The Application of Lean Principles to the Military Aerospace Product Development Process

by

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Submitted to the System Design and Management Program
in Partial Fulfillment of the Requirements for the Degree of

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ABSTRACT

The aerospace market is as demanding as many industries in terms of the challenges on firms to deliver world class performance and quality at reduced cost and lead-times. These challenges extend to the military side of the aerospace market which is faced with the challenge of developing, delivering and supporting systems with ever increasing complexity in an environment of significantly reduced defense budgets. These challenges suggest that application of innovative improvement strategies will be required for market success. Additionally, the ability of the armed forces to maintain superiority in this environment is highly dependent on the aerospace firms' achievement of significant reductions in the cost of ownership of these systems. Since the major portion of the cost of ownership of aerospace systems is determined by the decisions made during the product development process, focus of improvement efforts on this portion of the product life cycle is key to achieving success.

Recent research by James P. Womack and Daniel T. Jones suggests that application of five lean principles to the processes across the entire enterprise will lead to achieving a "lean" state. This lean state results from the elimination of waste from operations such that products can be developed with a minimum of overall expense in terms of human effort, material and time.[1] Nevertheless, the bulk of the discussion and application examples in this and other recent research have largely been focused on the manufacturing portion of the value stream. There are many examples in industry of where these principles have successfully transformed manufacturing organizations. But product development organizations have been struggling with how these principles apply to product development and what "lean" really means in the product development context. This difficulty in translating lean principles to product development is partially due to the differences between the processes used in the manufacturing setting and the product development setting, and the differences in the 'product' which these processes produce. The problem to be studied in this thesis is whether value stream mapping and lean principles, which have been successful in facilitating the lean transition in manufacturing, are effective tools in identifying waste and identifying an improved product development process future state.

This thesis will study the application of value stream mapping to a military aerospace product development program at Pratt & Whitney. Although it is recognized that in order to achieve the goals of lean thinking one has to apply the principles enterprise wide, this work will be limited to looking at application in a specific portion of the product development process. In so doing, sufficient process breath will be covered for demonstration purposes, while the scope of work will be limited consistent with the intent of this thesis. Prior to the case study, each of the lean principles is investigated from a product development perspective by researching the underlying concepts and comparing them to recent business process work of others. The primary focus will be on the definition of Value in product development and the Value Stream mapping process. Additionally, a survey of product development engineers is conducted which supports the existence of similar types of waste in product development as is seen in manufacturing.

Thesis Supervisor: Joyce M. Warmkessel

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[1] James P. Womack and Daniel T. Jones, *Lean Thinking: Banish Waste and Create Wealth in Your Corporation* (New York: Simon & Shuster, 1996).

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CHAPTER ONE

Introduction

Motivation

The aerospace market is as demanding as many industries in terms of the challenges on firms to deliver world class performance and quality at reduced cost and lead-times. These challenges extend to the military side of the aerospace market which is faced with the challenge of developing, delivering and supporting systems with ever increasing complexity in an environment of significantly reduced defense budgets. These challenges suggest that application of innovative improvement strategies will be required for market success. Additionally, the ability of the armed forces to maintain superiority in this environment is highly dependent on the aerospace firms' achievement of significant reductions in the cost of ownership of these systems. Since the major portion of the cost of ownership of aerospace systems is established by the decisions made during the product development process, focus of improvement efforts on this portion of the product life cycle is key to achieving success.

Problem Statement

Recent research by James P. Womack and Daniel T. Jones suggests that application of five lean principles to the processes across the entire enterprise will lead to achieving a "lean" state. This lean state results from the elimination of waste from operations such that products can be developed with a minimum of overall expense in terms of human effort, material and time. The specific principles are: precisely specify value by specific product, identify the value stream, make value flow, let the customer pull value, and pursue perfection.[2] Nevertheless, the bulk of the discussion and application examples in this and other recent research have largely been focused on the manufacturing portion of the value stream. There are many examples in industry of where these principles have successfully transformed manufacturing organizations. But there are striking differences between the processes used in manufacturing settings and the product development setting, and there are striking differences in the 'product' which these processes produce. The problem to be studied is whether value stream mapping and lean principles, which have been successful in facilitating the lean transition in manufacturing, are effective tools in identifying waste and identifying an improved product development process future state.

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[2] James P. Womack and Daniel T. Jones, *Lean Thinking: Banish Waste and Create Wealth in Your Corporation* (New York: Simon & Shuster, 1996), 10.

Goals and Objectives

The goal of this work is to broaden the understanding of the lean principles as they may pertain to the product development process and determine whether they are useful concepts in eliminating waste in this environment. Since the perspective of the customer is central to these principles, the objective includes establishing the meaning of customer value in the specific product development context. Once this meaning is established, and the principles are understood in this context, the goal of this work, through the use of a case study, is to demonstrate the applicability of the lean principles and techniques on a military aerospace development program process.

Overview of Remaining Chapters

Both research and a case study were performed to support the supposition that lean principles can be applied to the product development process to yield process improvements. The research involved reviewing current engineering and business publications on related concepts of value and process improvement, and evaluating these relative to the lean value principle to establish what is meant by value in product development. The research focused on the value principle, but the remaining lean principles were also investigated by evaluating and understanding each in the specific contexts of manufacturing and product development processes. Actual value stream mapping techniques were studied for their applicability as a tool in the product development lean transition process. Finally a case study was performed, wherein value stream mapping of a military aerospace product development program was accomplished and lean principles were applied to facilitate lean transitioning these processes.

Chapter Two takes a critical look at the first lean principle, Value. The meaning of value is investigated first in a general context, in the context of *Lean Thinking*, and finally in the context of other product development and business literature. This investigation found the value principle to be pertinent in the product development context and a specific definition of value was developed which facilitates an understanding of customer value in the product development arena, and assists in creating a customer focus in the lean transition process. Although *Lean Thinking* is customer value focused, the existence of other value perspectives is investigated. The linkage between these value perspectives is also discussed and the need to understand these linkages during the lean transition is established. Finally, specific high level attributes of customer value in the product development setting are established.

Chapter Three takes a critical look at the Value Stream principle. The definition of value stream in the product development setting was developed in this chapter. The relationship between the value principle, the value stream principle and the product itself was investigated. Finally, the categorization of process activities along the value stream used in the manufacturing setting, which is based on value creation, is considered for use in the product development setting as well, as a basis for process improvement.

The Flow principle as it applies to product development is investigated in Chapter Four. The concept of information being the 'product' in the product development process is proposed. To assist in identifying the wastes which stand in the way of generating flow in product development, an investigation was conducted to determine if the wastes and flow techniques which have been identified in the manufacturing setting could be applied to the product development environment. This investigation involved surveying engineers in product development for identification of wastes, determining if these wastes fit into the classic manufacturing waste categories, and finally determining if well known manufacturing flow techniques can be applied to mitigate these wastes or whether unique flow techniques are required for product development.

The final two principles, Pull and Perfection were investigated in Chapters Five and Six, respectively. The Pull principle is investigated primarily from a process control standpoint. Just-in-Time is a pull methodology used in manufacturing to control product flow. The current state of product flow in product development is discussed and the applicability of the pull principle is investigated. Finally, the perfection principle is investigated primarily within the context of other organizational change infrastructures. Having completed the analysis of the lean principles in the context of product development, Chapter Seven then investigates specific value stream mapping requirements and techniques which can be utilized to facilitate the lean transition process in product development.

A case study is presented in Chapters Eight through Ten, wherein the above lean principles and value stream mapping techniques are applied to a specific military aerospace product development program.

CHAPTER TWO

The Value Principle and Its Perspectives

Value is the first lean principle offered in *Lean Thinking*. Womack and Jones emphasize the need to express value in terms of a specific product that meets customer needs at a specific price at a specific time.[3] In order to assist in defining what is meant by value specifically in the product development process, it is appropriate to review definitions of value in modern literature and in contexts other than the product development. What better place to start than *the Oxford English Dictionary* for an understanding of what is meant by the term 'value' in value stream. The first definition for value in this reference is as follows:

> "1a. That amount of some commodity, medium of exchange, etc., which is considered to be an equivalent for something else; a fair or adequate equivalent or return."[4]

> "1b. A standard of estimation or exchange; an amount or sum reckoned in terms of this; a thing regarded as worth having."[5]

Based on definition 1a, it is evident that in the context of this work that value implies equivalence between the cost of a product to the customer and the product itself. Note that this consideration of equivalence is in the eyes of the customer and not of the producer. Additional insight is gained by the third statement in 1b; "a thing regarded as worth having". The summation of value added along the value stream must be great enough that the customer deems the product as worth having. And in fact the *Oxford English Dictionary* includes the phrase "value added" in its definition of value and defines it as:

> "the amount by which the value of an article is increased at each stage of its production by the firm or firms producing it, exclusive of the cost of materials and bought-in parts and services"[6]

This is the value we are talking about mapping in the product development process, although we may choose not to exclude anything. There is one more aspect of the definition, which adds to this discussion, and that is a reference to the product usefulness or function. Again from the *Oxford English Dictionary*:

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[3] Womack and Jones, *Lean Thinking*, 16.

[4] *Oxford English Dictionary*, 2nd Edition (1989), s.v. "value".

[5] Ibid., s.v. "value for money".

[6] Ibid., s.v. "value added".

"6a. The relative status of a thing, or the estimate in which it is held, according to its real or supposed worth, usefulness, or importance."

and

"6f. The quality of a thing considered in respect of its power and validity for a specified purpose or effect."[7]

These definitions tie the previous customer's perception of worth directly to the product usefulness for a purpose and importance. And interestingly, the definition also ties in the product's quality to its value. Prior to considering the specific product development context, the following summation is proposed for the meaning of 'value' for use in this study:

Value is a measurement of the worth of a specific product or service by a customer, and is a function of (1) the product's usefulness in satisfying a customer need, (2) the relative importance of the need being satisfied, and (3) the exchange cost to the customer.

Note that this is an initial definition which is revised later as other contexts are considered.

Customer Value

We now turn to other possibly more pertinent sources for our definition of value in the context of product development. Overall, there seems to be reasonable agreement in the definition of value in recent publications relating to value in the business environment. In *Managing Customer Value*, Bradley T. Gale suggests a relationship for value as shown in Figure 2.1.

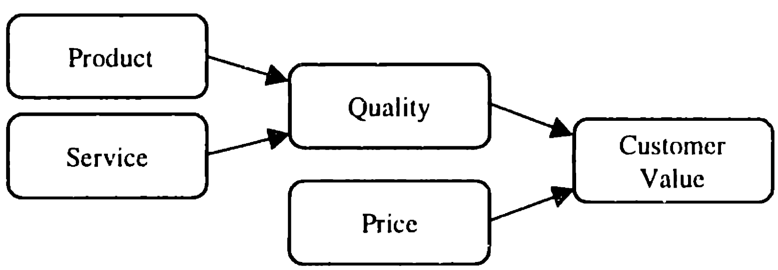

Figure 2.1. Customer Value Relationship

Gale defines Customer Value as market perceived quality adjusted for the relative price of the product or service, where market perceived value is the customers opinion of the product or service relative to those of the

[7] *Oxford English Dictionary*, s.v. "of..value".

competition.[8] In this definition, Quality includes all non-price attributes associated with both the product and/or service. An aspect of this definition missing from the previous discussion is that value is defined relative to the competition.

This market perception approach to defining value is different than the *Lean Thinking* perspective. Womack's approach demands putting benchmarking and measurement relative to the competition aside. Lean Thinking suggests an absolute approach where value is be measured against an ideal, a condition without muda. In other words, value should be measured relative to perfection. The counter argument is that the customer is sensitive to his needs in the context of the entire market. The customer will naturally compare products to each other to establish which one best satisfies his utility function for value. If the customer is doing this comparison, then it behooves the business enterprise to understand the competition.

The measurement against perfection seems appropriate when one is focused on the "Price" portion of the value equation. A company should strive to eliminate all waste and thus achieve the 'ideal' cost of producing a given product or service. But this 'ideal' is based on a given set of non-price product or service attributes, the "Quality" portion of the value equation. There is no 'ideal' set of non-price product attributes, rather these attributes are variables from company to company based on target market segments and product positioning strategy. Differing targeted market segments will have differing desired non-price product attributes. So it seems that the two major elements of value could benefit from different measurement techniques, an absolute approach for "Price" attributes and a relative approach (to the competition) for non-price attributes.

