodology that concentrates on doing more with less could ultimately strain this management/employee relationship.

There is a belief in the management team of both companies and the executive management of the Air Force that to change a culture or a standard of behavior in a large organization, with a legacy of military business, there must be a “crisis”. Crisis would be defined by declining financial performance (cancellation of programs, loss of program awards etc.) leading to the closing of plants and employee layoffs. This kind of threat has been used many times in the past as a catalyst to implement productivity improvement programs (as well as other management actions).
with anything that occurs with frequency, there is an immunity that is built up to the message and it gets harder to motivate the employees to help create change. Thus the trusting of the management’s leadership becomes strained and the enthusiastic participation in the new direction is minimal, especially if the companies have been performing well. The implementation is no different in that the management team is trying to find what motivates employees to incorporate this methodology. Having personnel scared is one methodology that has been practiced over the years with mixed results. The real issue is that “this doesn’t play in Peoria anymore” or, as they say down in Georgia, “that dog won’t hunt”. Employees have many more options than in the past as well as an indifference to intra city mobility that is common in society today. Trust is essential to change and the lack there-of can very easily be experienced in the application of lean off the manufacturing floor. Employees are very capable of participating in an activity without moving to conclusion and no oversight is continuous enough to assure optimal participation. Common goals with management are essential for employees to trustfully participate in the implementation.

This issue at the root cause is how fast can the return on investment for lean methodologies be realized? If the employees are motivated and focused, the methodology will disseminate faster thus being a catalyst for quicker results.

Company’s implementation: Consensus of the interviews was that, to drive an organization’s focus for a change of this magnitude, a crisis (perceived or otherwise) was essential. This meant that the companies who are not in immediate financial difficulty have had to define a crisis and
communicate it to the employees. The crisis is targeted on future growth, identifying that, if change is not successful, there is failure on the horizon. Ultimately this crisis is very real with the reduction of funding for military programs and the increased length of time for future program awards. The companies have to win the next competition or revenue growth will be stunted and employment will be put into question. The result of the aerospace industry’s consolidation is greater competition in program costs. The companies left have great technical resources to draw from and ultimately the technical challenges can be solved, the competition will focus on program costs. The philosophy of the crisis approach is to create focus and urgency in the implementation to gain the short-term returns necessary in today’s business environment.

Communication methods have been implemented to explain the need for lean, illustrate successful events and define the goals. This is being accomplished through meetings, letters from the president, and articles in company newspapers. They have created web sites for lean providing general information and identifying points of contact for the programs and functions. All communication is focused on the methodology and the implementation thereof.

Also, there is a separate management organization that flows into the other organizations (function or program) focused on communication and support. This organization brings expertise and experience to enhance the employee’s experience in the projects as well as defining how to transition into the daily work experience.
The focus of the communication plans and the Lean Organization is to build a relationship from within trying to work through the negative possibilities that could occur and to demonstrate the new experience realized once a process or family of processes are leaned out. The companies believe that once the employees experience the powerful capabilities of lean they will participate in the implementation, empowered to change their work environment for the better.

**Observation:** Companies hire individuals to be part of their organizations and to contribute to the successes of that organization. Why does their need to be a departure in the employee management relationship? Companies have experienced success in maintaining the direction that the organization is moving by communication to the major contributors of that movement, the employees. If a company is embarking on an ambitious undertaking in change, trust is paramount for success. The communication/employee feedback plan must be part of the implementation plan for lean. The plan must contain elements for communicating the strategy, activities, vision, Business State, employee feedback and schedule. With this kind of focus the company does not have to be in a crisis to create change! The data illustrates that the companies are concentrating on the dissemination of lean and not enhancing the information by defining the business states, the future business goals, and how lean will interact with those visions to contribute to success. Employees can be short sighted, especially if they are comfortable in their jobs, and will not adequately consider the impact of future problems. With the data, at least some will be informed. They still may not agree with the strategy but they will understand why. This interaction will start developing trust between the management and the employees. There is a legacy to this
relationship so it will not change quickly and will require constant nurturing. It is time this nurturing begins and the most efficient way is by constant and consistent communication.

6) **GOVERNMENT INFLUENCE**

**Issue:** Government contracts are not structured to support continuous productivity improvements for private industry. Government support is necessary for the contractor to be successful in implementing lean methodology.

**Discussion:** In general government contracts are structured in a way that companies are not directly compensated for productivity improvements for product development programs. Companies will implement productivity improvements to focus readiness for production but little focus is applied to the product development cycle. Product development programs are inherently risky financially and technically. To maximize the technical value the product development program's contract is structured in a cost plus basis. This format provides reimbursement for expenses of the companies as expended on the development program. The expenses that exceed the negotiated program forecast are to be reimbursed on a non-fee basis thus just covering the expenses of the program. This format is really focused on the technical development for the product allowing the company to take technical risks pushing the "envelope" as required to deliver a mission compliant product. The Government absorbs the financial risk, which can be in the billions. The follow-on production program award is where the productivity improvement focus is applied and thus the historical performance of cost over runs and schedule growth in
product development programs. Obviously there are positive gains by both private company and government agency if a method of contracting can be developed to continually improve product efficiency in the product development cycle while still striving for the technical excellence.

Control of the product development cycle time is the key to this success. What also needs to be addressed in the discussion is the interface of the company and the Systems Program Office (customer) which has influence on the performance of the program. The company can accomplish large gains but could be hindered unless the cooperation and action taken within the System Program Office (SPO) is focused toward the same goals. In a systems view, product cycle time can be effected by the SPO actions, which could override the positive effects taken by the company. The message here is that the employees are not the only contributors for success that must be aligned with the strategy to implement lean but also concurrence and action must also reside with the customer.

Incentives for a company to invest in lean off the floor are shallow at best. Today’s process of program award for the development and production of a product is structured on cost. This limits the ability for the companies to gain financially if they are able to achieve productivity improvement success in the development cycle. The reasons for applying company investment are always in the future contracts whether they are the follow on production contracts or new development contract awards. These incentives are at a time when new contract awards are few and production quantities are getting reduced as the program matures. To achieve improvements,
the product development contractual structure must find ways of defining financial "carrots" for the companies that achieve cost and schedule improvements during product development.

Company's implementation: The companies and the SPO have been working together to try to really change the business structure of the relationship. The SPO, as well as the industry, has a culture that could affect the interface as well as the exterior forces that can create negative results for the program. The SPO has been a catalyst for change within in the companies by applying pressure in many formats to fight cost growth. They also realize they must change in the relationship by applying lean to their internal processes. As we will see in the model section the companies and the program office are tied together in a complicated feedback network that supports the position the companies cannot change this culture within themselves without external change from the customer.

Observations: The companies that choose to apply lean methodology in the product development cycle must expand their strategy for implementation to include the customer. This inclusion will have to infer commitments of participating in applying these methods to the interface as well as support for the implementation within the program structure of the companies. Also they should gain some insight on what actions the customer is taking within its structure to increase productivity. This cross-pollination can lead to new ideas on both sides, which will fuel going further than initially detailed in the strategy. This application of both organizations involved
can lead to a better understanding of external forces and how they affect the ability to continue to improve.

The customer must also pursue initiatives that will promote productivity improvements in the product development cycle. This may take form in contract incentives focused on productivity improvements. The goal is to motivate the companies to start productivity improvements early, well before the awards of production contracts.

The belief that will be pursued in the models section of this paper is that the product cycle time is driven by many internal and external forces that all have to be viewed by both the companies and the customer when defining the lean implementation strategy. Together the team must realize the exterior forces that can negate the productivity improvements and have intervention methodology planned if any of these forces become active.

7) OWNERSHIP

Issue: Who owns the responsibility of lean implementation across the enterprise functions or programs. Pace of implementation for cross-functional interfaces are not coordinated.

Discussion: Both companies as well as the SPO have extensively implemented Integrated Product Teams so they all have functional processes as well as program specific processes that have to be addressed. Moving away from the programs and supporting functions, there are several
functional activities (i.e. finance) for the total enterprise isolated from the daily activities of the programs and supporting functions. Data flow between both organizations is very important. This relationship creates a very complex system of information flow that must be viewed at the system level. If this is not accomplished, the projects that appear to be successful may only be adding waste to another process outside the viewing screen of the project or other processes may overshadow results from a completed project thus negating any gain. Remember, focus on lean off the manufacturing floor resides in the flow of information, quality of that information, and the timing of the information contributing to the overall cycle time of the processing of that same information resulting in cost and schedule performance.

These complex interfaces require the coordination of the lean projects across the total enterprise as well as choreographing resources to support the projects. The success of this coordination will define the speed in which the returns are experienced as well as the pace in which the enterprise is learning. Additionally, the interface with the SPO will also need to be coordinated with the enterprise implementation plans to assure their participation. In the early start-up phases of lean applied off the manufacturing floor there are different levels of participation for various functions and programs being experienced causing frustration and inefficiencies. This is a direct effect of the different organizations having to balance different demands and commitments that is on there near term schedules. This will effect the pace in which the lean methodology is disseminated and results are achieved.
Company's implementation: The companies as well as the SPO have created an organization whose responsibility is coordination, lean expertise, and program or function support. They have given ownership of the responsibility to the process owners. If it is a specific program process, the program manager is responsible for implementation. If it is a functional process, the functional manager is responsible for the implementation. The interface processes are negotiated between the owners and the responsibility role is assigned. The lean organizations also have oversight responsibility to assure activity and tracking results of completed projects.

Observations: The answer commonly provided is that everybody in the organization has responsibility. That answer provides little guidance on how to assure that the implementation pursued is the most optimum. The process owners should have the responsibility of implementing lean. There are many interfaces that also must be owned and a strategy must be developed for those. Reviewing the interfaces will surface the differences in focus from each organization. If the focus is not coordinated, the projects will not be supported, and the employees will get more frustrated with the implementation process, diminishing their efforts. This is were the lean organizations must view the implementation as a system and provide coordination between the programs and functions assuring support for approved projects.

Most of the ongoing implementation applies to specific projects that meet a certain criteria. The alternative would be to take strategic intervention on specific cross-functional processes, which if not reviewed first could override other gains that could be achieved. This elevates the strategy
for implementation to a systems level, which will enhance dissemination of lean. The employees, unless trained in system thinking, will not be able to analytically make these decisions though they will naturally migrate to many of the processes that have previously hindered their progress. The systems view will provide visibility to those processes that could have a negative impact, overriding the gain. This process is to enable the success at the aggregate level when the projects are finished. There is a real possibility that projects can be successfully completed but there is no effect on total cycle time or cost. This phenomenon is experienced regularly because other events have greater influence on cycle time or costs and the underlying processes, even though they are more efficient, they are not on the critical path for success.

Feedback is imperative for a successful implementation. Within the implementation strategy there must be a feedback mechanism that will gather responses from all levels of employees. This feedback needs to be used in the gauging of the success of the implementation strategy as well as providing a tool to identify problems and keep them visible until corrective action has been put in place.

8) **COMPATIBILITY WITH BUSINESS SYSTEMS**

**Issue:** The business systems are not capable of tracking what financial gains are being made at the detail level when applying productivity improvements.
Discussion: The general way of obtaining the reduction of costs are from estimates made by the team of a lean project and then “rolled” up to a total cost savings that is coordinated through the Lean organizations. These estimates are accomplished through the same processes used during any estimating activity. The issue is to be able to trace completion costs. Ultimately, the user of the process can see remarkable differences from the existing operation and realizes savings (evident from tracking metrics) for that application. Why is this saving not visible at the program or functional level? This is back to the discussion on the processes that are overriding the gain accomplished on other projects. There are other processes that are on the “critical path” that have yet to be identified for review and they are the major cost contributor to the total cost.

Collecting the data at a project level is to track success and to maintain visibility for the health of the program. There are questions raised when the financial data for the product development programs or functions are totaled and the magnitude of savings has not been experienced. Thus the focus becomes on the return on investment for the application of the methodology and not on the metrics in which was designed to track the performance of the processes. Sustainability of the commitment can start to waiver if this phenomenon is not understood.