This apparent difference in approaches to value measurement can be partially explained by the focus on a specific product in the *Lean Thinking* approach. The market analysis is complete and many product quality attributes have been established by the time our consideration is down to a specific product. Value maximization in this case is then focused primarily on the non-quality value attributes.

In *Value, It's Measurement, Design and Management*, the authors, M. Larry Shillito and David J. DeMarle, make a strong case that value is a function of time.[9] This is consistent with the *Lean Thinking* inclusion of "at a specific time" in the definition. The timing of when a product reaches market has a strong influence over the perceived value of the product. Based on this assessment, the above model should be modified to include time as a primary factor in the makeup of value as shown in Figure 2.2.

[8] Bradley T. Gale, *Managing Customer Value: Creating Quality and Service That Customers Can See* (New York: The Free Press, 1994), 29.

[9] M. Larry Shillito and David J. DeMarle, *Value: Its Measurement, Design, and Management* (New York: John Wiley & Sons, Inc., 1992), 11-14.

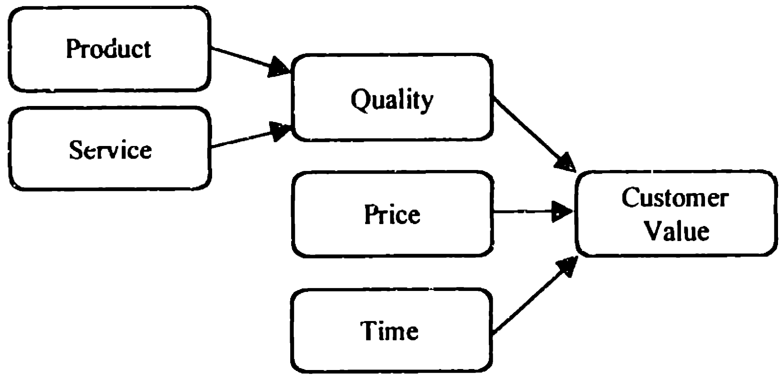

Figure 2.2. Customer Value Relationship With Time Attribute

Additionally, to add clarity to what is meant by price, this attribute should be redefined to be cost of ownership. In this manner, it is put into the customer's perspective and both the acquisition cost and the other factors involved in life cycle costs to the customer can be accounted for. The Support and Retirement costs need to be considered here in addition to the acquisition cost due to the fact that they are significantly driven by decisions made in the product development process.

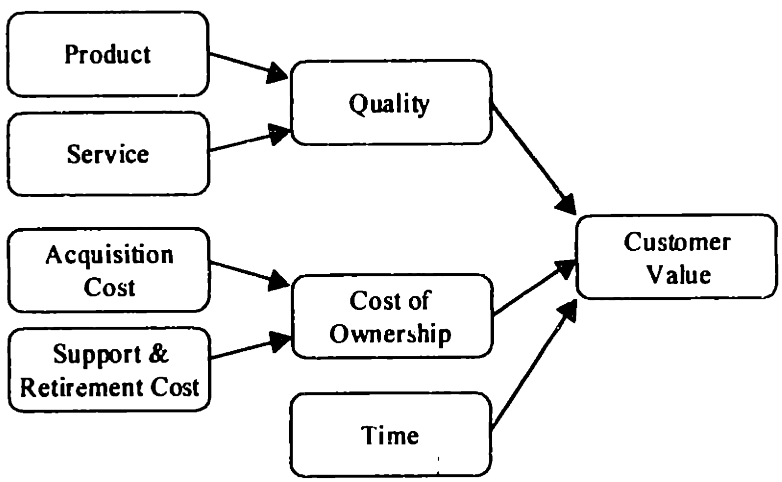

Figure 2.3. Customer Value Relationship With Expanded Cost Attribute

This model appears consistent with the criteria outlined in *Lean Thinking* for expressing value, that is in terms of a specific product, price and time.

Incorporation of the above additional perspectives in the definition of value results in the following:

> **Value is a measurement of the worth of a specific product or service by a customer, and is a function of (1) the product's usefulness in satisfying a customer need, (2) the relative importance of the need being satisfied, (3) the availability of the product relative to when it is needed and (4) the cost of ownership to the customer.**

Shillito and DeMarle also take a more quantitative approach to describing the nature of value from which we can gain additional insight into the relationship between the attributes, which comprise value. Value is defined as being directly proportional to the product of the need for an object (or service) and the ability of this object to satisfy this need, and it is inversely proportional to the cost of the product or service.[10] Note this matches nicely with the word definition derived from the *Oxford English Dictionary*. In mathematical terms:

$$\text{Value} = \frac{N \times A}{C}$$

Where: N = the need for the product or service

A = the ability of the product or service to satisfy the customer need

C = the cost of the product or service

The above formulation is very similar to that used in traditional Value Engineering where value or a value index is defined as the ratio of essential function over cost. Value analysis uses this ratio to assist in identifying lower cost approaches to provide a given function. This formulation is also quantitative in nature and lends itself to comparative assessments along the value stream.

But the above formulation does not capture the time sensitivity of value. Keeping it general at this point, we can generate what amounts to essentially a customer utility function for value as follows:

$$\text{Value} = \frac{N \times A \times f(t)}{C}$$

Where f(t) provides the dependency for the timing of the product or service. Since this time function is likely to depend on many factors and may vary from one case to another, we will not further define it at this juncture.

The above value discussion is generic in nature and still at least one level of abstraction too high for application use in value stream mapping and process improvement. We started with the generic term value, moved on to the term value as it pertains to the product development process, but up to this point we have not dealt with a specific product nor involved a specific customer in this process. A key aspect of lean thinking is to focus on value as defined by the customer for a specific product. The above variables need to be put into specific customer and product terms during the process of mapping. Any lean effort in the product development realm must start with specific understanding of the customer's perspective on value. This lower level of abstraction and detailed application is discussed in a case study starting at Chapter Eight, herein.

[10] M. Larry Shillito and David J. DeMarle, *Value: Its Measurement, Design, and Management*, 9.

This section provides a basis for an understanding of customer value. But this understanding is not complete without considering the existence of other value streams and the potential interactions or linkages between them. These interactions and linkages are discussed in the following section.

Other Value Perspectives

Up to this point, the definition of value has been from the customer perspective. Womack makes a point that ultimately this is the only value that matters. But the fact is, there are other value perspectives, which could influence the success of implementing value stream mapping and lean thinking in the product development organization. Two other perspectives are that of the shareholders and that of the employees. Why consider these other perspectives? In *The Value Enterprise*, John Donnovan, Richard Tully and Brent Wortman propose that management processes should be developed to ensure simultaneous optimization of investor, customer and employee value.[11]

One question which this raises is whether it is suitable to focus only on improvement of Customer Value, with Shareholder Value and Employee Value being a fallout of this process, or whether Customer and overall system value maximization would benefit from a broader focus on all three perspectives. Even if you accept that focusing on a single value dimension is sufficient, there is not consensus in business literature as to where to apply this focus. Although Lean Thinking is clearly customer value focused, there are other researchers, like Peter G. W. Keen author of *The Process Edge*, who believe that shareholder value is the driver of our age.[12]

The more global view would suggest that beyond the customer, the employee and the shareholder dimensions, that there are other stakeholders; suppliers, the community, and the environment for example that also should be considered in the value creation process. John Donnovan et al, suggest that the most successful companies create value for all stakeholders, creating win-win situations where enough value is created for each one to prosper. Unless the primary constituencies receive sufficient value, the enterprise will not prosper, customers will go to competitors, investors will invest elsewhere, and employees will seek employment elsewhere.[13]

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[11] John Donovan, Richard Tully, and Brent Wortman, *The Value Enterprise: Strategies for Building a Value-Based Organization*, with a forward by Barry Hedley (Toronto: McGraw-Hill Ryerson Limited, 1998), xi.

[12] Peter G. W. Keen, *The Process Edge: Creating Value Where It Counts* (Boston: Harvard Business School Press, 1997), xiv.

[13] Donovan, Tully, and Wortman, *The Value Enterprise*, 18.

Robert S. Kaplan and David P. Morgan offer yet another perspective which supports the need to consider multiple value perspectives. In *The Balanced Scorecard,* these authors discuss observations which they have made working with many companies wherein there is recognition that a single measure cannot provide adequate insight into critical business areas. Similar to the concerns which Womack raises relative to the potential for localized process improvement leading to sub-optimization of the entire value stream, *The Balanced Scorecard* warns against single dimension measures due to potential sub-optimization of performance.[14] The authors propose four perspectives for performance measures or goals to provide business strategic direction, two of which align directly with the value perspectives proposed herein:

- financial perspective equates to shareholder value
- customer perspective equates to customer value
- internal perspective
- learning perspective

To evaluate whether the previously defined value linkage model needs modification in light of these additional perspectives, the internal and learning perspectives need to be further defined. Kaplan and Morgan offer the following relative to the internal perspective:

> "Customer-based measures are important [direct measures of customer value], but they must be translated into measures of what the company must do internally to meet its customers' expectations....Managers need to focus on those critical internal operations that enable them to satisfy customer needs....Managers need to decompose overall cycle time, quality, product and cost measures to local levels."[15]

This suggests that the internal perspective dictates measurement of internal process performance along the customer value stream within a business, and that these measures are in direct support of maximizing customer value. Based on these facts, the internal perspective is not an additional value perspective. It is another interpretation of the need to focus on the customer value stream within the business organization and hence is consistent with the *Lean Thinking* approach.

Kaplan and Morgan offer the following relative to the learning perspective:

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[14] Robert S. Kaplan and David P. Norton, "The Balanced Scorecard – Measures That Drive Performance," *Harvard Business Review* (January-February 1992): 71-73.

[15] Ibid., 74-75.

"A company's ability to innovate, improve, and learn ties directly to the company's value. That is, only through the ability to launch new products, create more value for customers, and improve operating efficiencies continually can a company penetrate new markets and increase revenues and margins – in short, grow and thereby increase shareholder value."[16]

This again suggests that the learning perspective is not a unique value perspective, rather it is a perspective for operating improvement measurement and goals, which support increased customer and shareholder value. *The Balanced Scorecard* clearly supports multiple value perspectives, customer and shareholder, although it makes no mention of employee value. And it is complimentary to *Lean Thinking*:

- Both share a customer value focus.
- Both recognize the need to focus on the internal activities which support the generation of customer value (value stream in lean terms).
- Application of lean principles is an improvement strategy which is encouraged by the learning goals in *The Balance Scorecard.*
- Implementation of value stream mapping creates an opportunity to identify the key operating parameters required to generate a balanced scorecard.

The bulk of evidence in recent research supports the multiple perspectives of value. A decomposition of the customer value perspective into value attributes has been proposed to facilitate an understanding of this perspective and to facilitate customer value creating improvement efforts. To create value for the other primary stakeholders, it is necessary to gain an understanding of the unique value attributes of each value perspective, specifically, employee value and shareholder value.

Employee Value

The employee value perspective can be decomposed similar to the method used for customer value decomposition. Donovan, Tully and Wortman offer a similar approach to defining employee value as was used to define customer value. The value an employee takes away from his or her job is a function of both the compensation the employee receives from the company as well as job quality.[17] In this case, job quality consists of all non-compensation based attributes associated with working at the firm. This can be represented as shown in Figure 2.4.

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[16] Kaplan and Norton, *The Balanced Scorecard*, 75.

[17] Donovan, Tully, and Wortman, *The Value Enterprise*, 71-72.

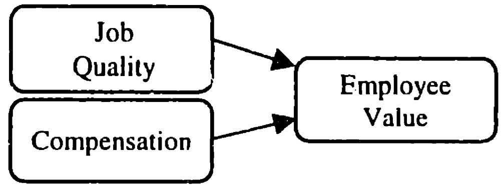

Figure 2.4. Employee Value Relationship

Since job quality and compensation are from the employee's perspective, these are inherently measured relative to what is available elsewhere in the job market. Compensation includes base salary and other compensation based attributes like health care benefits and retirement benefits. Job quality attributes include work/life balance issues, training and skill development, performance management, and growth opportunities. Different employees will have different utility functions associated with job quality, similar to the customer relationship with product quality. By creating value for employees, firms can develop an advantage based on their people and their skills, ultimately leading to competitive advantage in the marketplace.

Shareholder Value

The value of the product development process to the shareholders is the potential for future sales and profits of the realized product. The greater the margin achieved for a given product, the greater the value of that particular program to the company. Contrary to customer and employee value, the shareholder perspective of value is purely an economic concept. The concept of Economic Value Added (EVA) states that a company only creates value for its shareholders when its operating income exceeds the cost of capital employed. Robert C. Higgins in *Analysis for Financial Management* defines EVA as follows:[18]

$$EVA = EBIT * (1 - \text{Tax rate}) - K_w * C$$

Where: EBIT * (1 – Tax rate) is the firms after-tax operating income
K_w is its weighted-average cost of capital
C is the capital employed by the firm (creditors and owners investment)

EVA can be used for investment analysis, including investment opportunities in a firm's processes. These opportunities are evaluated by calculating the present value of the investment's annual EVA. Thus we can evaluate the shareholder value created for a given investment. This is accomplished by calculating the opportunity cost of capital employed, which is equal to the cost of capital times the book value of the investment.

[18] Robert C. Higgins, *Analysis For Financial Management*, 5th ed. (Boston: Irwin/McGraw Hill, 1998), 299.

Subtracting this from the expected EBIT minus tax, results in annual EVA, which is discounted to establish present value.

Linkage of Value Perspectives

A suggested generic model for linking the three primary value streams, customer, employee and shareholder, is shown in the Figure 2.5. In this figure the primary attributes for each value stream are shown; product quality, price and schedule for customer value, job quality and compensation for employee value, and economic value added for shareholder value. Additionally, links between these attributes are shown which provide some insight into the interactions between the value streams.

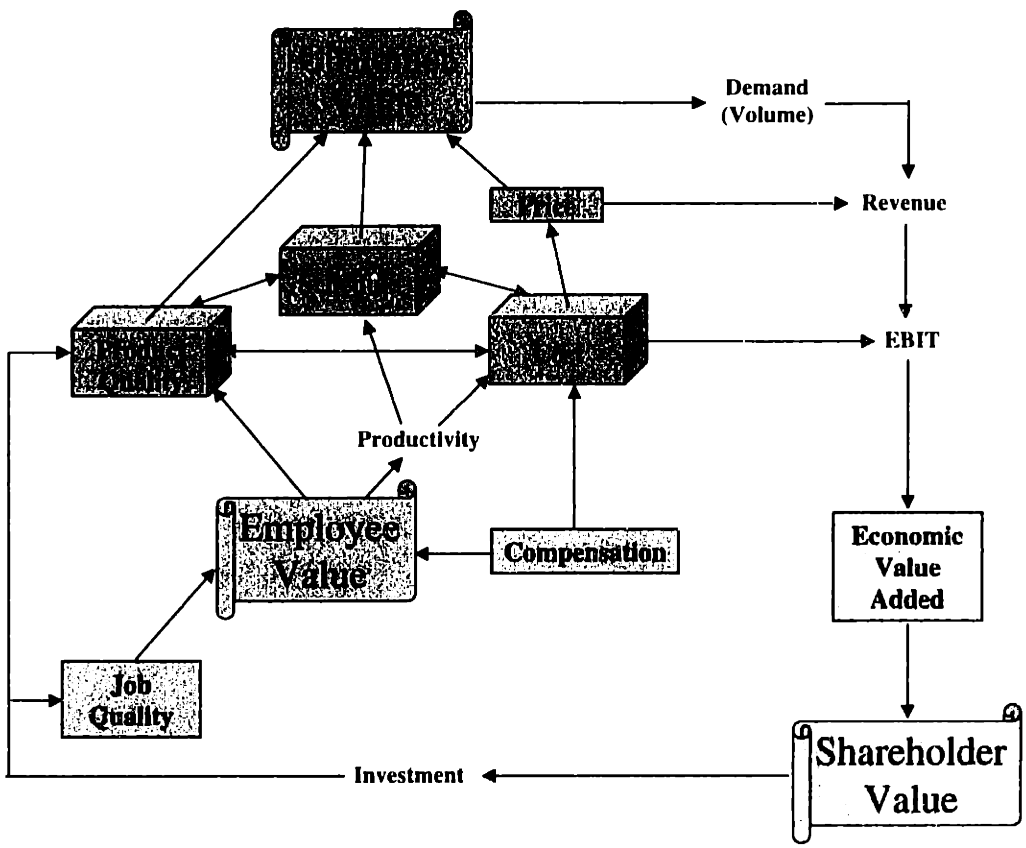

Figure 2.5. Model For Linkage of Multiple Value Perspectives

The link between customer value and shareholder value can be described as follows; increasing customer value relative to the competition will lead to additional demand for the company's product which increases revenue. The increased revenue minus the fixed and variable costs associated with producing the product results in increased earnings before interest and taxes, and finally after interest and taxes and the cost of capital are taking into consideration, the economic value added (EVA) results in an impact on shareholder value. Increased shareholder value stimulates additional investment, both in terms of the company's product offerings as well as in the workforce. Hence the linkage between shareholder value and customer and employee value. The resulting improvements in product and job quality then have a direct bearing on customer and employee value. An additional linkage worthy of discussion is that associated with employee compensation. Increased compensation improves employee value, while increasing costs which has a potentially negative impact on customer and shareholder value. In this case there are several influencing factors, the increased cost associated with higher compensation, and potential improved productivity and product quality associated with the higher employee value. The resulting impact on customer value and shareholder value will depend upon the strength of these interactions.

This model is not meant to be a rigorous model of the overall enterprise. Rather it is meant as an aide to visualize the relationships between the differing value streams and to help bound the nature of this thesis. It is evident that changes in one value stream have impacts on others, and these impacts need to be understood (at least the direction of the impact) to improve overall enterprise value. As we identify lean improvements in the product development process to maximize customer value, a business case analysis is required to verify that the investment required to implement those improvements will provide a positive return for the enterprise enhancing shareholder value. Similarly, an understanding of the impact of these changes on employee value is necessary to ensure the long term viability of the improvements. If employee value is negatively impacted by a process change, it is less likely that the new process will be embraced and followed by the employees and that the anticipated benefits in customer value will be realized. This is particularly true in "white collar" processes like product development where process visibility is not as clear as it is in a manufacturing setting. In the manufacturing environment it is quite evident when workstations are moved and processes are redefined that the work force is working to the new process. In the office environment this visibility is not as clear and employees may revert back to the old ways of doing business if the lean effort does not take into account employee values.

In summary, it is acceptable to work within an uni-dimensional model focusing on customer value as long as the above analysis of employee and shareholder value is accomplished prior to implementation of any change. There is good reason to simplify our model to the customer value dimension. A straightforward, simple approach to customer value stream modeling will facilitate the lean effort being enthusiastically embraced by the lean transition team.

Customer Value Attributes in Product Development

This work is focused on the product development process, the customer value stream and its primary attributes of product quality, schedule and cost. Note that these attributes are often in tension during the product development process, and the resolution of this tension has a direct bearing on customer value.

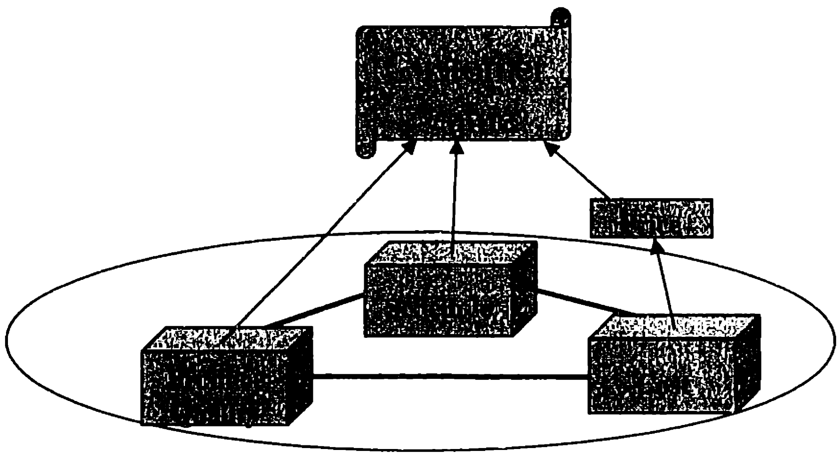

Figure 2.6. Primary Attributes of Customer Value In Product Development

Revisiting the equation for value,

$$\text{Customer Value} = \frac{N \times A \times f(t)}{C} \quad \text{where;}$$

(N), the importance of the need for the product or service. The value of (N) is fully determined by the customer.

(A), the ability of the product or service to satisfy the customer need. The value of (A) is determined by how well the product development process is executed.

f(t) is the availability of the product or service to the customer, relative to the customer need date.

(C), the cost of ownership, is a function of product and service attributes as well as the efficiency of the product development process.

Note that the quantity (N) represents the importance for a given product. In the context of development of complex systems, a given product may have a multitude of needs or requirements with specific individual importance. The above equation therefore could be used to evaluate value for a given requirement or function, or it could be used to evaluate the aggregate value of the product. The generalized aggregate value equation takes on the form:

$$\text{Customer Value} = \frac{\Sigma(N \times A) \times f(t)}{C}$$

Note that (A), the ability of the product to satisfy the customer need, can be viewed in terms of probability. Viewed in this sense, the term (A) would increase as the product progresses through the product development process until verification of the requirement has been accomplished at which point it would be a maximum (1).

A product which has demonstrated by test the ability to meet a requirement has eliminated the risk associated with this requirement and is of greater value to the customer than a product which has an element of risk associated with meeting this same requirement. The ability of the product to satisfy a customer need can be related to risk by the following simple relationship:

$$A = 1 - R$$

Where: A = probability of a specific product meeting a specific customer requirement

R = risk, (the probability of a specific product not meeting a specific customer requirement)

With the above, we can establishe a relationship between our definition of value and risk in the product development process.

$$\text{Customer Value} = \frac{\Sigma[N \times (1 - R)] \times f(t)}{C}$$

The denominator of this equation, (C) cost of ownership, is equivalent to the total life cycle cost of the product in the aerospace product development context. This life cycle cost includes:

- development program costs
- product acquisition costs
- support, operations and retirement costs

This implies that to maximize customer value in the product development domain we must consider all of these costs during development decision-making processes. Although only development program costs are actually expended during the product development process, the costs associated with acquisition, and support, operations and retirement, which may comprise on the order of 90% of the life cycle cost, are committed during the product development process. To maximize value, all of these costs need to be carefully considered during development prior to being locked-in. Understanding the customer's utility function for cost is also required. The customer's total budget picture and budget available versus time may dictate how these costs get traded during the development program decision-making process.

Development program costs need to be controlled within budget limits using appropriate cost management techniques. This is particularly important from a customer's perspective on programs which are cost-plus type reimbursable contracts. Product costs are largely established by the chosen design of the product or system. Value maximization dictates that cost estimating models or tools be used during the design/development process to enable an understanding of impacts on product cost and to ensure that product cost targets are accomplished as the product is transitioned to production. This same discussion applies to support and operations costs. These costs should not be relegated to occasional consideration during design trade studies. Cost estimating models and tools should also be employed for support and operations costs, like they are for product costs, to ensure that product life cycle costs are understood and accomplished.

This total life cycle cost focus is appropriate for both the military and commercial aerospace industry sectors alike. New commercial contracting approaches for jet engine power may actually increase the need for this broad cost focus. Options to buy "power by the hour" exist, where airlines essentially lease engines by the flight hour, while the engine contractor owns and maintains the engines. This ownership and responsibility for support costs will heighten the contractor interest in understanding and controlling these costs when they are committed during the development phase.

The attributes of customer value can be expanded yet further when addressing the (A) term, the probability of a specific product meeting a specific customer requirement, from the numerator in the above equation. This term corresponds to the quality attribute which has been introduced as pertaining to all non-price attributes associated with the product. This attribute can be decomposed into two parts:

- functional and performance properties – what functions does the product provide and what performance is offered for each of these functions
- degree of excellence – the degree of excellence in providing intended function and performance (or its inverse; this could also be discussed in terms of defects – shortfalls in providing intended function and performance)

These sub-attributes apply to both products and services and again are based on customer perceptions. Although this decomposition may be obvious, it is an important distinction given the differing actions required by a firm to provide these two different attributes.