The business systems are not designed, nor should they be, to track costs at a per process level. The method of measure is the metrics that track performance, which will focus the employees on operational attributes that they can effect. If the metrics do not indicate the path to the costs then the measure needs to be questioned.
Company’s implementation: The tracking of metrics and cost savings is being accomplished within the companies. The metrics are focused on quality and cycle time which are directly associated with costs. The tracking of estimate cost savings is to keep a pulse on the health of the program and to give an indication on the return on investment.

Observations: The focus for tracking success needs to remain on the metrics developed during the lean projects. They will indicate the success or failure of the changes within the processes and provide information for changes in direction if necessary. It is not necessary to trace the estimated cost savings in operation if the metric selection is correct and managed. To achieve visible cost savings lean methodology will have to be institutionalized where employee participation will be second nature and the projects are focused on achieving perfection.

9) IMPLEMENTATION

Issue: Implementation policy i.e. what restrictions should be applied to focus teams and is it a different strategy to pursue the quickest implementation.

Discussion: There are different philosophies in implementing the lean methodology, each focusing on how to pursue the company goals with limited resources to achieve success. The quickest way to change the culture is to have the structure of the working environment change favorably toward the direction of the desired cultural change.
One approach is focused on the dissemination of the methodology by applying a philosophy of implementing productivity improvements on any process that is seen to have waste. This process allows participation by the masses and emphasizes learning by doing. The employees are empowered to choose the projects and define the resources required for participation across all functions. Very few restrictions on the project type, emphasis on implementing. The financial results may not be as dramatic as they could be in the early phases of implementation but may generate faster improvement due to the large participation of the employees. This method only is as successful as the training and the support given by the lean organizations with the management team recognizing return on investment may be less than desirable early but should improve as the program matures. The focus is on specific company goals that include quality and cycle time metrics that will guide the employees in the selection of the projects.

An alternative approach is to have the employees generate prospective projects with cost estimates focused on driving toward the company goals that include cycle time and quality. The project is approved for implementation if the predicted cost savings exceeds a target value and the project can be completed within a certain time frame. As in the above approach, employees are empowered to define the resources required for participation across all functions. This approach will generate larger estimated savings earlier but also will discourage some participation by eliminating projects based on cost savings or time of implementation. The focus here is the most efficient usage of limited resources by applying them to the higher payoff projects. This may have a negative effect on the employee’s participation where less of the employees may choose to
participate due to their problems not being addressed. If it does have an impact on participation, the methodology will take longer to become institutionalized thus sustainment of future large savings may be more difficult. Training is less of a burden in this approach due to the limited projects implemented by a core group of employees that are trained in each of the functions. This can be an advantage to help in balancing the other commitments that each of the functions and programs has.

**Company's implementation:** Companies are currently applying both approaches illustrated above. The company goals and project bounds have been defined to try to gain maximum benefit of the limited resources.

**Observation:** There is more implementation planning that will need to take place that will be supported by the experimentation that is being accomplished now. The key issues are how fast can the methodology be disseminated while being balanced with the other commitments and still appease the management team to sustain support. There will not be a general right answer but a tailored answer for each company's aspirations and resources.
FRAME WORK

There will be unique features in the implementation of lean, as with any other program.

Nevertheless, we would like to present a framework that will be general in nature and can be applied, we believe, to any productivity improvement program in any company/corporation. The framework is meant to encompass the issues determined from the interviews as described above, as well as to define a process that will create and use systems modeling. Also featured is a communication plan that is not confined to information only flowing down to the employees but also provides a feedback mechanism that will provide a process for employee feedback to flow up (two-way communication plan) back to the executive management team. Both these features are in the author’s points of view, very critical to the success of the implementation of Lean Methods. The philosophy and methods of lean, as has been discussed, will breed a cultural change within the aerospace industry which means this methodology has the capability to shape thought processes and employee behavior as well as to transform structural work flow processes within an environment. The message here is that there is not a partial answer for the application of this methodology, as the industry is starting to show commitment for change, it must pursue this change throughout the entire enterprise. This is the kind of program that places emphasis on commitment and in which removal of executives that are not committed and do not exercise unbounded support is necessary. Lean has great potential because of its vast reach and great strength to rapidly create environmental changes that are required to compete in the market place.
The following will discuss thoughts on these comments as well as individual characteristics of the framework attempting to provide the reader with a tool that can facilitate a journey of this magnitude. Figure 6 shows our Plan for Implementation of Lean. We will briefly discuss each box in the “Flow to Lean implementation”.

**Plan for Lean Implementation**

- Define Requirement
- Benchmark Outside and Inside Industry
- Define Tools Available That Align With Requirements
- Identify Resources of Experts
- Define Expectations (Investment, Duration, Goals, Timing, Returns)
- Select Tools and Experts That Align With Expectations
- Create Organization for Implementation Reporting to the President

**FIGURE 6 PLAN FOR LEAN IMPLEMENTATION**

**DEFINE REQUIREMENT**

One of the most important of the initial steps, the requirement definition is where the formulation determines whether this is the start of a new paradigm or an upgrade to an existing program.
Whether this is a program for the full enterprise or for focused functions or programs within the enterprise. Whether this is a program that will have the urgency for company survivability or to strategically position the company to sustain future growth. The requirement definition must define the vision and the time frame for implementation. It must define the characteristics that the company/corporation is trying to resolve or create and its relationship to the End State. This vision must be operationally related to productivity improvements (cost reductions, capacity usage, through put increases etc.) versus strategically positioning in the market place or company restructuring. It defines the bounds of commitment and scope of implementation for the enterprise. The management team must revisit these requirements, as more data becomes available. If the vision is not defined and given a priority, the program will not be aggressively pursued and money will be wasted.

**BENCHMARK OUTSIDE AND INSIDE INDUSTRY**

Once the requirement is defined and operationally related to productivity efficiency, the company/corporation needs to benchmark different practices within the same industry, outside the industry, and inside academia. It is important to understand the methodology but also to evaluate the success of each of the companies used as benchmarks. At first it might be enough to see the “marketing story” but, as they say, “the proof is in the pudding”. Before considering implementation, visible results are a must! The trick is to be able to sort through the data and determine what is relevant and what is advertisement. The benchmarking process should help
define and gather as much relevant data as possible with the goal of formulating a menu of methodologies and tools. At the end of this process step, this menu must be complete.

**DEFINE AVAILABLE TOOLS**

Through the benchmarking effort, tools need to be reviewed. These tools must be researched and determined if applicable for the company’s situation. One key attribute in determining the adaptability of the candidate tool sets that are being reviewed is the capital assets and training required for the respective tool usage. For example, if the tools are very complex and highly analytical, the chances of dispersion and common usage across the enterprise gets extremely difficult because the skill level of the user may be unique. The choice of implementation tools must align with the requirements and be considered on their capability but also on their adaptability to the targeted using employee population. Companies have a tendency toward tools of high complexity with many options without realizing the requirements for training and the length of time it takes to be proficient.

**IDENTIFY RESOURCES OF EXPERTS**

The planning for implementation will require outside experts for their experience as well as reinforcement in the implementation when issues arise as the journey is initiated. Experts’ chosen must be compatible with the company and the employees that are participating in the implementation. This is important! Experience has shown failure in a new initiative due to the lack of compatibility of the company’s employees and the experts. Also, clear definition of the
scope of tasks needs to be communicated to the experts to assure common knowledge of the expectations. During implementation, the company/corporation must ensure that the team does not deviate from the intended path. This is a mission to find capability and compatibility. Sources for experts can be found from the usual consulting firms but also focus on academia for other alternatives.

**DEFINE EXPECTATIONS**

The management team is required to define the expectations in investment, duration of implementation, goals, timing, returns etc. Obviously the management team is not going to determine the numbers but they are required to have “total buy-in” at the end of this phase. That means any issues concerning misalignment of requirements and expectations must be resolved. This is where the vision takes shape in forms that management teams understand, budget and human resources. Here is also where it is vital to discuss options for the sources of the investment, whether it is going to be supported by corporate allocation, new business, or reallocations of the existing funding pie. These options need to be pursued and finally agreed to by the management team. Whatever options have been determined as sources they need to be exercised and understood to a level of defining a funding profile that is servicing the projected length of time described in the expectations. The aggregate funding profile is to be managed by the management team.
DOWN SELECTION OF TOOLS AND EXPERTS

Selection of tools and experts must have the management team’s participation and must secure their total commitment to the tool set and the experts selected. The management team will require briefings of the tool sets as well as executive over view training for the tool sets that are strong candidates for selection. This creates an environment of equity in the knowledge of the capability of the tool sets and commitment for their use. Remember that the choice of the implementation tools must be adaptable to the consumer of the tool, the employee population. The criteria of the tool selection should also be based on the training requirements as well as the required time to obtain proficiency.

ORGANIZATION FOR IMPLEMENTATION

The requirements and expectations for the company have been defined, experts and the tools have been selected, and all with the participation of the management team. The next step is to establish an organization outside of the function/program organization designed to integrate the tools and methodology across the enterprise. This is a necessity because the daily business continues to move on and the management focus will be on the business commitments. The new organization’s tasking is to remain focused on the implementation of the productivity improvement program now known from here on as Lean Methods, and report to the executive management team on the status of the program. If the scope of the new program is not the total enterprise then there is less need to create an organization outside the existing structure. This organization should report directly to the president of the company/corporation, while this
provides symbolism for the importance of the program as well as the operational streamlining if decisions or issues need to be discussed. This organization shall:

- Develop centralized processes as agreed to by the management committee and assure those processes are entrenched in each function/program organization
- Develop the implementation plan for the enterprise and gain management team support
- Develop communication plan for the enterprise
- Develop integration plan of their organization into the function/program organizations
- Provide technical support to all function/program organizations for lean training requirements and implementation issues
- Discuss and assure general customer’s commitment to the implementation plans and support function/program organizations with their local customer interfaces
- Provide status to the management team on the overall progress utilizing relevant metrics

INITIATE COMMUNICATION WITH EMPLOYEES

This is an initial communication to the employees, which needs to be accomplished with confidence and strength, indicating a change to the enterprise and the need for all employees to support. Communication with the employees is of utmost importance to the success of the implementation. This is where the requirements and vision are identified and where the methodology and tool sets are introduced. The employees should be made aware of the short-term goals and important milestones. This is the time to “sell” the company on the methodology and vision. Company newspapers and special notes from the president need to be issued with the
program description and vision. The initial contact with the employees needs to be informative on the “why” and where the company is going. This communication should focus on the “real” data whether financial or strategic. The employees should have enough data that describes the company/corporation’s vision and future with the interplay of lean. This is the first step in creating the trust that has to ultimately occur for a successful implementation.

**DEFINE IMPLEMENTATION STRATEGY**

The strategy should address the transition of the vision to operational implementation, defining limits to enable the development of a detail implementation plan. It should cover the breadth of the focus by addressing training, participation, methods of obtaining status, method of dissemination, responsibilities, level of empowerment, level of visibility, breadth of program and interface with the customer. The strategy needs to focus on the most efficient process to empower the employees with a given tool set for quick implementation. Also, it must provide an environment that will nurture successful projects as usage increases. The strategy should also address the company/corporation’s policy on providing alternate choices for those employees that are working themselves out of employment focusing on training for other internal jobs as well as outside employment.
FIGURE 7 IMPLEMENTATION PLAN

DEFINE IMPLEMENTATION PLAN

The implementation plan (Figure 7) is the coordination tool that needs to be agreed to by the management team defined by the employees. It ultimately will effect the total enterprise incorporating training, support, and project selection criteria, accounting structure and
communication plan. Not all of the steps will be described below because some of them are quite
evident by their description in Figure 7.

**OBTAI N  I N T E R N A L  S U P P O R T**

As discussed throughout, the management team must provide unbounded support to be
successful. There must be continuous discussion on the importance of support and how the
company is tracking to the plan. The lean enterprise organization tasks are to maintain focus on
continued support, and to develop methods to keep the program visible at all levels of the
enterprise.