Similarly, the time or schedule function in the numerator of the above equation, f(t), can be decomposed into two elements or attributes in the product development context:

- Product lead time – amount of time from order placement to availability or delivery to the customer.
- Product Development Cycle Time – amount of time from identification of the market need for the product to initial availability or delivery to the customer.

The considerations of this product development discussion are included in the customer value model as shown in Figure 2.7.

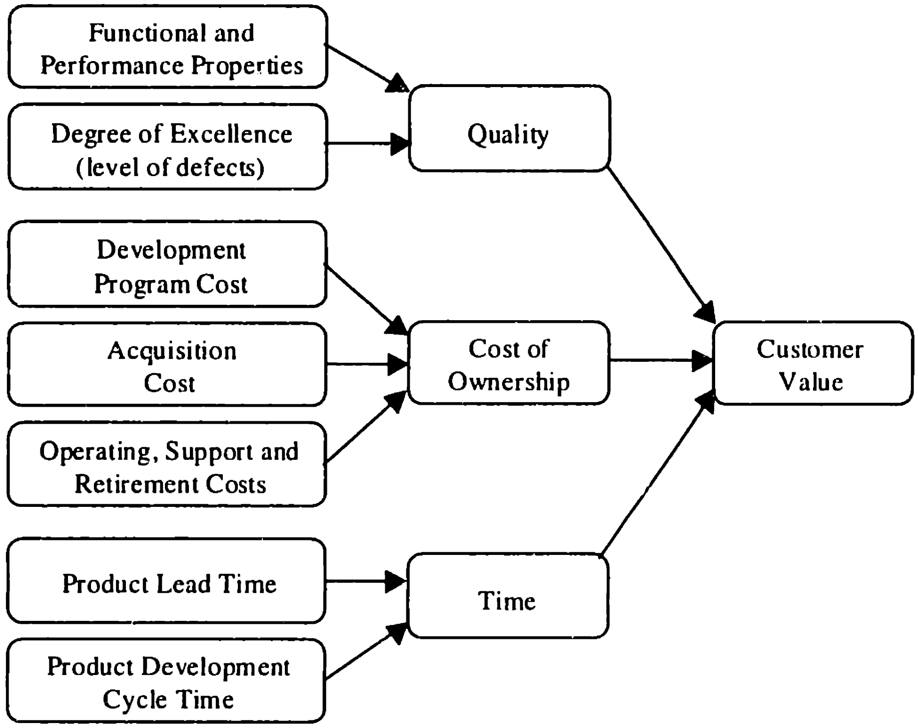

Figure 2.7. Expanded Product Development Customer Value Model

In this chapter the definition of customer value and the attributes of this value are investigated in depth. Value is defined as a measurement of the worth of a specific product or service by a customer, and is a function of the product's usefulness in satisfying a customer need, the relative importance of the need being satisfied, the availability of the product relative to when it is needed and the cost of ownership to the customer. The existence of other value perspectives, specifically employee and shareholder value, along with unique attributes and linkages with customer value, is also proposed. These linkages suggest that all three primary value perspectives need to be considered in the pursuit of the lean product development organization. Finally, specific attributes of customer value in the product development setting are discussed. These attributes involve the classic tension between performance, cost and schedule, and a link between value and risk is proposed. These attributes help in identifying the product development value stream which is the next lean principle discussed in the following chapter.

CHAPTER THREE

The Value Stream Principle

Lean Thinking defines value stream, the second lean principle, as the set of all specific actions required to bring a specific product through the critical management tasks of any business.[19] Again, the important distinction here compared to other process perspectives is that value stream is focused on a singular or specific product as opposed to an aggregate process focus or an organizational focus.

Similar to the approach used above in defining value, other resources and contexts can provide insight into what value stream is in the product development process. Although this search for the definition of the "stream" part of the value stream was somewhat less fruitful, reaching back into the *Oxford English Dictionary* and wading through the various references to bodies of water, one can come up with the following:

> "5a. An uninterrupted succession of persons, animals, or things, moving constantly in the same direction."[20]

The key phrases in this definition for this study are "uninterrupted succession", "moving constantly" and "the same direction". These statements are at the core of lean thinking and tie directly to the next lean principle, namely "Flow".

Putting selected portions of the above individual definitions of value and stream together, the following definition is proposed for further use in this study:

> **Value Stream - The uninterrupted succession of product development activities along which there is continuous addition of product attributes including quality, functionality and usefulness, which directly address customer needs.**

Categorization of Value Stream Activities

Note that prior to the lean transition, not all steps in a firm's value stream for a particular product may be value creating. Womack and Jones in *Lean Thinking* have established categories for process steps based on their value creating potential. Process categories are; actions which create value for the customer, actions which do not create any value for the customer but are required for some other reason (Type One muda), and finally actions

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[19] Womack and Jones, *Lean Thinking*, 19.

[20] *Oxford English Dictionary*, s.v. "stream".

which do not create any value for the customer and can be eliminated (Type Two muda).[21] It is proposed that there is a fourth category of actions which may exist in a firm's value stream, and these actions are those which not only do not create any value for the customer, but they actually reduce customer value. This can occur in process steps where customer value is not fully understood and good intentions of adding value actually have the opposite effect.

Value Stream – Value – Product Relationship

Figure 3.1 is a generalization of the value stream associated with a given product and its relationship with the previously defined principle of value. The value stream is the succession of activities, or processes, or steps which a firm utilizes to generate value in a given product. The value generated can take the form of any of the attributes discussed in Chapter Two, including added functionality or reduced risk or uncertainty. Shown is the overall enterprise value stream, the specific focus of this thesis being the product development portion.

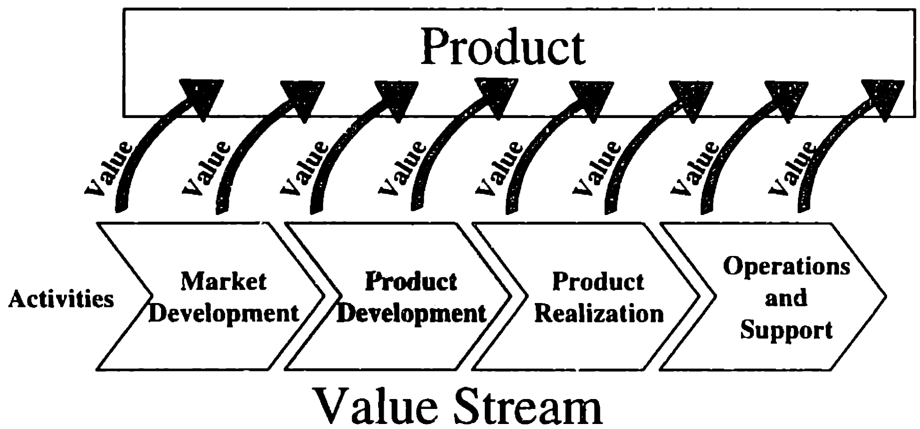

Figure 3.1. Value Stream – Value – Product Relationship

Understanding the product development value stream and the action category for each process step is necessary to enable elimination of waste and achievement of a lean product development organization. An example of one area of the product development value stream of particular interest is the test process. How should testing be treated relative to the product development value stream? One may consider testing to be just a form of inspection, and therefore muda, since it's purpose is to verify or inspect for conformance to requirements. But in the context of our definition of value, which includes the risk of meeting functionality, testing serves the purpose of reducing risk and boosting customer confidence in the product. This perspective suggests that testing is actually a value creating activity. This idea of testing being value creating in the product development process is particularly applicable to the aerospace industry and the military aerospace sector in particular. Aircraft engine

[21] Womack and Jones, *Lean Thinking*, 38.

companies could not sell engines to commercial or military airlines if testing had not been conducted to verify that they can be flown safely.

In this chapter, the definition of value stream, the second lean principle, was introduced. The value stream is considered to be the uninterrupted succession of product development activities along which there is continuous addition of product attributes including quality, functionality and usefulness, which directly address customer needs. These value stream activities can be categorized based on their customer value contribution to the product. The relationship between value and value stream was defined. The value stream activities are what the enterprise uses to infuse the intended customer value into the product. With this understanding of value stream, the next lean principle called flow can be introduced. This principle applies to the movement of the product through the value stream.

CHAPTER FOUR

The Flow Principle

The third lean principle is flow. Again using *Lean Thinking* as a guide in interpreting the meaning of flow; flow is defined as the lining up of all the necessary sequence of activities required to achieve a steady continuous job flow, without interruption, wasted steps, batches or queues.[22] In order to be successful in getting work to flow, you have to fully understand the value stream associated with the work flow. If the value stream is not understood, then the link to customer value has been lost and process changes made may not in fact provide the overall desired improvements. Focusing on the actual work object(s) and the value associated with them, the objects are made to flow without waste from the very beginning of the process to the very end of the process without regard to boundaries or barriers. The objective of flow is to focus on the specific product and to make it flow throughout the enterprise by revising work processes and tools to eliminate waste. The concept of flow is generalized in Figure 4.1 below.

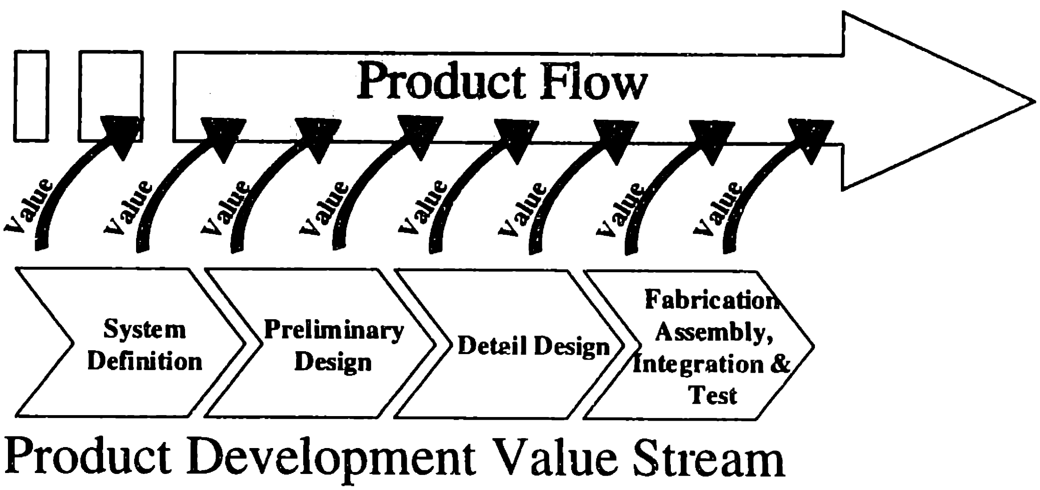

Figure 4.1. Concept Of Flow In Product Development

Information Flow

To get an understanding of flow in the product development setting, we now need to wrestle with what the "product flow" is. In the manufacturing environment we can equate the product flow to physical material flow. In the product development process, in addition to some physical material flow (physical mock-ups, prototypes, development hardware), the product which is flowing will for the most part involve information flows. If we accept that the primary product flow in the product development process is in the form of information, then it is

[22] Womack and Jones, *Lean Thinking*, 52.

appropriate to consider the types of information which exists in these processes. Information in the product development process can be categorized into several different areas based on the purpose of the information. Four categories are proposed; product information, project information, process information and business information.

Product Information – This is the information directly related to the ultimate product that will be realized upon completion of the product development process. Product information includes transformation of customer requirements to parts requirements and transformation of parts requirements to design parameters. This is the information required to create the physical product and manage the technical effort associated with the product.

Project Information – This is the information directly related to the management of the project or program. Project information includes project related resource planning information, cost management information and schedule management information.

Process Information – This is the information that defines how the product development process is to be executed. Process information provides direction to employees on how to accomplish their job functions. It includes the set of procedures which satisfy ISO9000 requirements for work processes to be documented.

Business Information – This is the information related to the business processes of marketing, sales and finance. Business information includes general ledger, accounts receivable, accounts payable, revenue accounts, inventory, purchasing, orders and sales.

Information is the 'product flow' or work object which is to be made to flow through an uninterrupted product development value stream. In implementing lean principles in the product development process, all four types of information exist in the value stream, with product information being the core flow of interest in this work. Project information also plays a significant role given the sensitivity of customer value on cost, schedule and risk. Although process information may play a role, updating of standard work for instance as part of lessons learned, it is deemed secondary in nature for this thesis. As we implement lean principles into product and project information flows, process information will have to be updated to document and capture these process improvements. And finally, although there are direct interfaces between the product development process and business information, the primary focus of this thesis is on engineering processes and therefore the information flow of primary interest are the product and project information flows.

Other Flow Views

While contemplating just what is information flow in the product development process, it is appropriate to consider traditional views of the product development process and consider how value, and information flow, might relate in these contexts. One such approach is to look at value and information flow within the Quality Function Deployment (QFD) or House of Quality framework. Within this framework, it is quite easy to visualize the value creating activities of transforming customer requirements into design requirements and then transforming these design requirements into part characteristics. Continuing though the form stages of this process are the value adding steps of translating part characteristics into process operations and finally translating process operations into production requirements. This framework assists in visualizing the core product development information flow, starting with customer requirements and undergoing multiple translations or transformations into information which can be used to produce the product. This core information flow is the customer needs flow, the flow associated with the core 'Quality" attributes of customer value. This process is depicted in Figure 4.2.

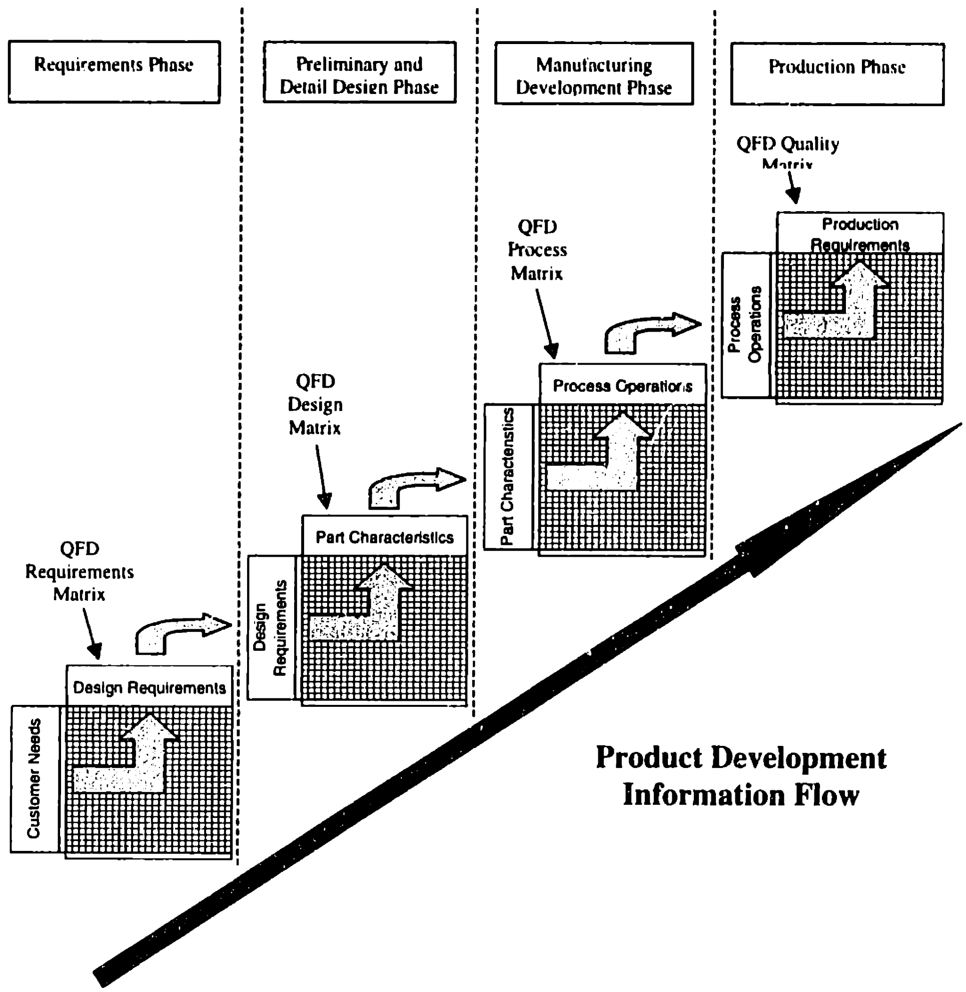

Figure 4.2. Quality Function Deployment Information Flow Framework

Other frameworks offer similar visions, albeit not quite as encompassing as QFD. The Systems Architecting process of mapping functional requirements onto physical chunks provides another glimpse of the product development information flow. Information is transformed in this process from requirement information into physical description information. This mapping process of alternating between the functional requirement domain and the physical part domain is creating customer value by building in functionality tied to customer requirements at all levels of the system architecture, the systems level, the subsystem level and the part level.

These frameworks turn out to represent idealized segments of the product development process. They represent the "what" domain; what is it that we need to accomplish in the development process. It is quite easy to envision the information flow from this perspective. But what is missing in the above frameworks is the "how"; how do we accomplish these tasks. The frameworks do not reveal the underlying activities undertaken by the product development team that are required to execute the information transformation. It is these underlying processes, the value stream of activities, which require analysis for waste elimination to make the information flow and achieve the lean transition.

Muda in Product Development

To further develop the application of the flow principle to the product development process, it is helpful once again to look at the manufacturing analogy. The approach used to evaluate muda and flow in the product development arena was to first investigate the applicability of manufacturing muda types to product development. The investigation attempts to answer the questions, "do these type muda exist in the product development process?" and "are there any unique types of muda existent in product development which do not show up on our list of manufacturing types?" Secondly, a review was conducted to determine the appropriateness and viability of using manufacturing lean flow techniques to mitigate these wastes in the product development environment.

Other researchers and practitioners have established a recognized 'set' of waste categories or muda which occur in manufacturing activities. The identification of these wastes is mostly attributed to Taiichi Ohno's work at Toyota. Additionally, Womack in *Lean Thinking* proposes a couple of others. There is also a generally recognized set of tools which have been applied to the manufacturing environment to eliminate these wastes and make the product flow. To support the investigation into how the flow principle can be applied to product development, a survey of product development engineers was conducted at P&W to gather examples of waste or muda in the product development environment. This data was then compared to the manufacturing waste categories to help establish whether there are any similarities between the two environments.

Muda Survey Design

A total of 41 survey requests were distributed to project development engineers within one product development firm (P&W). The survey requested:

> **"a short specific example of what you consider to be waste in the product development process"**

Upon receipt, the wastes identified in the responses were reviewed to determine if they fit into the definition of any of the previously mentioned manufacturing waste categories. These categories are discussed in detail in Lean Thinking:[23]

- wait time muda
- transport muda
- inventory muda
- defects/scrap muda
- overproduction muda
- over-processing muda
- movement muda
- complexity muda
- time lag muda

Muda Survey Results and Analysis

A total of 25 responses with product development waste examples were received. The definition of the above wastes and example responses that were deemed to fit into each category are tabulated in the following section. A summary of the survey response data versus waste category is shown in Figure 4.3. As can be seen from the graph, wait time and over-processing muda were the most often cited wastes in the survey. The high count for wait time muda relative to the other waste types may be explained by the rather generic nature of this waste category. Wait time muda is the difference between the total processing time and the time necessary to complete the value creating activities. Therefore, any process which has non-value added steps theoretically could fit within this waste category. Wait time muda becomes rather a catchall for wastes that do not fit into the other categories. The relative high count for over-processing muda in product development is also not unexpected. Over-processing muda is the waste associated with extra processing that is required due to poor tool or product design. The examples received fit into the category of wastes driven by poor tool design. The examples indicate

[23] Womack and Jones, *Lean Thinking*, 60, 309-310.

that the product development process would benefit from better process tools, i.e., requirement definition tools, analytical modeling tools, etc.

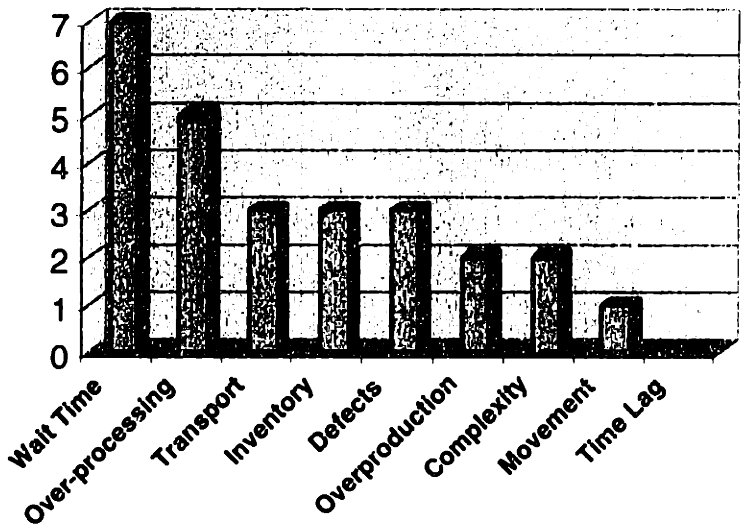

Figure 4.3. Product Development Muda Survey Results Bar Graph

In general, it was relatively easy to fit the survey responses into the waste categories of the manufacturing setting. One of the more interesting examples where the categorization into a waste category was not obvious dealt with requirement iteration. In product development, particularly with complex systems, requirement iteration is the norm as opposed to the exception. If this iteration continues to later phases of the development process, significant rework can result. This example was categorized as defect/scrap muda since the contractor did not have the requirement definition correct. The real customer requirements were not flushed out during the requirements definition phase of the program and therefore the 'product' is deemed defective.

Note that there is a fair amount of judgement in this process of categorization. The fact that all of the survey responses could be categorized within the bounds of the manufacturing classifications does not necessarily support the supposition that these classes of wastes are all encompassing. Not only was the categorization process subjective, but the survey consisted of a rather small sample size and responses were limited to a single firm. Additionally, the fact that no responses were fit into the time lag muda category does not suggest that this type of muda does not exist in the product development environment. Time lag muda is associated with quality problems that go unnoticed due to time lags between process steps. In the product development environment, an example of this is the detection during verification testing that a component does not meet requirements. Any hardware which had been manufactured prior to this detection all suffer from this requirement shortcoming, and in some situations may require retrofit of corrective action. The costs associated with the delay in detection in this case could be classified as time lag muda. This example also shows a close relationship between time lag muda and defect muda. Time lag muda therefore does exist in product development even though no survey responses fit in this category.

Linkage Between Muda and Value

To assist in investigating the question whether the classes of manufacturing wastes are all encompassing for the product development setting, the linkage between these wastes and customer value is explored. The table in Figure 4.4 maps the three primary attributes of value (quality, cost and time) developed in Chapter Two to the waste classes.

Value Attributes \ Waste Categories	Wait Time	Transport	Inventory	Defects	Overproduction	Over-processing	Movement	Complexity	Time Lag
Quality				X					
Cost	X	X	X	X	X	X	X	X	X
Time	X	X		X		X	X		X

Figure 4.4. Linkage Between Muda And Value Attributes

This table attempts to show the specific customer value attribute which is enhanced when waste or muda in a given category is eliminated. Note that all three value attributes are addressed by these waste categories. All waste classes appear to drive the cost attribute. Even if the primary linkage of a waste category is to the quality or time attributes, these wastes in many cases ultimately end up also driving the cost attribute. The time attribute, the availability of the product relative to when it is needed, has a very similar meaning in the manufacturing and product development contexts. One would expect the types of wastes associated with time delays in product lead time (manufacturing) are very similar or the same as the types of wastes which cause time delays in product development cycle time. But there are distinct differences in the sub-attributes of quality and cost between the manufacturing and product development value models. These differences are significant enough that the manufacturing waste categories may not adequately address wastes in the product development process. The quality attribute was selected to illustrate this point.