**DEFIN E  S Y S T E MS  V I EW**

To be able to leverage spot applications due to limited resources, a systems view must be taken by
the functions/programs of the processes and how they interact. As will be seen in the model
section of this thesis the development of a causal loop diagram identifying behavior relations and
feedback mechanisms can illustrate local areas of focus that can be the initial areas of
implementation. This process can also determine how policy interventions applied to the system
will affect the system's behavior. These tools provide a systems view of the process. The
implementation focus resides at the process level and the employees accomplish the execution by
developing solutions for removal of waste and improving efficiencies.
DEFINE EXECUTIVE TRAINING PROGRAM

Develop a training program that will allow the executives and managers to acquire a working knowledge of the tools. This will improve communication with the employees in a language consistent with the tool set, enhances their ability to make informed decisions and provides insight into potential problems encountered ensuring the implementation phase. All executives and managers must be trained. Commitment is key!

TIME FRAME

This is the meat and potatoes of the scheduling. The incorporation time frame must be clearly defined. The program should develop a detail schedule for implementation which must include schedules from each one of the function/program organizations addressing training, project definition, project resolution and implementation of the solutions. The lean enterprise organization will be responsible for “roll-up” of the schedules to assure fit with the expectations.

INVESTMENT PROFILE

The function/program organizations will identify the implementation cost aligned with the schedule and identify a spending profile also aligned with the management team’s funding profile. This shall be summed again by the lean enterprise organization. Differences within the spending profile and the funding profile need to be addressed and communicated back to the organizations on the corrective actions. It is important to recognize once this is defined it becomes a vehicle, carrying a message that is sent to the managers by the management team in the form of committed
resources. The impression this message formulates upon receipt can determine the focus and urgency that the managers undertake in pursuing the implementation and ultimately will contribute to the performance in meeting the company's/corporation's expectations.

**Define Metrics**

Metrics must be the function of the teams who are developing the solutions, though there are certain metrics that must be institutionalized which will satisfy the management team's units of measure. Choices for metrics must be compatible with the data available from the information data systems. If the data is not available mechanizing the information systems to acquire the data is necessary. Manual tracking and composing for metrics is inefficient and defeats the purpose of lean.

**Integrate Productivity Improvement Organization**

The lean enterprise organization should be striving to eliminate their jobs! The goal here is to mechanize the implementation so as to be institutionalized in as short a time frame as possible. This philosophy is important because the ownership of any process needs to be applied at the level of the implementation, which is where the knowledge and application resides. The necessary portions of the lean enterprise organization can then be integrated into the existing structure after the initial implementation is complete focusing on growth and sustainment.
Processes for Project Selection

Define the method for projects to be selected. Projects can be selected based on cost savings, system model analysis, random selection, funding profile, immediate problems, etc. Whatever the method for selection, once again, management team agreement and clear and concise communication with the using population is required. Also, develop a policy for capital investment if this is going to be handled differently than existing processes. The recommendation is to keep it within the existing processes.

Coordination Process

Many processes cross through different function/program organizations that need to have a method to manage the interface, to assure the total system is being considered. The process needs to identify a method of declaring ownership and to obtain commitment for support by all of those involved. This process needs to address coordination of the projects so as to allow the managers to manage their commitments and levels of manpower.

Accounting Structure

Simply put, all projects must be evaluated using the same Accounting Methodology. The method, again, needs to be mechanized within the existing information data systems. The employees should be informed and assisted with the incorporation of this structure.
INTEGRATE THROUGH THE VICE PRESIDENTS

Ownership, commitment, and implementation need to flow through the respected Vice Presidents of function/program organizations. The change must start from the top illustrated by the implementation flowing from the top. Any issue can be solved most efficiently through the existing management structure. Commitment is essential for prompt institutionalization of the processes.

COMMUNICATION PLAN

Use all methods of communication within the company/corporation to publicize, report, and discuss the lean program. Focus on positive results and lessons learned (not failures), building enthusiasm and illustrating commitment. Constantly discuss the program using the same terminology, providing a message of goodness and commonality across the enterprise. Develop a feedback mechanism for the voice of the employees to assure that the issues are being heard and that the temperature of the work force is being monitored. The communication plan should be treated as an extension of a marketing plan that illustrates the benefits and successes of the program.

IMPLEMENT TRACK AND ADJUST

Move out and implement. The organizations learn by doing. One strategy is to start in small-localized areas and expand as quickly as possible. The speed of implementation should be closely monitored and adjusted as required. Maintain focus and commitment!
DEVELOP FOLLOW-ON PLAN

Create a vision of what the sustainment program will look like. Understand its features as the program expands and identify what will it take to continue to strive for perfection. The follow on plan should leverage the teams and the employees who have demonstrated proficiency.

FRAMEWORK SUMMARY

The framework focuses on commitment from the senior members of the company/corporation with clear definition of the requirements and expectations. These kinds of changes take immense amounts of energy and require great effort to gain the trust and support of the work force. The plan has focused on the generation of those requirements and the importance of a communication plan directed to the employees. The communication plan provides an avenue for communication (feedback) from the employees to management voicing concerns, enabling the opportunity to build trusts. It also introduces the thought of systems thinking, pursues its value in strategically applying lean methods for the most efficient gains. It also suggests training the empowered employees in systems thinking which will add to his/her tool set at the level of implementation and contribute to the efficiency of the plan. This is a powerful tool in understanding the environment in which we work and the forces that are interacting with lean implementation, painting a portrait of these dynamics and allowing detailed planning in lieu of trial and error behavior. The framework also indicates that the definition of the requirements, expectations, definition of tools and experts are key for successful implementation. The importance of compatibility of experts and tool sets can not be understated as a large sum of money will be invested by the
company/corporation which can be inefficiently spent due to a lack of attention to these selections.

The interviews suggest investment is not sufficient and short-term financial view can override the importance of the institutionalizing the behavior for future growth. Institutionalizing the behavior is the ultimate goal that must be achieved to compete in the future. Focusing on short-term results and not long-term integration illustrates a management team that lacked, in the early stages of planning, the definition of the scope and commitment. These characteristics result in starts and stops discouraging employees and causing program difficulties in moving forward.

The framework also suggest creating an organization outside the existing functional/program organizations to focus on lean implementation with a view of incorporating the processes and organization into the existing structure as fast as possible. Through the interviews it is suggested that this timeframe can be as long as five years. The organization has proven to be necessary to provide daily visibility on the progress of the implementation plan because of the natural business focus that will dominate the functional/program management initially. At the end of the initial phase, measured by the institutionalizing of the behavior, the responsibility must be accepted by the Vice Presidents of the functions/programs to maintain focus and nurture the sustainment of the methodology. This is important in that the company's/corporation's goal is to bring the methodology into the existing organizational structure creating an environment that enables the employee to naturally incorporate these methodologies into their every day working lives.
The framework also focuses on the method of measure for the executive team. This is a direct fallout of the requirements and should be compatible with the company's data systems. It is important to recognize that each project will identify a meaningful measure to assure the implementation of the solutions is performing correctly. The management team must resist creating more and more metrics and should focus on those that satisfy the requirements. The employees are empowered to manage the process and the implementation of the solutions. Trust must be nurtured constantly.

The framework does not singularly focus on the implementation of lean methods but is meant to be a little more general in an effort to illustrate that any productivity program in the future can be applied with these simple steps. The ingredients are requirements generation, systems thinking, commitment, communication and implementation. The results will be a trusting employee population and a successful program.
MACRO MODEL

Our macro product development model attempts to identify the key external forces affecting a major military program during the engineering and manufacturing development (EMD) phase. Many managers' mental models of a program's operational environment lack the understanding of the influences of many external forces that can lead to poor management decisions. When this situation occurs the program will eventually be labeled as having poor program management and unsatisfactory performance. Many of these forces can dynamically interact with the internal program causing abrupt changes in direction (program efficiency loss) due to the lack of understanding of their influence. This situation, predicated on a lack of understanding of the system's dynamic complexity for a product development program, can also negate the implementation of productivity improvement programs. Without understanding of the external influences (that we hope is illustrated in the Macro Model), productivity programs can be labeled as failures even though they are quite successful. With this model we would like to pursue the effects of these external forces on the program, concentrating on the interventions that can be derived to soften the effects of the dynamic influences, depending on different interactions that could take place in affecting the product development cycle time.

Why product development cycle time? We touch on this earlier but would like to expand. After discussing the contributions of the common program development attributes (quality, technical risks, design iterations etc.), that are thought to be the fundamental key measures of performance
in a program setting, we determined that all these internal measures contribute to the behavior of the product development cycle time. As well, the external forces to the program (Political Support, Air Force Support, and Company Investment) also contributed directly to the behavior of product development cycle time. This determined that product development cycle time was the program attribute that linked the exterior environment and the interior environment within a development system. After that observation, the next question was are the historical productivity improvement programs ultimately focused on the behavior of cycle time. Productivity improvement programs focus on quality, cost and schedule which all are major contributors to the behavior of cycle time. As well, reviewing lean thinking, the focus is on these same attributes but more fundamentally on enhancing flow. The flow and timing of information (schedule), completeness of the information (quality), and the quantity of effort to accomplish a task (cost), are all building measures for the length of time that passes to complete a task (cycle time). Thus lean can be used to ultimately effect the behavior of cycle time. There are many positive benefits to managing cycle time that programs can take advantage of in the product development environment. It provides the program manager the ability to manage cost, provides flexibility for design maturation and enhances customer support. Thus, product development cycle time is the centerpiece in this discussion, the key attribute in a product development program as the measure of whether a program can achieve success in cost and schedule performance. On with the model!
The model can be best described in four sub-phases that affect the development cycle time. We describe these four sub-phases as Government Support and Incentives, Program Technical Performance, Company Investment, and Program Cost/Schedule Performance.

![Diagram](image)

**FIGURE 8 MACRO MODEL SUB-PHASES**

All these sub-phases (Figure 8) create forces that dynamically interface with the program's environment that could have a significant effect (positive or negative) on the program's development cycle time. For example, the program development cycle time can be affected by a change in government support as related to changes in program funding, technical support and political support. If the government negatively adjusts the funding stream, changes the design requirements, or modifies the program schedules by enforcing a program delay, the program cycle time will unavoidably be affected. This will inherently lead to cost and schedule performance
deterioration independent of the internal effort from the program, which could include productivity improvements associated with the reduction of cycle time. Depending on the magnitude of the change, the program's internal adjustments can in itself lead to further change in government support creating a potential reinforcing behavior, which will continue to extend the cycle time of the program. The increased cycle time will lead to deteriorating program cost and schedule performance and creating an environment that can lead to program cancellation or program reduction. Obviously both cases are viewed as failures.

Another characteristic of the system is the importance of the quantity and timing of the company's/corporate investment in areas such as training (skills up grading), technology (hardware and software), personnel and productivity improvement programs which can all positively affect program cycle time. In the technical performance sub-phase, dynamics such as design iterations required in attempting to achieve the desired technical performance can also negatively affect program cycle time. In military aircraft programs, this continued pursuit of achieving design requirements is expected and can completely drain the program of critical resources and dry-out any financial contingency reserves causing a deterioration of cost and schedule performance. Finally, in the cost and schedule performance sub-phase, cost and schedule performance also dynamically affect the behavior of program cycle time by contributing to the attributes such as Air Force Support or Political Support. If either of these external forces negatively imposes change to the system, possible program extension or interruption of funding flows could result, extending development cycle time. If this dynamic continues, a reinforcing
behavior could result, thus causing further deterioration of program cycle time and possible program cancellation.

What sub-phase provides the greater leverage and therefore should be carefully understood is difficult to identify though in this paper we will explore interventions that will relate to dominant system behavior. What’s extremely important is to realize that they are all, in fact interrelated and focusing on only one of the sub-phases is absolutely, positively the wrong strategy to pursue.