Recall that the quality attribute of customer value comprises all non-price attributes associated with the product. In the manufacturing setting, the primary sub-attribute of quality is conformance to requirements (or "degree of excellence" as discussed in Chapter Two). That is, the primary driver in the quality attribute of value is the traditional definition of quality. How well does a firm deliver on its promises? But in product development, the quality attribute of customer value takes on a broader meaning. The manufacturing process can only impact whether the product is delivered defect free. The product development process not only impacts whether the product is delivered defect free, but it also establishes what quality attributes are going to be provided in the first place, in terms of functionality, performance, etc. Therefore, one would expect there to be "wastes" associated with this product development unique branch of the customer value attribute tree. Figure 4.5 displays this discussion pictorially.

This argument suggests that there may be unique wastes associated with this sub-attribute of quality, which do not exist in manufacturing. The survey results do not support this, but the results may be biased by what is traditionally considered to be waste. It is easy for engineers to envision waste associated with cost and time. "Waste" associated with not fulfilling the optimum set of customer needs does not fit the term waste in the traditional sense. But it is waste in terms of lost customer value. This suggests that there is at least one muda category which needs to be added to the manufacturing set of wastes already defined for use in the product development lean transition process.

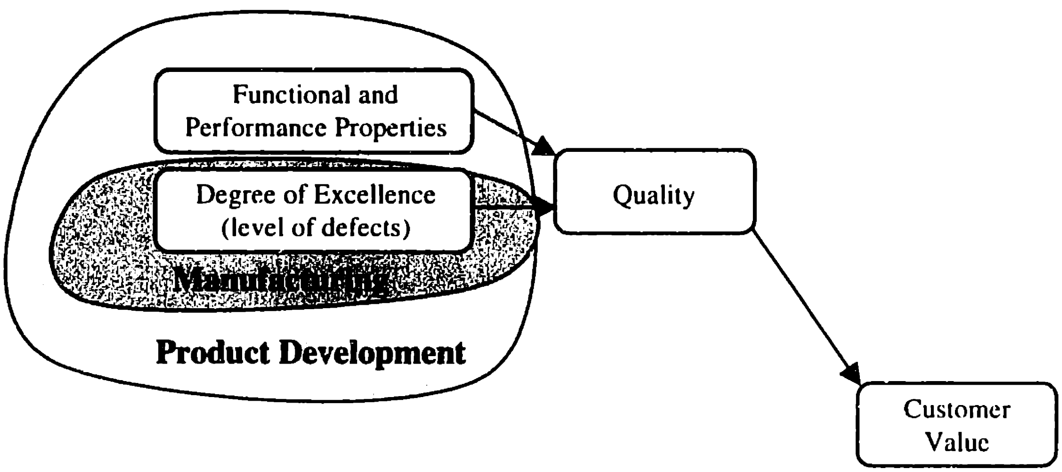

Figure 4.5. Quality Attribute Differences Between Manufacturing And Product Development

Waste Description and Product Development Examples

The following table includes survey response examples for each of the manufacturing muda categories. The waste descriptions as described in *Lean Thinking* are shown in the left-hand column of this table.[24] The product development muda examples from the survey are in the right hand column.

Waste Description	Product Development Examples
Wait time muda	
Wait time muda is the difference between the total processing time and the time required for just the	This type of muda clearly occurs in the product development environment just like it does in the

[24] Womack and Jones, *Lean Thinking*, 60, 309-310.

Waste Description	Product Development Examples
value creating activities. The value stream can be considered to be non-flowing during this wait time. Set-up time on a machining center is an example of wait time muda.	manufacturing setting. An example includes inspection stamp requirements on qualification hardware process steps. Engineers document actions taken on the hardware, but hardware is held pending stamp off by inspectors who in most cases have no cognizance of the value added action taken. This inspection requirement adds processing time to the hardware. Another example is the requirement for multiple levels of management to sign-off supplier invoices to be paid. An analyst makes a determination if the invoice should be paid or not and then multiple signatures are required prior to authorization for the invoice to be paid. In fact, management signatures on engineering change documents was a third wait time muda example and the second associated with multiple authorizing signatures. Taking information as it is generated in the process and reformatting just to conform to someone's 'standard' format (i.e. test plans) is another example of non-value adding activity driving wait time muda. Another example associated with format is when Engineering defines the requirements for a purchase order and then these same requirements go to Purchasing and get rewritten. This is duplication of effort (wait time muda) and often creates errors (defect muda). Another example of duplication of effort is when a contractor conducts testing on a component part which has already undergone by the supplier of that component. The supplier's test quite often can be designed to capture the component data the contractor needs during his testing, saving the extra test processing.
Transport muda	
Transport muda is associated with the time the product is in transport. The time in transport is time where no physical transformation is taking place. Transport is time over which no value is added to the product. Another measure of transport muda is the number of times the product is picked up and put down. Again, these actions do not create value in the product.	This type of muda clearly happens in the product development environment just like it does in manufacturing. Although reductions in transport muda are evident with the now widespread use of fax machines, e-mail, and shared servers, transport of information still remains a source of muda in product development. But this same technology introduces another example of wait time muda and that is the incompatibility of differing platforms and software. Incompatibilities drive rework in terms of driving the need to have the information reformatted and/or resent. Another example of transport muda occurs when a jet engine test stand becomes unclassified and the entire classified control system has to be moved back to a lab located five miles away. This process takes at least two people most of one day. This muda was eliminated by using a local classified storage room that is about 150 yards from the test stand. This way the equipment could be moved by the controls technicians without the

Waste Description	Product Development Examples
	involvement of a transportation organization which saves time. A third example of transport muda is associated with the process of getting classified software from a contractor to a remote testing location. In the current process, the code goes through two language conversions, two media conversions and is processed in three separate labs. This example has elements of transport muda and over-processing muda. The suggested improvement involves a secure link between the contractor and the test site, allowing the remote site to "pull" the required files when needed.
Inventory muda	
Inventory muda is the waste of carrying finished or unfinished product in queues within the process, between process steps, or actually in inventory at the end of processing. These inventories are enterprise assets and consume valuable resources that could be used for other value generating activities.	We see queues in the product development process just like we do in the manufacturing environment. One example is where queues of information stack up in functional organizations, where functional expertise is chimneyed, and multiple programs compete for priority to accomplish specific tasks. We therefore face similar issues of capacity versus queue size. In fact, due to the inherent variability in the product development process, management or elimination of queues may be more difficult than in the manufacturing arena. Another source of inventory muda is associated with product development processes that have significant gates associated with program milestones. These gates can be compared to a batch or lot in manufacturing terms, leading to the build up of development program information (a queue) which is held until all requirements associated with the gate have been met. Since queues exist, one can surmise that the product development process is prone to the associated wait time muda and time lag muda, just like the manufacturing environment. There has been an enormous growth in computing systems with a correspondingly enormous growth in electronic file traffic, size and storage which consumes valuable disc space. There has been no effort to manage and conserve file/disc storage space.
Defects/scrap muda	
Defect muda is the waste associated with dispositioning non-conforming material. It is the waste associated with the loss of product due to quality problems or the rework of the product to correct a quality problem. This muda is quite well understood and is the focus of other enterprise process improvement efforts including Six Sigma and ACE, Achieving Corporate Excellence.	A classic example of this type of muda in product development is engineering escapes or defects. Engineering escapes occur when requirements are overlooked or not considered, appropriate analyses are not conducted or system interfaces are not adequately considered. Escapes also occur when standard processes are not followed or lessons learned are not captured. Finally, an additional category of engineering escapes can occur, these are validation escapes. Validation escapes are those escapes that were not detected during

Waste Description	Product Development Examples
	validation testing and escaped into the customer's hands. Engineering escapes drive rework (pure muda) similar to fabrication errors during part manufacturing. Just like manufacturing, the later the error is detected in the process, the greater the muda. Short term budget planning constrains the creation of reusable modeling components. Reusable model components take substantially more time to create and test but can be reused over during the life of the program with reduced maintenance costs. They also can be used or adapted for use on other programs. Currently models are created and used for the program goals/crisis at hand and then scraped.
Overproduction muda	
Overproduction muda is the waste associated with producing too much of a product. Overproduction muda is tied to the concept of push where upstream processes flow a quantity of product regardless of what the downstream process needs are. Overproduction muda is closely related to inventory muda since overproduction typically results in increased inventories.	One example of overproduction muda is the widespread dissemination of information via e-mail to recipients who are not directly on the related value stream. This results in a significant time 'sink', where copious amounts of time are spent sorting through and reading unnecessary messages. This can result in information overload. When this occurs, messages are left unread or discarded, leading to the potential for missing necessary information. Receiving hardware for non-production programs on the scheduled delivery dates after the program has slipped results is overproduction muda. In a development program problems typically arise with the design and if hardware is delivered before it is actually needed, then it has to be returned to the supplier for retrofit. This returning of hardware wastes a lot of time and requires additional processing.
Over-processing muda	
This is waste associated with the extra processing steps which are required due to poor tool or product design. Poor tool selection can result in greater processing time than would be required with the proper tool for the job. Similarly, a design which has not had the benefit of design for manufacturing expertise also results in manufacturing run times which are not optimum for the required part feature.	Retaining legacy requirements while writing product requirement specifications can be a source of over-processing muda. There often is a tendency when writing requirements documents to start with what you have done in the past. This process can lead to the carrying-over of requirements that are not required by the customer or by lessons learned. This can be considered a form of overproduction that unnecessarily drives product design or engineering effort. The current process to create a real time Control System bench model is to first convert *existing* component and system models used for control system design and analysis *from* MatrixX (a GUI modeling tool) *to* FORTRAN (this step is very labor intensive), and then to convert the FORTRAN to C code suitable for running on real time benches (this step is somewhat labor intensive). A tool exists that allows automatic conversion directly from original MatrixX model to real

Waste Description	Product Development Examples
	time C code. This situation exists due to different tool choices between different departments. A third waste is associated with "re-inventing the wheel". This occurs when trade study results or analysis results from previous programs are not well documented such that the information can be used on future programs. This lack of information capture can lead to doing the same work twice.
Movement muda	
Movement muda is the unnecessary movement of employees (not product as in transport muda) that is required during the course of work. Examples of wasted motion include movement required for looking for parts, tools and drawings.	A good example of movement muda in product development is associated with the remote location of engineering laboratories. At P&W, component assembly and test areas are located miles away from the engineering office building. This remoteness has two muda effects. On is the direct loss of the time required to travel to and from the remote location. The other indirect effect is that the remoteness acts as a barrier and causes personnel not to make the trip when they would have otherwise if it were close coupled to their work location. This represents lost opportunity for value added activity.
Complexity muda	
This muda is associated with unnecessary complexity in production support hardware and machinery. Complexity muda often takes the form of excessive cost for maintaining complex support equipment which have capabilities which are greater than that required to achieve continuous work flow.	An example of complexity muda is the use of an antiquated mainframe software system for cost reporting activities. The system is complex, slow, labor intensive and frustrating to use when compared to personal computer based software systems and adds non-value adding processing time and being mainframe based requires significant support activities. This could just as easily been categorized as over-processing muda (muda due to poor tool design). Another example of complexity muda is the in-house fabrication of complex test stands. In many cases outside test labs have similar facilities which can be used instead of having dedicated in-house stands with low utilization rates.
Time lag muda	
Time lag muda is associated with quality problems that go unnoticed due to long time lags between process steps. The additional costs associated with not discovering the quality issue immediately are time lag muda. This muda also is closely related to inventory muda. Inventory stacked up between process steps can delay detection of these potential defects, allowing additional parts to be flowing through the suspect process generating additional suspect parts and muda.	Although no survey examples fit this category, the product development process is probably more susceptible to this type of muda than the typical manufacturing process just due to the inherent length of the product development process, in particular, that employed in the defense aerospace industry. Many problems can go unnoticed until verification testing in the latter part of the process. Recent focus on improved analytical tools at P&W is directed at pulling up the detection of design related quality problems, and thus is directed squarely at this muda. Enhanced analytical tools enable better understanding of complex system interactions during the design process and offer

Waste Description	Product Development Examples
	detection and prevention well in advance of verification test activities.