The overall Macro Model is shown in Figure 9. The Macro Model has five reinforcing or positive feedback loops and four balancing or negative feedback loops. The casual loop diagram illustrating the complex dynamics of a product development program is comprised of 24 discrete variables which will be describe in detail. Please do not dedicate to much time reviewing the overall model at this juncture. We will describe the model incrementally to assist in the understanding of how the model was developed and how each loop affects the dynamics of the system.
DEFINITIONS OF MACRO MODEL VARIABLES

(01) Development Cycle Time – length of time, measured in months, from the contract-go-ahead to a major completion milestone (i.e. first flight, completion of flight test, etc) in a military aircraft EMD program preparing for succession into a production contract
(02) Design Iterations - Number of iterations applied to the product in pursuit of achieving a set of desired program requirements (i.e. funding profile, technical performance, etc)

(03) Company Improvement Programs – Initiatives under implementation by the contractor team to improve productivity efficiency (i.e. Lean Methods, Quality Program, etc)

(04) Desired Cost/Schedule – Baseline program cost and schedule agreed upon contract award

(05) Program Cost/Schedule – Actual program cost and schedule performance

(06) Cost/Schedule Gap – The difference between the desired cost and schedule and the actual cost and schedule

(07) Capability of Tool Set – Capability of the tools utilized to create and analyze the design

(08) Acceptable Technical Risk – Amount of risk deemed acceptable by the customer and company to proceed with the EMD program

(09) Actual Technical Performance – Measure of technical performance, by analytical tools, of the program at a given time with a associated technical risk of achieving the analytical performance

(10) Technical Risk Gap – The difference between the risk of achieving the actual technical performance and the acceptable technical risk level

(11) Desired Technical Performance – Technical requirements estimated by the customer as necessary to the success of the program which are acknowledged contractually by the company

(12) Technical Performance Gap – The difference between the Actual Technical Performance and the Desired Technical Performance
(13) Training – Amount of training facilitated by company investment, formal and on the job acquisition of job skills

(14) Funding Stability – The consistency of the funding stream as was profiled in the original program expectations

(15) Political Support – Continued budgetary support from Congress/Senate

(16) Threat to National Defense – Change in the World Balance which might be perceived as a threat to the United States or requiring support from the US military

(17) Public Opinion – General public sentiment toward Defense investments

(18) Air Force Support – Support by the United States Air Force for continued investment and technical support in a specific development program

(19) Life Cycle Performance of Current System – Cost of keeping the existing military platform in operation

(20) Life Cycle Performance Gap – Difference between the actual analytical performance of the new platform under development and the life cycle performance of the existing system

(21) Distribution of Program Across the US – Integration of the amount of local “benefit” in terms of political support provided by the execution of the development program gained by infusing work across the United States

(22) Company Investment – Amount of Corporate/Company investment in resources (employees, analytical tools, information systems, floor space etc.) for the direct benefit of an specific program
Life Cycle Performance of New System – Analytical estimate of life cycle cost of the new program under development including cost and reliability numbers for comparison with the existing baseline system.

Air Force Productivity Improvements - Initiatives under implementation by the Air Force Team to improve efficiency internally and with the contractor interface (i.e. Lean Methods, Process Streamlining, Acquisition Reform, etc)

DISCUSSION OF MACRO MODEL

The overall Macro Model is very complex and difficult to visualize without having a good understanding of systems dynamics. To better illustrate how the model was developed, we will break down the model into simpler balancing and reinforcing loops and we will add additional loops incrementally until the complete model has been explained. We will describe each loop as it relates to the four sub-phases and will attempt to explain the rationale behind each of the variables as they are related in the casual loops. The objective is to describe possible behaviors of the system, ultimately illustrating the necessity to view the environment in total when implementing a change as dramatic as lean. Let's start with the critical sub-phase labeled program cycle time and expand from the central reinforcing loop (R1 Cycle Time Loop) by adding one reinforcing (R2 Cost/Schedule Performance Loop) and one balancing loop (B1 Technical Risk Loop) respectively, shown in Figure 10.
The center of the four sub-phases is defined as Development Cycle Time which again is the key metric which can be related to program overall performance. This loop is a very simple reinforcing loop that identifies the strong relationship between Design Iterations and Development Cycle Time. This relationship is shown in the model as the Cycle Time Loop (R1) and it’s
described as a reinforcing or positive loop. By examination of the Macro Model (Figure 9) and the simple relational model shown in Figure 1 one can start to visualize the key role that this loop plays in the overall behavior of the model.

There may be some question at this juncture in the relationship of Development Cycle Time and Design Iterations whose behavior is illustrated with a plus sign next to the arrow pointing at Design Iterations. This indicates a cause and effect relationship, such as, if development cycle time is increased due to external forces the effect is an increase in the number of iterations accomplished within the program. First let's give an example to illustrate the concept of cycle time in the context of design iterations in a development environment which can be shown by the relationship of a structural designer and a support function such as a structural analyst. The analyst's responsibility is to provide information to the designer to develop a design that can be of sufficient strength for the specific application. The designer is responsible to provide information to the structure analyst to enable the analysis of the design. In practice, this process is very intimate and cyclic as the design matures. Incomplete data or insufficient quality of information passed at the interface is cause of many of those cycles. Each one of these cycles is defined as an iteration. As these thousands and thousands of iterations are accumulated the program development cycle time is constantly redefined. This iterative process is known as maturing of a design.
Now back to the positive relationship of Development Cycle Time and Design Iteration, which indicates, if Development Cycle Time were to increase due to an exterior influence (i.e. funding stability) then there would be a subsequent increase in design iterations. This interrelationship was touched on earlier but it is important to review. When there is a growth in cycle time due to an interruption in the funding flow for example, programs try to react by reducing manpower in an attempt to reduce cost. This attempt brings to the surface problems in the time it takes to remove personnel on large programs as well as the need to maintain critical expertise. The result is that the program fails to reduce manpower enough to meet the funding reduction. As this turmoil is going on personnel are still available and the design is still being iterated, striving for a better product. This is not a behavior due to a change in the Derived Technical Performance of the customer but a local behavior that is in large part historically accepted, striving for technical excellence. As this continues the number of design iterations increase and fill the additional time made available by cycle time growth that was initiated by the exterior forces.

A side note, this iterative process can be managed better by eliminating the wasted design iterations caused by incomplete or insufficient quality of information that is passed across an interface (discussed in micro model) to a downstream user within the program. This is where lean can be of great use and would leverage positive result in reducing development cycle time. The development cycle time iterations are also affected by the quality and level of analytical performance, capability of the tool sets used for analysis, and data flow as well as the skill level of
the employees. We look at cycle time as a critical path function but in reality it is an aggregate of the iterative methods used in the design development process.

The loop R2 is identified as the Cost/Schedule Performance Loop and is the loop in which the outside world uses to evaluate the program’s health. As shown in the model Development Cycle Time is positively correlated to the cost and schedule performance of a program. Remember that this relationship is easy to visualize with the concept that “time is money”. As the program continues to extend schedule, cost continue to rise thus negative performance results and is measured in the Cost/Schedule Gap measure, which is a comparison with the desired performance. Working around the loop if the Cost/Schedule gap indicates negative performance the Air Force Support will diminish and Funding Stability may be impacted. If Funding Stability is impacted and results in an interim break in the funding flow the development cycle time would once again grow illustrating the reinforcing behavior of this loop.

Moving to B1 loop, Technical Risk Loop, the key measure is the number of design iterations that as discussed, effect development cycle time. This loop defines the reality of maturation in a design development process. The more iterations that are accomplished the better capability the tool sets will have and thus the higher the Analytical Technical Performance will be achieved, which provides a result of less technical risks. As this performance is measured in the Technical Risk Gap there is an attempt to achieve a balance with the acceptable technical risk level the
company/corporation and customer will accept. If the risks are still too high more design
iterations will be required.

One key contributor to cycle time in a development environment is the effort that is required to
obtain an out lying technical performance requirement. This dynamic is illustrated in the balancing
loop B1, Technical Risk Loop, in which continued design iterations are required in order to
reduce risk of achieving the technical requirements to an acceptable level. Development programs
frequently are faced with having to put forth-great effort to achieve very challenging
requirements. A contributor for additional iterations is the pursuit of requirements to a point of
diminishing returns (technical excellence versus balance of performance measures). A balance is
difficult to achieve because there is “pain” if these requirements (usually critical to mission
criteria) are not achieved. This loop illustrates the possible negative impact of a program striving
to achieve a technical excellence in lieu of all else. Internal or external forces can cause this
behavior.

Let’s add one additional loop to illustrate more dynamics. In Figure 11 we now have added an
additional reinforcing loop R3, Government Support Loop, and the three external variables that
can directly affect Air Force and Political Support. These three variables are Threat to National
Defense, Distribution of Program Across the United States, and Public Opinion all of which will
influence funding stability through their relationship with political support or Air Force support.
This loop explains the importance of analytical performance to maintain Air Force support and also illustrates an uncontrollable feature within the system, political support influence. Analytical performance is a manageable attribute for the program if, as discussed above, the Air Force and program managers' work closely together in creating an environment in which the technical performance can be achieved. This loop defines the importance of this because programs are not only evaluated by their cost and schedule performance but also technical performance which effects directly Air Force support. As illustrated, external forces can extend the Development Cycle Time even though program performance may be acceptable. As a side note, lean implementation applied within a program may be successfully accomplishing productivity improvements with progress documented by the applicable metrics and still be reporting negative performance. This behavior illustrated effects on Funding Stability, which then directly is related to R2 loop dynamics that extend development cycle time, which degrades Cost and Schedule Performance in a reinforcing behavior. As will be illustrated later this reinforcing demise of performance will effect company/corporate investment that will also effect Development Cycle Time, Analytical Technical Performance and Cost and Schedule performance. The key point here is to realize this could all be initiated from outside the program bounds of influence and could ultimately cause great pain for the program. Without a system view a program manager may not realize the effects of this systems behavior and react to the situation incorrectly, which ultimately can be avoided.
Further discussion on the interfaces of the R3 loop addresses Public Opinion and Threat to National Defense which are related but in many cases, public opinion can change dramatically.
when negative publications reach the public disclosing deteriorating program cost and schedule performance. Obviously it also can change dramatically supportive if there is a new real threat to nation defense! Distribution of Program Across the USA, which is controllable by the program, is a variable which could influence political support, though less impressionable on political support in general, since Representatives and Senators from a State that has significant local interest in the program may provide strong program support. All three of these variables externally contribute to the influence of the Political Support variable, which can directly effect the funding stream for a program. This particular behavior (or dynamic) is becoming more prevalent in the on-going programs because of the falling defense budgets (tight money) and the lack of a strong visible national threat. The results can be misleading in that reduction of support can overshadow a very productive lean implementation program.

The basis of this discussion, as illustrated, is that the Development Cycle Time can be extended by exterior forces creating a situation on the program in which the immediate action is to reduce manpower to meet the new funding profile. As seen before, this is an action that is taken with the urgency to minimize the schedule expansion so as not to extend beyond a critical length of time. The difficulty is that downsizing is interrupted by “critical mass”, people who have critical capabilities, whom if removed, will be very difficult to get back if ever. Also, there is “the marching army” which are those employees that are supporting many activities within large programs. Once dismissed, effectively replacing them at a latter time might be close to impossible. As the down sizing scenario plays out, there is a loss of efficiency while reducing and
then a loss in efficiency when bringing personnel back on the program. New employees will have to move up on the learning curve to achieve the same efficiency and capability. These inefficiencies will also contribute to growth in the number of design iteration (more quality and technical problems) which will be discussed as having a direct relationship with Development Cycle Time.

The Threat to National Defense also influences the Air Force Support since it can directly drive the need for specific military capabilities and as described earlier in the thesis, defense funds typically increase with an increase in the threat to national defense. Describing further the Dynamics of the R2 Loop, if Air Force and Political Support increases, they tend to provide increased funding stability which as expected, can directly affect the Development Cycle Time, “all else being equal”. This terminology is critical to the understanding of System Dynamics. It allows us to connect two variables and describe their relationship without having to consider other key variables at the same time. It’s obvious that Air Force Support is not the only driver of Funding Stability and the Macro Model clearly shows the complexity of that relationship. But again, all else being equal, it’s logical to assume that as the Financial Stability increases, the program cycle time should decrease (hence the negative sign). Returning to the R3 loop, as the Development Cycle Time increases, the Design Iterations increase which drives the Capability of the Tool Set. All else equal again, as the ability to analyze or evaluate a product’s performance increases (iterations), the Analytical Technical Performance of the Product Increases. The Life Cycle Cost of the New Product is estimated based on the analytical assessment including
reliability and maintainability performance and is benchmarked against the current product in
service as well as the product requirements.