Application of Flow Techniques

The previous section established that many of the wastes found in the product development process fall into same categories as wastes found in the manufacturing setting. Based on this similarity, it is appropriate to investigate the set of lean techniques that have been developed by the manufacturing industry over the years to combat these wastes for their applicability to product development. The following table identifies some of the key concepts or techniques in use for generating flow in the manufacturing environment and offers comments on specific applicability of each to product development. The manufacturing flow techniques listed in this table are as described in *Lean Thinking*.[25]

Manufacturing Flow Technique	Product Development Context
Systems Capability	
The team must include core members all along the value stream who understand the capabilities of the system such that the product can be made to flow smoothly from start to finish. The key point here is the systems understanding of the team members facilitates keeping the product flowing through all process steps. Knowledge of just a few process steps does not enable one to grasp the concepts necessary to keep the product flowing across process steps and process boundaries.	This concept is close to that of concurrent engineering and the subsequent integrated product team approach to product development. This approach to product development brings a core team together for the duration of a project involving multiple disciplines to bring whole value stream perspective to the process. Probably the most leveraged example of this is detailed involvement of manufacturing engineers early in the design process. But the integrated product team approach is not sufficient to address all systems issues and having systems engineers who have both product and development process knowledge of the entire value stream is required to successfully execute a product development program.
Takt Time	
The concept of takt time is a technique used to pace the rate of production to the rate of sales to customers. Synchronization of the rate of production to the rate of sales eliminates inventory muda and overproduction muda (as well as underproduction muda).	It is not obvious how takt time can be used in product development. At a high level perspective, takt time could be considered the length of the new product development process. For the jet engine business, this would be the time from product launch to flight certification. But takt time is used for operational control in manufacturing and no direct corollary was identified for product development.
Visual Control	
Visual control is used to ensure team members are aware and understand the status of the operation and product flow. This visualization facilitates operating to takt time and allows immediate adjustment if required to meet changes in customer demand.	This technique has been found to be an effective approach to aligning teams and whole organizations towards meeting shared goals. This technique can be and is applied in product development. One example is the use of the "war room" approach where information

[25] Womack and Jones, *Lean Thinking*, 55-61.

Manufacturing Flow Technique	Product Development Context
	key to the progress of a project is posted continuously in a location where all team members can see it in the normal course of carrying out their work. Information such as program development schedules, top issues status, and program strengths and weaknesses are posted. Use does not necessarily facilitate operating at takt time, but it does facilitate adjustments in direction to meet changing program requirements.
Just-in-Time	
Just-in-Time (JIT) is a manufacturing control system used for moving material through the manufacturing setting that requires a minimum of inventory. JIT features small work-in-process inventories and typically a kanban information flow system which provides an efficient means of tracking parts. JIT is effective at reducing in process inventory muda and time lag muda.	Just-in-Time and the related Pull Principle are discussed in detail in Chapter Five herein. Like takt time, the applicability of this flow technique to product development has not been established.
Level Scheduling	
Level Scheduling is used as a method to create and smooth daily schedules. Typically a months production requirement is divided by the number of workdays to establish daily production requirements, thus smoothing the flow. Because JIT can be unsatisfactory in an environment of changing production demand, level scheduling facilitates implementation of Just-in-Time by making the flow requirements more predictable.	There are methods to level schedule in the product development environment, but it is probably used less here due to the fact that it is easier to adjust capacity (move/add people) than it is to do so in the manufacturing environment where adding capacity also involves machinery, facilities, etc.
Physical Proximity	
Production steps are arranged in close physical proximity and in sequence to eliminate transport muda. Often these arrangements are called cells. Cells are typically arranged to minimize employee movement as well, thus also addressing movement muda. At a higher level, supplier's facilities are located in close proximity to their customers, allowing closer integration of process functions and waste elimination.	Commonly referred to as co-location, physically locating product development teams in close proximity is often used to facilitate team communicatio and cohesiveness. Co-location helps break organizational barriers as well as barriers between suppliers and contractors. Co-location facilitates integration of highly complex information flows.
Single Piece Flow	
A process is set up to flow from one step to the next with no (zero) inventory buffers between steps. This is often called single piece flow which eliminates batch and queue processing and eliminates the associated inventory muda. Single piece flow also reduces time lag muda. Quality problems can be identified and corrected on a single piece basis as opposed to discovering a quality problem on a whole lot of parts.	Like takt time and Just-in-Time, the applicability of the single piece flow technique to product development is questionable. Product development is not repetitive in the same sense as manufacturing. A potential product development corollary is single program flow. If a product development organization has multiple product development programs in progress at the same time, competition for resources between programs could lead to delays in the information flow resulting in inventory muda and wait time muda. Dedicated single program teams could be used to eliminate this type of waste.
Capable Processes	
Implementation of fully capable processes, process equipment and employees. Process capability	This is a given for all business processes. In the manufacturing environment, processes are inherently

Manufacturing Flow Technique	Product Development Context
eliminates variability driven defects and scrap muda. Capability is verified through certification processes of both process/equipment and employees.	repetitive, so statistical data can be gathered and analyzed to verify and monitor process capability. Process equipment in the product development process can be thought of as the analytical tools used to develop product designs. Because the product development process is non-repetitive in nature, identification of metrics and confirmation of the capability of these tools is more difficult, but the same level of attention should be demanded. Capability of employees is typically addressed through appropriate training programs. In the manufacturing environment, formal programs like Certified Operators are used to ensure employee capability is in place. Application of employee training programs is just as important in the product development process as it is in the manufacturing environment. Although many companies offer formal training classes associated with product development, these same companies typically heavily rely on on-the-job training for new employees and employees changing jobs, and don't have formal certification type programs in place. This potentially opens the process up to variability.
Standard Work	
Standardized work processes are established. Standardized processes go hand-in-hand with fully capable processes to reduce variability driven defects muda. Standardized work processes provide the basis for process documentation and the capturing of lessons learned.	Standard Work is used in product development for the same purposes as it is used in manufacturing. Standard Work in product development may involve the definition of specific tools to be used, definition of specific product attributes, or even specific verification approaches.
Cross Training	
Cross-skilled team members are used to ensure flexibility in task assignments. This flexibility is used to address shortfalls in resources along the process path which may arise due to any number of causes. Cross training allows resources to be shifted along the flow eliminating the potential wait time muda which may result from a resource problem thus ensuring continuous flow is maintained.	Cross-skilled team members ensure flexibility in meeting localized demand variations by reassignment of personnel. Two perspectives of product development come to mind when discussing cross-skilled team members. One is that product development is typically executed by a cadre of project engineers who are sort of the jack-of-all-trades, having a wide breadth of capabilities. This flexibility is therefore inherent to a degree already in product development. The second is that much focus has been placed recently on the creation of 'generalists'. Creation of the 'generalists' provides this flexibility as well as expanding employee's perspective allowing a better understanding of the impacts of decisions being made. But this focus has also raised concerns within the community relative to the erosion of specific expertise, that the capability in terms of breadth was negatively impacting capability depth. An example is the use of design engineers who are able to accomplish structural analyses requirements in addition to actual design work. This use eliminates the need to pass the work off to a dedicated structural engineer. Eliminating this hand-off and coordination assists the

Manufacturing Flow Technique	Product Development Context
	work flow.
Total Productive Maintenance	
Total Productive Maintenance (TPM) is used to ensure 100% availability of process equipment. TPM eliminates both wait time muda, muda which arises due to a process machine going 'down', and defects muda associated with non-conforming parts, which is caused by machine or tool wear and tear.	Application of this technique to product development is warranted. Product development tools including analytical tools, design tools, software development tools all require upkeep to ensure availability when needed and work flow.
Mistake-Proofing	
Systems are employed to allow employees to monitor their own work and utilize mistake-proofing techniques. Mistake proofing reduces wait time muda by eliminating dedicated inspection steps and can reduce time lag muda through early identification of quality problems.	Again, product development would benefit from the use of this technique. Some current examples exist, particularly in the area of computer aided design tools.

Flow Versus Muda

Data has been presented which supports the existence of the same types of waste in the product development process as in the manufacturing environment. Additionally, a review of existing manufacturing flow techniques has been accomplished which identified those techniques which could be applied to product development to eliminate waste and facilitate work flow. The table shown in Figure 4.6 correlates the waste categories to the specific flow techniques that can be used to mitigate the waste.

Flow Techniques \ Waste Categories	Wait Time	Transport	Inventory	Defects	Overproduction	Over-processing	Movement	Complexity	Time Lag
Systems Capability	X	X				X		X	X
Visual Control					X				
Level Scheduling					X				
Physical Proximity	X	X					X		
Capable Processes				X		X		X	X
Standard Work				X		X		X	X
Cross Training	X	X					X		
TPM	X			X				X	
Mistake Proofing	X			X					
Takt Time			X		X				
JIT			X		X				
Single Piece Flow			X		X				

Questionable Applicability to Product Development (Takt Time, JIT, Single Piece Flow)

Figure 4.6. Correlation Between Waste Categories And Flow Techniques

Additionally, the table identifies those flow techniques whose applicability to the product development lean transition effort is questionable. (shaded area). The three manufacturing flow techniques, whose use in product development is questionable, all address the same muda types, inventory and overproduction. Since no other flow technique directly addresses inventory muda, some other, possibly unique flow technique is required in the product development setting to address this muda category.

In this chapter, Flow, the third lean principle was introduced. The concept of information being the 'product' or work object in the product development process was presented and Flow was defined as the lining up of all the necessary activities required to achieve a steady job flow without interruption, wasted steps, batches or queues. Flow is achieved by eliminating waste in the product development value stream of activities, such that information flows uninterrupted without regard to barriers. To assist in identifying the wastes which stand in the way of generating flow in product development, an investigation was conducted to determine if the wastes and flow techniques which have been identified in the manufacturing setting could be applied to the product development environment. This investigation found that the primary set of manufacturing wastes do apply to product development, but that this set is not all inclusive of the wastes in product development due to the more complex nature of customer value in this context. And finally the investigation found that not all of the manufacturing lean flow techniques have use in product development. In the next chapter, the fourth lean principle, pull, which was introduced in this chapter, will be discussed in greater detail.

CHAPTER FIVE

The Pull Principle

The fourth lean principal is the concept of pull. Pull occurs when no one in the value stream produces a product until the customer immediately downstream of this person requests it.[26] This occurs all along the value stream, such that upstream processes do not produce anything until the process immediately downstream asks for it. A kanban or signal card is typically used to signal the demand between processes.

Searching for analogies between pull in the manufacturing environment and pull in product development was found to be much more difficult than the concepts of value, value stream and flow. At the highest level of abstraction, one could draw a parallel to the case where a company doesn't initiate developing a new product until a customer (or customer group) has indicated intentions of buying the product. An example is when P&W holds launch of a new engine program until airframe and airline customers have committed to the program. But counter examples exist where companies are willing to risk investment in the development of a new product prior to having commitments from customers, particularly in fast paced technology industries. The launching of a new product development effort is a strategic issue and therefore does not fit nicely into the pull concept.

But once the decision is made to initiate development of a new product, are there advantages to structuring the program and processes such that information is pulled through the process as opposed to being pushed through the process? There are some marked differences between manufacturing processes and product development processes which bear on this discussion. Manufacturing processes are generally sequential in nature, they are non-iterative and they are repetitive. Contrast this with the product development process which is highly networked involving both sequential and parallel processes, it can be highly iterative with feedback loops to earlier process steps, and in general, is not highly repetitive (at least for long duration aerospace projects). These basic differences should cause us to question if the same process control method, namely pull, can or should be applied to the product development process with the same success it has brought manufacturing.

The pace of the product development process is typically controlled through the use of schedules. Schedules are usually hierarchical in nature starting with key customer milestones. Integrated Master Schedules (IMS) are used in some companies to tie lower tier program processes to these highest level program milestones. These schedules are generated usually using right to left planning, starting with the required customer completion date, and backing up the process lead time to determine when a given process step requires initiation. Is this

[26] Womack and Jones, *Lean Thinking*, 67.

scheduling process related to the pull concept? In the broadest sense, the customer milestones are "pulling" the product development work effort according to the program schedules and lead times. But the fact is, the scheduling process used in product development is very much akin to push processes used for scheduling in manufacturing, not pull. Steven Nahmias, in *Production and Operations Analysis*, contrasts both push and pull planning systems, Materials Requirements Planning (MRP) and JIT, respectively. The IMS system used in product development appears most similar to the MRP system where a master production schedule is derived from customer demand and specifies the exact amount and timing of production of end items. This schedule is then broken down into detailed production schedules for each of the components of the end item, and ultimately into shop floor schedules.[27]

Another perspective is to take a look at what is currently in place in the product development process that addresses overproduction muda, since pull is directed towards eliminating this type of muda. What controls which efforts get worked on, and which efforts do not get worked on in the development process? At P&W, a Request for Engineering Action (REA) system is used to initiate, track and execute all engineering activities. This includes new design jobs, engineering changes and problem investigations. All REA's have to be approved by the program prior to any effort being expended. This approval process controls the amount of work authorized in the program at any given time. This authorization to work is controlled by the configuration control board (CCB). Even if we consider this process the pull, the customer is not directly involved in this CCB action, although he is appraised of all current jobs and has the ability to provide input on the decisions. This process not only determines what gets worked on but to what schedule it gets worked to.