The Life Cycle Performance Gap variable basically compares the life cycle cost of both products.
As the life cycle cost of the new product increases, the gap decreases, which makes the existing
product more attractive, all else equal. To complete the R3 loop, as the Life Cycle Performance
gap decreases, it stands to reason that the Air Force support as well as the political support will
decrease since the attractiveness of the new product as compared to the existing platform is
decreasing.

The behavior described in this loop's relates technical performance, Air Force Support and
Political Support (with external forces) with the potential of a stable funding flow. As discussed
above, the negative stability of the funding flow can create a negative reinforcing behavior for the
program that can overshadow any successes experienced by productivity programs. Worse, this
flow generates a reinforcing behavior that can cause continuous problems once the instability
starts. It will contribute to further deterioration in cost and schedule performance that will
contribute to another loop (R2) and affect Air Force Support leading once again to deterioration
of Political Support.

Let's continue to add loops (Figure 11). The Technical Performance Loop (B2) is a balancing
loop which illustrates the importance in the Capability of the Tool Set in order to converge on the
Technical Performance Gap as compared with the Desired Technical Performance. The other balancing loop now labeled is the Life Cycle Performance Gap Loop (B3) which is also a balancing loop that compares the actual life cycle performance of the new system with existing platforms.

As illustrated in the model, if there is a technical performance gap that means that the challenge of achieving the desired performance has not been met, Air Force and Political Support will be effected through Analytical Technical Performance, which can affect funding flows, the lifeline of any development environment. How to deal with this issue continues to be reviewed by industry and Government organizations jointly. Our comment is that we should be aware of the fact that any analytical process has tolerances and limitations. These tolerances are defined with very complex and technically advance methodologies. If there is a requirement that is essential, the program should consider building the system and testing it’s performance. The technical design view behind this statement is that it is more cost efficient to have actual performance data at a systems level to correct any problems if they arise. This provides the opportunity to correlate the analytical methods and tools to actual data. The goal is to reduce the design iteration impact to cost and schedule in the design/analysis phase and to apply the funding available strategically, based on actual performance data, as other problems occur in testing. In balancing technical excellence, cost, and schedule, gaining actual performance data as quickly as possible is the most fiscally prudent program strategy for development programs.
FIGURE 12 PARTIAL MACRO MODEL

Let's add the few remaining loops to complete the model. Figure 12 shows clearly the addition of the R4 Incentives Loop and B4 Design Capability Loop and Figure 13 shows the complete Macro Model which was obtained by adding the Company Investment Loop (R5). The R4 Loop, which by now is pretty difficult to follow, relates Company/Corporate Investment to Company Productivity Improvements and their effects on Development Cycle Time through Program Cost/
Schedule Performance to Customer Incentives. This loop identifies potential leverage points for reducing cycle time by providing incentives to the company for investments in productivity improvements therefore having a positive effect by reducing the development cycle time.

The B4 balancing loop relates Capability of Tools Set to Analytical Performance through Air Force Support to Customer Incentives and finally effecting the Company/Corporation Productivity Improvements which ultimately effect Capability of Tool Set. This loop illustrates the dynamics between the estimated analytical performance of the new product design and how Analytical Performance can affect the Air Force Support for the development program. One more loop, the R5 Company Investment Loop mirrors R4 Incentive Loop with the exception of the departure at the Company Investment variable. This departure, as illustrated, moves into Training, skills upgrading, directly effecting the Capability of Tool Set. Though this loop follows a different relationship the fundamental issue is how customer incentives reinforce company/corporate investment.

The loops (R4, R5, B4) described all effect the program’s cost and schedule performance through customer incentives and its relationship with the corporation’s/company’s investment in productivity improvement programs and training (skills upgrading) of personnel. The issue is what incentive structure can be implemented and what are the dynamics that effect sustained support from the Air Force to maintain the incentive reward.
Let's interrupt the discussion about incentives and discuss a few words on the timing of when to implement something like productivity improvement programs in the product life cycle.

Historically as mentioned in the paper numerous times, productivity improvement programs were oriented to the production phase of a program. Contributing to this legacy is the contracting history of military development programs and also the historical focus of other productivity programs, which in general are applied to the production phases of a program. The challenge is to bring productivity improvement programs like lean into the product development cycle from the beginning with the focus of improving efficiency, which in return needs to generate financial return in a timely manner for the company. Loops R4 and R5 illustrate the interrelations of the company and the Air Force and the effect on company/cooperate investment.
FIGURE 13 MACRO MODEL

The Incentive Loop (R4) is driven by program performance, which if positive, can induce positive behavior by controlling cycle time and meeting the desired performance measures. The reinforcing behavior of this loop will continually support investment, if contractually structured, thus improvement, of course all else equal.
Further discussing the Company Investment Loop which is very similar to the Incentive Loop (R4), focuses on company/corporate investment, reinforced by the incentives, generated by Airforce support. Though, the interrelationship is through analytical technical performance and the comparison of the life cycle of the existing platform, which effects positively or negatively the Airforce Support. Here again, this dynamic is extremely complex but the reinforcing loop illustrates the company's potential return on investment (financial or otherwise) as shown by the positive relation with the Air Force Support and Customer Incentives variables. Most programs have extreme difficulty "quantifying" this benefit and fail to invest in their future. The incentive model used today in military programs need to be reviewed focusing on the dynamics that are being addressed in this discussion. The company obviously is looking for return on investment, which may take form as the production contract, profit based on certain measures or a reputation that will help with the next competition. These options and more need to be pursued and investigated in the new culture of acquisition reform understanding the dynamic effect on the product development system. But with all that said, companies/corporations need to choreograph their investment strategies with the technical training requirements and the productivity improvement requirements. They both will support each other and make an over all success. The concern is that companies are focusing on the implementation of lean methods and neglecting what got them to the dance. The training, even in times of change, must be balanced to support the technical advancement of the enterprise. But all else equal, if the company invests in improving the core competencies such as technology and manufacturing, this competitive
advantage may be the reinforcing loop driving the system. This is frequently overlooked and can be effected by the program performance and as shown by the customer’s incentive structure. This investment variable describes the general investment needs for employee skills upgrading, analytical tools upgrading, productivity improvement programs, information and management system upgrading and capital assets upgrading. Obviously this is key for the long-term view that is essential for all the other parts of the system to sustain operations. Usually, this investment is the easiest to postpone or eliminate when performance is deteriorating. This is a big mistake, in our opinion. Historically the contracting methods for product development do not provide incentives in the early stages of the program, using the philosophy of the production follow on contract as the leverage for investment. This has proven to be faulty in implementation because of the competing forces in the company/corporation for the limited investment dollars and the length of time it takes for financial returns to be realized. Normally the investment is applied later in the product development phase as the contract award for the production program nears. This has little impact in the product development cycle. To move earlier in the product development cycle where investment can be taken advantage of the contracting philosophy needs to pursue innovative ways that will provide returns for investment starting when the program is awarded.

In general the overall model illustrates that exterior forces defined in the Government Support and Incentive sub phase can initiate negative behavior in the system influencing reinforcing behavior that can result in negative program performance. The model also illustrates that the program has the ability to manage the system by performing well through technical capability and for example
applying lean methods to the processes of passing data to the downstream user, minimizing design iterations thus development cycle time. This will also influence funding stability and as well minimize the impact of the external forces such as political support. There is a strong relationship through the Company Investment sub phase for strong intervention within the program to influence the performance measures. Possible intervention is to view the contracting methodology as a field for continuous change pursuing continued acquisition reforms. As discussed there is a balance that must be achieved between technical performance and cost and schedule performance that we believe is essential to obtain, influencing in many ways the sustaining of continued support for the program. Many forces affect the Technical Performance Gap of a program. Historically, behavior of the system has been dominated by this variable. The balance in achieving cost, schedule and performance is swayed by the need to excel technically. Based on experience of one of our careers it has been said “they won’t fire you for negative cost or schedule performance but will fire you for delivering negative technical performance”. This illustrates the imbalance of the three major measures of over all performance for a program. The model defines, in loop B1 and B2, the continuous behavior of striving to minimize the technical gaps will lead to constant growth of design iterations, which is strongly related to growth in development cycle time. The imbalance is vividly illustrated when the analytical performance of a system is very close to the desired performance and further iterations are providing diminishing returns. The program continues to iterate to achieve the analytical solution. Obviously, one can argue the continued pressure of achieving some of the performance measures generates break through technology.
There are many experiences that will support this statement but the environment in the market has changed, requiring balance while delivering the highest standards of technology.

Also, when viewing the whole model one can see the managers' challenge to be able to work within this system and make good business decisions. Obviously there are lower level models that can be created to go deeper into each one of the systems of the different sub-phases. The goal here is to discuss where can the program manager leverage, using lean methodology, to meet expectations in managing cost and schedule. Our recommendation is development cycle time, analytical performance, training (not lean training but skills upgrading) and interface with the customer (communication outside the program) which we believe are the dominant forces in this system. Each one of these is a candidate for the applications of lean principles and can influence the system for a successful program.
MICRO MODEL

Our micro product development model attempts to identify the key internal forces affecting a major military program during the engineering and manufacturing development (EMD) phase. The model is described using some basic relationships within the program, which are technical performance, flexibility, productivity, and quality, all of which are affected by the efficiency of the work force and the structural processes utilized. This model is extremely complicated if the basic structural configuration, as shown in Figure 14, is discussed in the context of phases within a development cycle for a major program. Because of this complexity we have removed the illustration of these phases though they are very prominent in any development program. These phases, preliminary design, detail design, manufacturing development and test are contributors in the evolution of a development program. The "loops" defined in the micro model can be and are applicable to each of these respective phases all contributing to development cycle time. The internal dynamics of this model is more focused on the flow of information and the processes that relate to the transition of information from one user to another. This aspect, though already touched on, is a contributor to the critical path within the program and is an ideal application for lean methods. In general this model is different from the Macro Model in that the managers (contractor and customer) within the program can effectively influence all aspects. Unfortunately though, through development cycle time and company/corporate investments, the external forces as described in the Macro Model can intervene and become influential within the Micro Model. Also, illustrated in this model is the relationship of manpower level and manpower skills and the
effects on work force productivity, influencing the design performance of the system, which ultimately gets back to design iterations and development cycle time. There will be little time expended on the relational importance of design iterations and development cycle time here but this relationship is, as in the Macro Model, the main attribute in viewing program performance.

In order to introduce all the variables and provide the necessary definitions, we introduce the complete Micro Model as shown in Figure 14. We understand the reader might have some difficulty following the many feedback loops all at once. To resolve this issue, we will slowly build up the model by incrementally adding complexity as in the Macro Model presentation. Nevertheless, we felt it was necessary to introduce all the variables at this time and the clearest way was to show the overall model first and then follow with detailed definitions of each of the variables in the model.
FIGURE 14 MICRO MODEL
DEFINITIONS OF THE MICRO MODEL VARIABLES

(01) Actual Work Force Skill Level = A function of the formal and informal training (skills upgrading) as well as available experienced employees (measured in years experience or actual experience) in the company’s work force.

(02) Company Investments = Amount of Corporate/Company investment in resources (employees, analytical tools, information systems, floor space etc.) for the direct benefit of an specific program

(03) Design Iteration = Number of iterations applied to the product in pursuit of achieving a set of desired program requirements (i.e. funding profile, technical performance, etc). An iterative process which is an attempt by the program to converge or reduce the Performance Requirements Gap, improve the Quality of Technical, which typically results in increased Development Cycle Time and therefore cost and schedule performance deterioration.

(04) Design Performance = A function of Tool Set Capability, and Work Force Productivity Level defined as the performance level (quality of output, capability for complexity, schedule performance) deemed appropriate to complete the design.

(05) Desired Manpower Level = The number of employees deemed appropriate by the respective managers to complete the task.

(06) Desired Performance Requirements = The level of technical performance as required by the customer and the contractor team. Technical requirements
estimated by the customer as necessary to the success of the program, which are acknowledged contractually by the company.

(07) Desired Quality of Technical Data = The data required, in content, format, schedule performance and detail level to pass to the downstream user to continue to progress in the design cycle without interruptions.

(08) Desired Work Force Skill Level = The number of employees required as a function of the cross functional technical disciplines required to efficiently complete the task which will include experience level (number of years in service) and actual in time functional experience.

(09) Development Cycle Time = length of time, measured in months, from the contract-go-ahead to a major completion milestone (i.e. first flight, completion of flight test, etc) in a military aircraft EMD program preparing for succession into a production contract driven by a iterative process required to complete the task.

(10) Efficiency of Information Systems = A function of Company Investments in tools which relate to state of the art technology to improve the productivity of the work force and the capability of the tool set. Focused on the impact of the effect on quality of data and timeliness of data by automation versus human tracking outside the information system.

(11) Manpower Level = The number of people at a given time in the program.

(12) Manpower Level Gap = A function of the Desired Manpower level and actual Manpower Level, which measures the difference between the desired and actual
number of people in the program. Focus on the “right” capability of employee as well as number of employees.

(13) Performance Requirements Gap = A function of the Desired Performance Requirements, Design Performance, and the Willingness to Change Requirements Gap which measures the difference between the desired and actual technical performance at given intervals in the maturity of the product design. Each of the phases (preliminary design, detail design, manufacturing development, and test) within product development can be illustrated here as well contributing to the performance of the product.

(14) Process Improvements (Integration & Communication) = A function of Efficiency of Information Systems, Quality of Data Package, and the Work Force Productivity Level which directly affects the Quality of the Data Package, focus on the structural processes of developing and moving data and therefore contributing to the number of design iterations.

(15) Program Sensitivity = A measure of how critical a particular technical requirement is as a function of the perceived mission and potential threat to the product while in service.

(16) Quality of Data Package = A function of Tool Set Capability, Process Improvements (Integration & Communication), which indicates the measure of the completeness, timeliness and utility of the data package generated in support of the different design phases as data is passed to a down stream user.
(17) Quality of Technical Data Gap = A function of the Desired Quality of Technical Data, which measures the difference between the desired and actual quality of the information at a given time, once again as data moves to a downstream user.

(18) Technical Risk of Achieving Performance Requirements = An estimate of the potential difficulty (technically) in attaining a desired level of performance.

(19) Tool Set Capability = Capability of the Tool Set utilized to create and analyze the design.

(20) Training = A function of Company Investments which defines the level of training (skills upgrading as well as productivity improvement) made available to the work force.

(21) Willingness to Change Requirements Gap = A function of the Program Sensitivity, Technical Risk of Achieving Performance Requirements, and the Performance Requirements Gap which defines the minimum level of technical performance that might be acceptable to the customer.

(22) Work Force Productivity Level = A function of the Company Investment, Manpower Level Gap, Personnel Skills Level Gap which defines how efficient is the work force in accomplishing the design, development, verification and manufacturing task during the EMD phase of the program.

(23) Work Force Skill level Gap = A function of the Actual Personnel Skills Level, Desired Personnel Skills Level, Training, Employee Productivity Level which
measures the difference between the desired and actual work force experience and efficiency in creating the “right” technical data.


discussion of micro model

To better illustrate how the model was developed, let's start with a few fundamental loops and slowly increase the complexity of the model. Let's start with what we hope is a familiar reinforcing loop. The Development Cycle Loop (R1) is the reinforcing loop that relates the cycle time of the program with the number of design iterations pursued. The Micro Model will examine what forces can internally drive the number of design iterations and therefore the development cycle time.

Figure 15 illustrates some of the fundamental dynamics of the Micro Model, which attempts to describe key events encountered in the EMD phase of a major military program. The Design Refinement Loop (B1) is the fundamental dynamic loop in achieving technical performance. This loop illustrates the nuts and bolts of the EMD phase. One simplification of the model in this phase has to do with the Design Performance Variable. The design of a military aircraft, like many other highly complex products, is incrementally refined as the data and internal requirements mature. Typically the maturity of the aircraft can be described as preliminary design, detailed design, etc. To simplify the model we introduce the B1 Loop concept, which basically captures the design refinement as a function of time. The balancing loop describes the relentless pursuit of the performance requirements as a function of program maturity.
FIGURE 15 PARTIAL MICRO MODEL

This pursuit is driven primarily by an ever-increasing number of design iterations. "Walking" through this simple balancing loop we can see that as the number of design iterations increase, the tool set capability increases. The improvement in the tool set should then reduce the gap between the desired and the actual analytical performance of the platform (Performance Requirements Gap) which should in turn limit the number of additional Design Iterations required to attain the desired design solution.

Throughout this model there will be a common theme as the loops continued to be described which is the passing of data to the next user. The iterative maturity process is highly dependent
on the “right” data passing through the handoff (transition) to the down stream user. The “right” data is not only defined by the technical credibility of the data but also by the format presentation, specific applicability, usability, completeness and timeliness of the data. All these factors are must be satisfied as the data matures into the next phase. The level of thinking we would like for the reader to have is a broad range for this concept because the transition of data happens at all levels within a program at very wide ranges of complexity and importance. But the fact is that all of these transitions contribute to the iterative behavior of the process. Every time a down stream user of data has to come back to the originator (for this respective user) for anything concerning the data it is an iteration and a loss of efficiency. Remember the processing of data is the essential operation of this model and to process data there are “handoffs” of the data which define the transitions to which another user is dependent on this data. As the description of this process is broken down to data and transition points, the concept of “flow” starts to take shape in the world of data as is thought of on the manufacturing floor with tangible parts. If this connection can be made the feasibility of implementing lean then becomes more and more appealing “off the manufacturing floor”.

The Quality of Data Loop (B2) illustrates the dynamic of generating data packages for internal customers for use by them to complete their tasks. Here again, the data will continue to mature with time and therefore numerous iterations are actually involved in this loop. The dynamic of this loop is very similar to the B1 loop. As the number of design iterations increase, improving capability of the tool set, the quality of the data should improve and therefore approach the
desired quality hence reducing the Quality of Technical Data Gap. This behavior as shown can be a result though not because of a discrepancy in the quality of the data but may be iterated due to a performance requirements gap. The interactions at this juncture indicates that if the program is passing bad data, the B2 loop can independently drive the iterative process and not fulfill the performance requirements.

The data package process is a "hand-off" process at the transition point in the flow of data, which is further complicated by the different time phasing (availability of the "right" data) of the different functional disciplines. Let us explain. For example, the detailed information and functional cross information required to release a drawing for a critical part during the Detailed Design phase of a program is an order of magnitude greater in complexity than the definition of the outside lines of an aircraft. These outside lines can be required to conduct an external aerodynamic assessment of the aircraft which requires less cross functional information thus less interfaces and timing issues. One problem that can be illustrated is that there is direct relationship between the external aerodynamics and the required definition of a detail part. The aerodynamic data is needed as just a part of the data required in designing a detail part. The timing can become a problem resulting in changes to the definition of the part if and when the external aerodynamic characteristics of the aircraft are revised. As a result, the recipient or consumer of the information might not get the level of detail or definition he or she requires. This can result in a very inefficient information exchange. If this example was then expanded to twenty different producers of data for the design of a detail part one can see the complexity in the system for the interfaces of the "right" data has
now been expanded and risks on iterative behavior is magnified. "Workarounds" for this
phenomenon occur frequently but as the program maturity increases and the pressure mounts, the
users behavior changes which becomes more selective on what "quality of data" is acceptable and
the whole iteration process slows down. The behavior described is an illustration of the
fundamental relationship between B1, Design Refinement Loop and B2, Quality of Data Loop.
This relationship is one of the drivers for development cycle behavior within the program.

The Requirements Loop (B3) describes the highly complex interface between the customer and
the contractor team. This balancing feedback loop simply relates the performance requirements
being pursued as a function of program maturity with the willingness to change these
requirements as technical risk and knowledge of the effectiveness of the weapon system changes
with time. The program has a set of defined design performance requirements developed in
support of the original contract award. These requirements are based on a perception of the
future threat and if fulfilled, will assure air dominance, as defined by the national defense strategy,
in an "expected" future engagement scenario. As the program matures, this feedback loop
provides insight into the risk related to attaining the requirements which can then be weighted
against the current understanding of the threat and the potential success (or failure) of the weapon
system if some of the technical requirements are revised. The auxiliary variable, Program
Sensitivity, is critical to the program flexibility loop. This variable, as previously defined, is the
interface with the perceived threat and roughly defines which particular design capability could be
reduced without significantly affecting the overall effectiveness of the weapon system.
Historically, this flexibility only comes into play late in the development phase, which means that numerous iterations and the corresponding increased development cycle time have already occurred.

The new paradigm in acquisition reform is called performance based contracting. In principle, this new methodology allows the contractor team to evaluate each specific technical requirement against the efficiency of the weapon system and internally to the program trade each requirement in an effort to manage the overall performance of the program. This is a change in culture, which is necessary for the success of this new paradigm, but is not engrained in either side of the contracting world. The Air Force and the contractor teams still focus on specific individual requirements based on functional disciplines and conduct fairly infrequent overall evaluation of the platform's overall capability. Each functional discipline continues to push for their specific requirements to be met and assume that some of the requirements associated with other functional disciplines can be reduced, but definitely not theirs! For this loop to be of significant leverage to controlling cycle time, system thinking is critical. The senior functional and product managers, with or without the new paradigm, must evaluate the overall efficiency of the system without concentrating on at times trivial functional requirements which if met, do not significantly improve the overall efficiency of the weapon but result in major investments in time and resources. As discussed in the Macro Model there are issues as well with the timing in making a decision on when to build and test versus continue to iterate and achieve diminishing returns on the iteration. This loop encompasses this decision process as well though the discussion in the Macro Model is
a vehicle to manage performance of the program without changing the desired performance before recognition of "real" data to be analyzed. Once the "real" data is understood then there could be a desire to work through this loop and determine strategically where limited program resources can be applied.

We are in no way suggesting that this is a simple task. In fact, we have been involved in many situations in which a peculiar functional discipline was pushed more strongly due to the functional upbringing that the majority of us have inherited. All this illustrates is that this balancing loop can directly affect the program cycle time and "soft" concepts such as culture, systems thinking integration and communication between the customer and the contractor strongly contribute to this highly technical balancing loop.

Let's now continue to build up the model by adding additional variables and the corresponding loops. Figure 16 shows the connection between the work force and the performance of the design. The Design Efficiency Loop (R2) basically illustrates that as the Work Force Productivity increases, the performance of the design should also increase, all else equal. These additional loops illustrate the dynamics between the pursuit of the platforms technical requirements and the work force productivity as illustrated by the balancing loops, B4, and B5 and the reinforcing loop R2. The dynamic appears simple but it is in fact extremely complex and is designed to provide maximum technical performance.
FIGURE 16 PARTIAL MICRO MODEL

As stated, the design will continue to be iterated until the Performance Requirement Gap is acceptable to the program. Reaching this level of performance might require significant effort in
work force productivity typically associated with increasing manpower allocations or
development of new tools. The relationship of the iterations within B1 striving to achieve the
design performances also enhances work force productivity contributing to increasing value in
design performance. This behavior is illustrated in the employees who are gaining experience
through the iterative process and becoming more familiar with the internal processes and tools.
This inherently provides a more experienced and productive work force. This is all negated
though if the manpower levels and skills are not meeting the desired goals (illustrated in B4 and
B5 loops). An example is if there is an under manned or under skilled work force, this can cause
a loss of productivity because of fatigue, even though the iterative process may be contributing to
the experience and productivity of the individual in the work force.

The Manpower Loop (B5) identifies the relationship between the number of people in a program
with the productivity of the work force based on the amount of company investments associated
with the specific program. The Training Loop (B4) accounts for the skill of the work force as a
result of company investments in the program through personnel training as it relates to the
productivity of the work force.

The market dynamic of attracting and retaining top level personnel is a topic of many debates in
corporate America. We rather focus on the company investments through training of the available
personnel. The work force is continually asked to perform more efficiently even through the
considerable downsizing in the defense industry has taken place. One logical way of improving

129
the efficiency is through training. The reality of the situation is that as downsizing continues to occur, the training becomes a secondary priority since managers tend to concentrate on completing the near term business commitments which is inevitably under significant schedule pressures. The managers can ill afford to offload the ever-reducing work force to attend training. This dynamic illustrates the conflict between the achievement of short-term goals and the ability to train personnel to attain the work force productivity improvements necessary to efficiently achieve the program requirements.

These loops are all fueled by the desired levels, which are required to successfully complete a program. The managers and their employees determine the manpower and skill levels required for completion of the detailed work. Historically the process for the determination of those levels is very contentious because the managers and their employee’s develop levels that are never what the program can afford. Thus there are many negotiations and guidance on what the employees can accomplish. This process has proven to be flawed in that, when those desired levels are not achieved, the workforce fatigues and morale declines adding to the loss of productivity. This phenomenon has happened in every program that either of the authors has been involved in and is not realized by program management in the maturation process until late in the development cycle. Recovery is difficult and does add to the inefficiencies in determining development cycle time. This discussion is to illustrate the importance of B4 and B5 loops and the attention they shall demand.
Let's continue to add to the model. Figure 17 shows the additional variables related to the information systems utilized by the program labeled “Efficiency of Information Systems” and the related Process Improvements variable. By introducing the two additional variables we have created three additional feedback loops. The Information Systems Loop (B6) and the Process Improvement Loop (B7) relate the companies investment in improved information systems with the potential for improvements in work force productivity as well as in the company's internal processes for data generation, documentation and transfer. The Process Improvement Loop (R4) relates, again, the processes and the Quality of the Data Package.

One of the options to be considered involves the Process Improvement (Integration and Communication) variable identified in the model. This variable can be indirectly affected by investments in new technology, both software and hardware; to improve the processes utilized for data generation and transfer. Another mechanism is to introduce a pull system for data and evaluate the performance of the data provider in relation to how his customer's performance. Better yet, have the customer of the data clearly define the necessary information and format requirements and ensure that the data provider follows these guidelines. The inevitable exceptions should be documented and understood in relation to the product development cycle time. Here again, it is essential to look at the whole system to understand what the value stream of the information really is.
FIGURE 17 PARTIAL MICRO MODEL
The program needs to identify consumers of the information and eliminate many of the data, which never gets utilized. The three loops B6, B7 and R4 all relate to processes in information and how they affect either work force productivity or quality of data packages. In today’s world it’s obvious that there are systems available which can help productivity by transfer of information faster than ever. This is where company/corporate investment is important and as we have seen can be effected by external forces as well. Improved systems and tools are a necessity but have to be dutifully addressed to assure the compliance with the need and the workforce. The same rule applies here as seen with the selection of lean tools as well, adaptability and compatibility. Any system that is introduced must be adaptive to the working environment while also compatible with the using population. Experience here suggests caution on what a major new system can deliver for work force productivity improvement but that does not mean these improvements must not be pursued. On the contrary, though, here is where the lean discipline can help define the attributes of a new system or multiple systems and integrate it into the environment.

Now let’s complete the model by adding the Process Efficiency Loop R3 which relates the dynamics between process improvements and the productivity of the work force. Figure 18 shows that simple dynamic and completes our Micro Model. The R3 reinforcing loop describes the relationship between work force productivity and the processes utilized to generate the design data packages. As the work force productivity increases, the opportunity to improve the processes increases which in turn lead to improve work force productivity, all else equal. Here as in the previous balancing loops described above this is another important attribute of the model,
which signifies the structural processes of the program. Programs spend a great deal of time
formulating better ways in “doing things”. With the lean tool available there is a reality in the way
to attack this attribute to make it more significant in the effort to accomplish the daily business
within a program. The reinforcing behavior tends to indicate continued improvement as the work
force matures and gains experience. This is true but if there are not structural changes
accomplished the continued improvement runs out of time synonymous with the program’s
conclusion. Structural changes must be taken if the advantage of those changes is to have any
effect on development cycle time. When viewing the whole model (Figure 18) one can see how
complicated and time consuming this process really is. Obviously we could have developed lower
level models to better understand the dynamics of the systems and of the different phases. At this
time, our goal is merely to identify potential levers that might help reduce the overall program
cycle time. Our recommendation revolves around improving internal communications, investing
in work force productivity and tools, and managing the flexibility to adjust requirements as a
function of the overall system performance, not functional requirements. Each one of these
options can be served by the application of lean principles. The Micro Model, similar to the
Macro Model illustrates the need for a systems view when addressing critical management issues.
This model also highlights the conflict between short-term goals and the need for significant
investment for continued improvement of the processes and the work force productivity.
FIGURE 18 MICRO MODEL
Although the customer is not specifically identified in the Micro Model, the culture of the company is definitely molded by the interface with Air Force. The shift from specific functional requirements to overall performance requirements is a long way from a reality. The flexibility necessary to manage conflicting requirements can only be effectively done at the system level. The decisions must reflect overall benefit to the program and not be an indicator of which functional discipline has the most internal power at a given time.

As shown by Loop B7, the program can also invest in tools such as hardware, software and information systems to assist in improving the work force productivity level. These investments also indirectly affect the Tool Set Capability variable which is a key variable in the execution of the design iterations and the development of data packages.

This Micro Model illustrates the importance of training to the success of the program and clearly correlates with the comments of the executives we interviewed. How to provide the necessary training for continued improvement is again not a trivial problem. Long term planning with the realization that even the most indispensable individual must attend training is the necessary first step. Another method to obtain training is to incorporate job rotations in which employees are moved from one job to the next in intervals of two to five years. Most of the defense contractors operate several different programs a one time. In our opinion, the benefits of periodically introducing different ideas into the system far outweighs the short term negative effect associate with the temporary loss of learning associated with new personnel. Many companies and
organizations attempt to cross reference lessons learned through a central functional office. The most effective way to achieve this cross-linking is to rotate personnel. Another possible action is to cross train in functional disciplines. This is a significant contradiction with the current trend for specialization but as the individual responsibility increases we believe that a better understanding of the system is required. This relates indirectly with Requirements Loop (B3) and the discussion around the tendencies of each of the different functional disciplines to concentrate on their requirements versus the overall system performance. Formal academic training is another option and, of course, who are we to argue with the need to send individuals to formal training like the Sloan Fellows Executive training program.
CONCLUSION

Throughout this thesis we have discussed Lean implementation concentrating on “off the manufacturing floor” in the Aerospace Industry. The process used was by describing real issues identified by high level managers in the industry interrelating the importance of understanding the surrounding environment and then introducing two key features in the form of an implementation framework and system dynamic models. We attempted to illustrate the value of system dynamics modeling, which can provide the ability to strategically focus the implementation of lean tools so as to achieve the greatest positive results. Also, in the process of creating the system dynamic models it became apparent that the product development cycle time, defined as the length of time from contract go-ahead to a major completed milestone (i.e. completion of flight test), was a very important variable, which needed our focus. A discussion was presented to provide a direct operational relationship between development cycle time and cost and schedule performance attempting to provide an argument that a program can have efficient processes that yield quality products and still experience poor cost and schedule performance. This realization supports the contention that there are many forces, internal and external, acting on a major development program. These forces can impact development cycle time even though a comprehensive set of lean tools might have been applied. This situation can ultimately reduce commitment for lean and eventually, incorrectly, cast lean into the category of the “fad for the decade” within the industry. The lean methodology has already proven to be enlightening and successful locally on the manufacturing floor. This is to be expected since lean principles follow the same principles of
other initiatives such as Total Quality (TQ). From the interviews, as well as from the author’s personal experiences and beliefs, it’s apparent that lean applied off the manufacturing floor should also be a powerful tool for the total enterprise.

The thesis addresses the philosophy of lean as a behavioral change for the aerospace industry identifying the need to revise the fundamental culture and providing means to restructure the environment in the workplace. The journey is not easy and requires commitment and patience from management, ownership by the employees, and a basic understanding of the total systems to be successful. This means creating well-defined expectations and implementation plans, and the willingness for “two way” communication between relevant interfaces.

The lean implementation framework presented was developed to address the critical issues derived from the interviews as well as integrating system dynamics into an implementation process for lean. The plan illustrates the importance in defining the requirements of the vision for the company/corporation. The vision addresses the level of urgency tied to the company’s/corporation’s operating future, defining the depth of the company’s/corporation’s participation, identifying the expectation of time and required investment returns, and providing an operational tie to productivity improvement programs. The framework also illustrates the lean tools and any outside expertise selected for the introduction of the productivity improvement program must be compatible with the company’s vision and adaptable to the using population.
Also addressed is the importance of providing a strong message to the employees by allocating the necessary resources in support of the implementation of the initiatives.

The customer is an important member of this journey and must be recognized as a participant within the company/corporation. The customer must also recognize the need for implementing a compatible methodology at the interface and internal to their own operations. The benefits of lean as applied to one side of the interface can be easily offset if the corresponding interface does not recognize the process changes being pursued. Cooperation and constant communication are therefore key to early success and sustainment.

The framework also addresses the importance of training, suggesting that training for lean and training for skills upgrading is also critical to the sustainment of the application. Companies have experienced a departure between skills upgrading and lean training focusing more on lean training and almost eliminating skills upgrading. This should not occur, the recognition of skills upgrading as a significant contributor to the sustainment and future proficiency in productivity must be recognized. The fundamental need for pushing the technological envelope requires constant investment in skill upgrading of the most valuable resource, the employees. The enterprise must therefore strike a balance between the resources allocate for lean training and skills upgrading. Keep in mind the fragile atmosphere a company/corporation has to address when applying a program to the entire enterprise in reference to the balance that must be achieved with the existing business commitments and the need to change. The focus on lean implementation can rapidly be
lost if there are not constant reminders of the successes and the positive performance achieved. These achievements, regardless of magnitude, must be made visible to the management team utilizing metrics that they prescribed and understand. This is addressed by the communication plan within the framework identifying the need to publicize successes such as in a marketing atmosphere and mechanize two-way communication between the empowered employees and the management team.

The focus for the implementation framework must be to define a plan that will disseminate rapidly and covers as many employees as possible. There is a strong relationship between doing and learning. The institutionalization of lean depends on learning and application. The framework was developed to give importance to the flow of each step. Different actions can be accomplished in parallel, but there is a discipline that must be followed to assure that each step within the framework is concluded before mass operations occurs. It is clear to the authors that lean can be applied "off the manufacturing floor". Analyzing the framework, one can gain insight to the importance of an applicable process to initiate a successful journey.

The first model defined in the thesis, identified as the Macro Model, gives us insight to the external environment for a major military development program. When viewing this model one can see the complexity of challenges for the managers of a program while working in this environment. The intent of building this model was to determine areas to leverage the application of lean and to describe what effects that would have on the system. The leverage areas as
discussed are really premised based on the operational relationship that development cycle time has on the cost and schedule performance of the program. As described in the thesis, development cycle time can be affected by internal forces as well as external forces and is the driving parameter that best will give visibility on the cost and schedule performance of a program. It is one attribute, though, that can be managed and is process driven in many respects. Being process driven allows for lean methods to be applied providing opportunity for improvement.

The reinforcing loop that is very much a contributor to the growth of development cycle time is R3, which includes design iteration. The loop was discussed in both model sections and is in fact affected by the proposed interventions. Balancing the reinforcing behavior of R3 in the Macro Model are both the B1 and B2 loops that contain the measure of technical performance of the weapons system.

The internal model, defined as the Micro Model, highlights that doing iterations is undoubtedly the driver for the behavior of development cycle time and is also strongly process driven. If in fact development cycle time can be controlled internally then, as seen in the Macro Model, program support form the Air Force and political support should remain strong thus maintaining funding stability and providing a reinforcing behavior to contain cost and schedule performance. Unfortunately, internal commitment and performance are not the only variables driving this behavior. The external forces of Political Support, Air Force Support, Threat to National Defense, Public Opinion and Company Investment are also contributors to the Development Cycle Time behavior that can easily over shadow the internal performance of a program. Though
clearly, if the development cycle time is managed, the cost and schedule of the program is as well, providing the most favorable environment for continued stable funding, the lifeline of a program. Of course, cost and schedule performance are not the only measures that are related to funding stability, as seen in the model, analytical performance of the weapons system is also a key contributor which provides insight to another area for leverage in the application of lean.

Analytical performance is interrelated with training and capability of the tool set and is evaluated by the measure of the technical performance gap which is derived by the comparison of the analytical performance and the desired technical performance. Here is another area where company/corporate investment can be a valuable contributor to the analytical performance in the shape of skills upgrade training and improvement of the technical tools. Obviously, there is some lag time between the company investment and the actual benefit from training for skill upgrades. The message here is that a strong, constant commitment to training is essential, and cutting these funds due to financial constraints can severely affect the long-term performance of the enterprise. The intervention should not only focus on investment but as seen in the Micro Model, it should consider internal forces such as the ability to maintain high quality of data at the interface from one user to another. These variables can also contribute to the reduction of design iterations by increasing technical capability and improving the efficiency of the processes. Once again, this is a highly process driven system where lean methods can be applied successfully. This valuable insight will enhance the analytical technical capability of the weapon system by providing the “right data” in a timely manner enhancing the ability to increase employee productivity therefore
reducing design iterations, and contributing to the overall stability of the program. Analytical technical capability can be successfully managed within the program. It’s a fact that pursuit of the "ultimate" technology by increasing the design can lead to diminishing returns. Like they say in the industry, it takes a great effort to attain that last 5 percent of the technical requirements. Sometimes it might be better to stop at 95 percent of the goal! If this is not recognized and addressed, in some instances the iterations can negatively impact development cycle time in striving for excellence causing negative systems impact and ultimately affecting funding stability. This is another leverage area for the application of lean at the interface with the customer, specifically as the analytical performance is compared to the desired technical performance.

The Micro Model is where there is discussion on effect of internal forces on design iterations and subsequently development cycle time but, at the Macro Model level, design iterations can be driven by the desired technical performance. As described in the model, if there is a technical performance gap, that indicates that the desired technical performance is not being met, another design iteration will be required. This, as was discussed, can have diminishing returns and cause greater and greater number of design iterations that ultimately will increase development cycle time, and therefore put negative pressure on the program’s cost and schedule performance. The intervention must consider the practical limits to the analytical tools and attempt to control the number of design iterations by recognizing this limitation. In some cases, when a particular technical requirement is perceived as critical to the performance of the system, it might be
advantageous to develop "actual" test information for correlation with the analytical tools in lieu of an ever-increasing number of design iterations pushing the capability of the analytical tools.

The Macro Model illustrates that intervention areas for lean application are development cycle time, analytical performance, training (not lean training but skills upgrading) and interface with the customer. All, as seen in the Macro Model, have a strong relationship to the development cycle time thus directly contributing to the cost and schedule performance of the program.

Let us try to illustrate the dynamics at the potential leverage points by looking at the Macro Model one more time in Figure 19. The triggering mechanism that a program might encounter could be a change in the Funding Stability due to extraordinary defense budget pressures like the need for supporting the Kosovo (1999) conflict. Looking at the R2 loop, if Funding Stability decreases then one would expect that the Development Cycle time would increase affecting the program's cost and schedule performance. One logical intervention is for the program to adjust by "changing" the Desired Cost/Schedule variable to accommodate the funding shortfall. This action obviously tries to drive the cycle time and therefore the overall cost will continue to deteriorate. Typically, these adjustments are very aggressive (optimistic) in nature, since the potential for eroding the Government Support is very real as shown in the R3 loop. Shortly after the adjustment is made, the program can easily start having difficulty meeting cost and schedule commitments. If the program decides to "adjust" its schedule too conservatively, this action
might result in undesirable planned delivery needs and therefore potentially reducing the Air Force Support which can further reduce the Funding Stability!

FIGURE 19 MACRO MODEL REVISITED

One typical mistake would be to try to offset the decreased funding available by slashing the Company Investments which will eventually further deteriorate the performance of the program as shown in the R4 and R5 loops. The model shows the need to consider other alternatives to
counteract this potential vicious feedback cycle. For example, the customer and contractor might want to consider intervening in the B2 loop by “adjusting” the Desired Technical Performance and counteracting the upward pressure on the Design Iterations variable and therefore on the Development Cycle Time. The other obvious (and very popular) intervention could be in the B1 loop by accepting increased Technical Risk. This could be a major problem, especially if decreasing the training resources for the program have already been reduced therefore potentially affecting the long-term Capability of Tool Set.

As previously stated, the Micro Model (Figure 20) focuses on the internal environment of a program and is similar to the Macro Model in that development cycle time is the primary variable of measure. This complex model attempts to describe the phases of development and how those phases contribute to the number of design iterations and development cycle time. The Micro Model illustrates that managing the Quality of Data and the Technical Performance is essential to the internal execution of the program. It also shows that the productivity of the work force and the methods used for integration and communication of information are two potential leverage points.

The interface at which data is transferred is one of the most valued leverage points in which lean can be used. As defined in the model, Quality of Data, which includes timeliness, completeness and correctness of data, passed at an interface with a downstream user can contribute to the number of design iteration. If the data is acted upon by the downstream user and is incomplete,
incorrect, or late, the downstream user ultimately will cycle the data back for more or better information or pass it to the next user potentially causing even further deterioration downstream in the process. Thus a number of additional design iterations could easily occur which will contribute to the reinforcing loop R1 increasing development cycle time. The intervention in the quality of data at the interface is one that is quite applicable to lean methods and is so vital in the development cycle. This by far is the most valued area to apply lean, which the authors believe will provide the greatest results. The model also illustrates that analytical performance as measured by the performance requirement gap contributes as well to the number of design iterations, once again creating a relationship that could increase the number of design iterations in pursuit of the desired performance requirements. The analytical performance is driven by two primary attributes, one that has already been addressed as far as lean applications is the quality of data but the other is the work force productivity level. The intervention area resides with the work force productivity level, which represents the skill of personnel, number of personnel and the information systems provided to the personnel. Work force productivity is positively related to the analytical performance and is directly compared to the desired performance requirements by the performance gap. As seen with the quality of data at the interfaces, work force productivity is process driven and therefore amenable to successful application of lean principles. These two intervention points described within the Micro Model are in the author’s perspective extremely critical to the successful operation of the internal environment within a program.
FIGURE 20 MICRO MODEL REVISITED
Looking at the Quality of Data Loop (B2) and at the Design Refinement Loop (B1) in the Micro Model (Figure 20), we can clearly see the relationship between these two loops and the number of design iterations and therefore cycle time. The B2 loop can be managed by investing in Information Systems (Loop B6) and by dedicating the necessary resources to improving internal communications and overall integration of the product as seen in the Process Loop (B7). These actions can be reinforced by the Process Efficiency Loop (R3) and the Process Improvement Loop (R4) which incorporate the benefits of investing in a productive work force. Lean principles are fundamental to the improvement of all these processes and the potential rewards from their incorporation are clearly evident in this model.

The same relationship is visible between the productivity of the work force and the Design Refinement Loop (B1). This link is shown in the Design Efficiency Loop (R2).

Looking at this loop one can see how the work force productivity could be affected by either cutting funding for training or reducing the manning levels. The secret is to understand the functional relationship between these critical parameters. Management tends to frequently attack increases in cost and schedule performance (Development Cycle Time) by leveraging the work force productivity, and that action is understandable. The value of the model would be in trying to evaluate what levels provide the best compromise and better yet, what other action or actions are appropriate to off-set this potential negative action. The internal model shows one additional loop that could be utilized. The B3 Requirements Loop could be used as leverage to counterbalance some of these possible actions. The key to “leaning out” this loop is to think of
the complete system and not of each of the parts. For example, many functional requirements are zealously protected by each of the functional disciplines involved in the development of the product. Many of these do not appreciate the overall “system” benefit for their particular requirement but their culture is to defend them at all cost. This behavior, if followed by all, would severely hamper the ability to converge on the performance requirements do to the lack of willingness to change the requirements gap. Technical managers frequently struggle with this dynamic situation.

The thesis has shown that even though a program can be managing development cycle times well, there are internal and external forces that can contribute to bumps in the road or even program cancellation. Program managers must recognize these forces and develop strategies to manage their impacts as required. This is one of the strengths in using system dynamics, which provides tools to recognize the environment and gives the ability to analyze the possible strategies for intervention.

The thesis has allowed us to conduct a quick study of the aerospace industry and specifically the dynamics related to the product development phase of major military weapon systems. Based on the information compiled during the interviews and the work conducted to complete the system dynamic models as well as the implementation framework there are two explicit findings we can conclude.
• Use of *Systems Thinking* is advantageous when involved in a complex process controlled environment.

• Lean Methods (productivity improvement programs) can be successfully applied to activities “off the manufacturing floor”. That is, information flow can be lean.

The first finding revolves around the complex dynamics related to a major product development program. Without the systems perspective it would be difficult to engage in a cultural change such as lean methods as well as manage the existing business commitments. The understanding of the system, focusing on the feedback mechanisms is extremely valuable and in fact essential for effective program intervention. *Systems Thinking* provides the ability to understand the relationship between the customer and the contractor and helps identify the possible variables that can affect the result of internal and external forces driving change. *Systems thinking* also allows us to better understand the significant conflict between long-term process improvements and short-term pressures related to daily program execution. The management challenge is to manage a balanced program, understanding event driven problems and being able to develop strategies applicable to the overall system.

The second finding is related to the feasibility of successfully implementing product improvement processes such as lean “off the manufacturing floor”. We see no reason why lean principles can’t be applied to the development process. The issue is of institutionalizing the behavior so as to reinforce the sustainability. The majority of development cost in a development program is
acquired “off the manufacturing floor” therefore the incentive is high to succeed in the application. As described in the thesis, lean implementation has developed some real issues but they are all solvable. The difficult challenge is the sustainment of the commitment to continue to invest and nurture for success. Each one of the companies must remain focused and in balance and they will be successful.

The thesis also illustrates the feasibility of applying lean methods “off the manufacturing floor” adapting to the flow of information as easily as the flow of parts. The models describe the dynamic relation between the internal and external forces and the effect on development cycle time. To transform the current trend of continued schedule and cost overruns, the industry needs to combine systems thinking and lean methods, therefore providing the program manager with a tool set that will assist in successfully managing a development program. The authors feel it is very clear that development cycle time is the parameter for managerial focus as well as a measure. This measure is directly affected by the legacy of the industry’s culture in striving to achieve technical excellence. The new paradigm must envision a balance between cost, schedule and technical performance therefore challenging the current trend to consistently pursue the maximum technical performance almost with disregard to the development cycle time. The current market environment for military programs is not projected to improve in reference to the budget allocations and in fact will continue to decline. Therefore companies/corporations who survive in the industry must dramatically change their behavior and the authors believe these tools are the vehicles that can be utilized for successful change.
The next step for application of Systems Thinking and System Dynamics Modeling requires calibration of the models utilizing historical information from several major programs. This would allow for the development of mathematical representations of each of the variables in the relevant units of interest (i.e. dollars, calendar time, etc). By achieving this, one can actually conduct "what if" exercises to attempt to develop approximations on what potential actions could be taken and how each action affects the overall program health. The beauty is that, since it's only a simulation, one can run as many cases as desired and try to develop sensitivities and intuitions for each action or for several combinations of each of the potential actions. The time and effort necessary to develop such refined models is beyond the scope of this thesis. Understanding the development environment, conducting detailed historical research and calibration, and applying extensive expertise in the refinement of the Systems Dynamics Models are all essential ingredients necessary to pursue this next step. Maybe in the near future, we might see this type of effort become a reality!


WOMACK, James P., and Danielle T. Jones, "Lean Thinking", (Simon and Schuester, 1996).