I leave the question on the applicability of the pull principle to the product development process open at this juncture at least from an overall planning perspective. It is one potential area for additional investigation by other researchers in the future. During the case study of applying value stream mapping to the product development process, opportunities for application of the pull principle locally to information flows may arise. These opportunities and the potential for implementation would be discussed in Chapters nine and ten herein.

[27] Steven Nahmias, *Production and Operations Analysis*, 3rd Ed. (Chicago: Times Mirror, 1997), 333-338, 373-377.

CHAPTER SIX

The Perfection Principle

Perfection is the fifth and last lean principle. Perfection is the future state of the value stream after elimination of all muda, both Type One and Type Two.[28] Perfection is the vision developed while applying the four other Lean Principles. Perfection is the state where every activity in the enterprise creates value for the customer. The pursuit of perfection involves continual execution of both incremental (kaisen) and radical (kaikaku) improvements to the value stream. These incremental and radical improvements are facilitated through the use of policy deployment. Policy deployment involves senior management direction and leadership in selecting goals, projects, resources and schedules for the improvement initiative.

Perfection pertains to the implementation process of improvement activities within the firm, execution of kaisen and kaikaku events and mobilization through policy deployment. The previous four principles provide guidance on understanding the current state of the value stream and facilitates a vision of the perfect future state. Perfection is the execution of the required activities to bring the future state to fruition. There is nothing unique about product development process improvement which would indicate that the same policy deployment techniques which have successfully been demonstrated in the manufacturing setting could be used in the product development lean transition. This perfection principle probably has less 'newness' or uniqueness relative to other process improvement initiatives than the other four principles which are unique to the lean vision.

If a firm has established process improvement mobilization strategies that have been successful in the past, then these same strategies could be applied to the product development lean transition process. Additionally, there is a wealth of mobilization strategies documented in recent business publications which could be adapted to implementing lean. Shoji Shiba, Alan Graham and David Walden offer an example of alternate strategies *in A New American TQM.* This work offers a strategy and structure for introducing change in the corporate environment in the form of a comprehensive infrastructure for mobilization. This infrastructure includes elements of perfection as defined in *Lean Thinking* but is broader in scope. The infrastructure includes elements of goal setting, organizational setting, education, promotion, diffusion of success stories, incentives and diagnosis and monitoring.[29]

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[28] Womack and Jones, *Lean Thinking*, 90-98.

[29] Shoji Shiba, Alan Graham, and David Walden, *A New American TQM: Four Practical Revolutions in Management* (Portland, Oregon: Productivity Press, 1993), 338.

An additional resource for strategies associated with implementation of change is offered in *Managing for the Future*. This work expounds on "The Ten Commandments" for executing change:[30]

- Analysis of need for change
- Creation of shared vision
- Separation from past
- Creation of sense of urgency
- Strong change advocating leader
- Political sponsorship
- Implementation plan
- Development of enabling structures
- Communication, involvement and honesty
- Institutionalize change

Given the general nature of change mobilization, there is no transformation or adaptation required for the perfection principle to be applied to the product development process. Further study of mobilization is available in current business literature and is not discussed further herein.

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[30] Rosabeth Moss Kanter, Barry A. Stein, and Todd D Jick, "The Challenges of Execution: Roles and Tasks in the Change Process," reprinted in *Managing Change in Organizations*, Module 11, *Managing For The Future; Organizational Behavior & Processes*, Deborah Ancona et al. (Cincinnati: South-Western College Publishing, 1996), 24.

CHAPTER SEVEN

Value Stream Mapping

Value Stream Mapping is a visual tool used to facilitate seeing and understanding the flow as a product makes its way through the value stream. The primary objective of value stream mapping is to provide a tool which can be used to categorize all process actions based on value creation. This mapping tool will facilitate elimination of non-value adding actions and making the remaining value creating steps flow.

The mapping needs to provide the 'big picture' to facilitate improving the entire value stream as opposed to just optimizing locales along the value stream. And the value stream may not be singular in nature; rather there could be multiple value streams or tributaries of a main value stream. Once the value stream is mapped, lean principles are applied to eliminate the muda. Similar to the approach used in previous chapters, value stream mapping is investigated as it pertains to the manufacturing setting first, and then these techniques and concepts will be evaluated for appropriateness from the product development perspective.

Mapping in the Manufacturing Environment

It is informative to study examples of value stream mapping, which have been utilized in the manufacturing environment. By looking at these examples, we can determine which methods can also be directly applied to the product development process, and where, due to the different nature of the environments, new methodologies need to be developed. The mapping is accomplished to provide a visual tool that represents all the processes along the value stream. The resulting process map shows all the material and information flows from the first process to the very last process.

Value stream mapping used in the manufacturing setting has typically been focused on the customer value stream. The mapping process starts with an information gathering stage where the processes are walked, and process data is collected. Typically, two maps are generated. An initial map is generated to document the current state of the production processes. This map is then used to visualize a future state or an ideal state for the material and information flow. This future state is then mapped for use in an implementation phase. Mapping involves documenting both the physical product, and process information that is used to control the process. Like other enterprise improvement initiatives, the mapping tools that have been developed for the manufacturing environment lend themselves to iterative improvement. Ideally, the mapping tool is used to identify both breakthrough improvements, as well as for incremental improvements.

Using manufacturing value stream maps as a guide and referencing specific value stream mapping techniques contained in *Learning to See* by Mike Rother and John Shook, the following generalized list of value stream mapping requirements are generated.[31]

- The value stream map is started at the customer interface, the point of delivery. The map is worked upstream from this point to assist in focussing on the customer value stream.
- Production processes are mapped.
- Process steps that are physically separated are separated on the map with the required movement and transport of material and information shown in between.
- The type of flow is identified on the map. In the case of manufacturing, this involves either material or process control information. The manner of flow between process steps is also noted. This involves documenting where material flows continually, where it is moving in batch and queue mode and where it stops. it involves noting how control information flows, electronically, fax, paper.
- The method used to control flow between process steps is identified, either push or pull.
- The location of inventories is recorded.
- Finally, data is taken on the performance of the current process and it is recorded on the map. For the manufacturing case, this data is typically used to calculate takt time and determine where bottlenecks are located. Typical data includes cycle time, tool or fixture set-up time, batch sizes, run times, scrap rates, etc.

Mapping in the Product Development Environment

As noted above, the primary objective of value stream mapping is to clearly identify those process steps which are value creating and those that are not such that improvement efforts can be focused on muda elimination. The value stream map also serves a couple of secondary objectives. The value stream map should provide a holistic view of the product development process such that the interrelationships between process elements can be understood and the system behavior in terms of customer value can be understood.

To establish a mapping technique to meet these objectives, consideration needs to be given to the level of detail and complexity of the model. Since one would like this technique to be accepted widely for use in the organization, a balance is needed such that it is simple enough that it fosters use and understanding, yet is sufficiently complex to simulate reality with acceptable accuracy. The mapping approach outlined in *Learning to See* is a relatively simple static modeling approach for the manufacturing environment. It does not attempt to map all value perspectives, nor does it map value as a function of time. At the other extreme, given the complexities of enterprise value and the dynamic nature of value, it is easy to see how a dynamic simulation

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[31] Mike Rother and John Shook, *Learning to See: Value Stream Mapping To Add Value and Eliminate Muda* (Brookline, MA: The Lean Enterprise Institute, 1998), 12-25.

approach like Jay Forrester's System Dynamic modeling could be used to understand the complex interactions of the different dimensions of value.

As discussed in Chapter Two, the approach to mapping just one dimension of the value stream, namely customer value, can be utilized as long as when it comes time to implement the future state, that the impact to the other value streams (employee and shareholder) are assessed. This approach satisfies the need to provide a relatively simple tool while ensuring that overall enterprise value will be improved.

The manufacturing model provides a reasonable basis for a product development mapping tool. Documentation of what is flowing is tailored to the previously identified product development information and material flows. Physical material flows of physical mock-ups, prototypes and development hardware are documented. As previously discussed in Chapter Three, the product development information flows can be subdivided into categories. The categories to be mapped correspond to the 'material flow' and 'information flow' definitions in the manufacturing environment. In product development, there is product information flow that corresponds to manufacturing 'material flow', that is, information along the value stream which is specific to the product definition. It is the information flow that includes customer requirements, functional requirements, design parameters, layouts and drawings. In addition to product information flow, there is program information flow. This is the information used to control the process and includes schedules, status reports, program management instructions, cost and schedule reports, etc. Program information flow corresponds to 'information flow' in the manufacturing environment.

Although this approach holds promise in identifying the customer value stream, it is not far removed from traditional process analysis tools. Process mapping has been used extensively as part of previous initiatives to improve business processes. On the surface, the above model for value stream mapping does not appear to significantly improve the picture of where process waste occurs when compared to these previous efforts. It's flow basis is new, but the fact we were unable to translate the usefulness of the pull principle to product development, partially negates the process control focus of this mapping approach.

An alternate approach investigated herein involves the use of the Function Analysis System Technique (FAST) to map product development processes with the same objective of categorizing activities based on value creation. The primary utility of the FAST model is that it uses functions for descriptors instead of activities as in traditional process mapping. This technique has been used successfully to maximize product value and holds promise as a technique for maximizing process value, particularly when combined with a focus on lean principles. The FAST modeling technique is widely used in the Value Engineering field to map product function to physical 'chunks' or parts of the product. This information is then used to determine the cost of function for the various parts and ultimately to facilitate elimination of functions or reducing cost of functions.

The FAST mapping process begins with the random identification of functions. A simple verb/noun function naming convention is used. A structured mapping process is then followed to sequence functions on the major function logic path first by expanding in the "how" and "why" dimensions as shown in the following diagram.

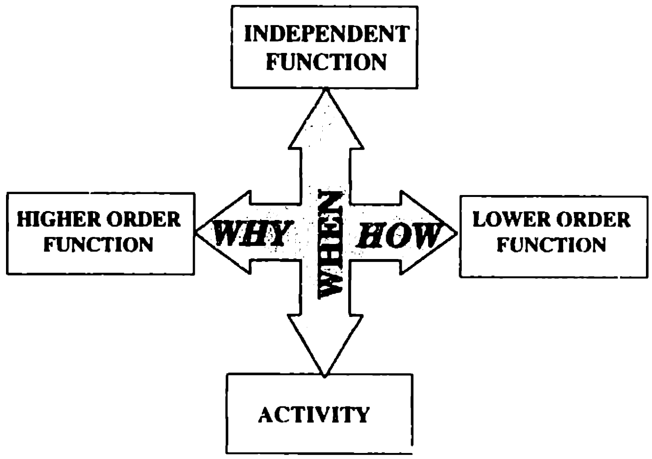

Figure 7.1. Mapping Convention Using FAST Technique

The function is decomposed by continually asking the question "how". The "how" domain is recorded from left to right on the map. This flow is tested by asking the question "why" when reading the map from right to left. The vertical axis is reserved for the "when" functions. A basic FAST model is shown for reference in Figure 7.2. The ultimate product of the FAST technique is a value stream map which defines the functions that generate value for the customer. It will be assumed that the reader has sufficient knowledge of the FAST technique precluding further definition herein. Any good Value Engineering book can provide a full explanation of the process should the reader desire additional information on the technique.

Application of the FAST model to value stream mapping is investigated in the case study which follows. The approach used was to start with the highest-level process function, i.e., satisfy Air Force Customer, and work upstream along the primary customer value stream. Once the primary value stream is identified, supporting functions and activities are added until the map is complete. Analysis of the value of the process activities can then be accomplished.

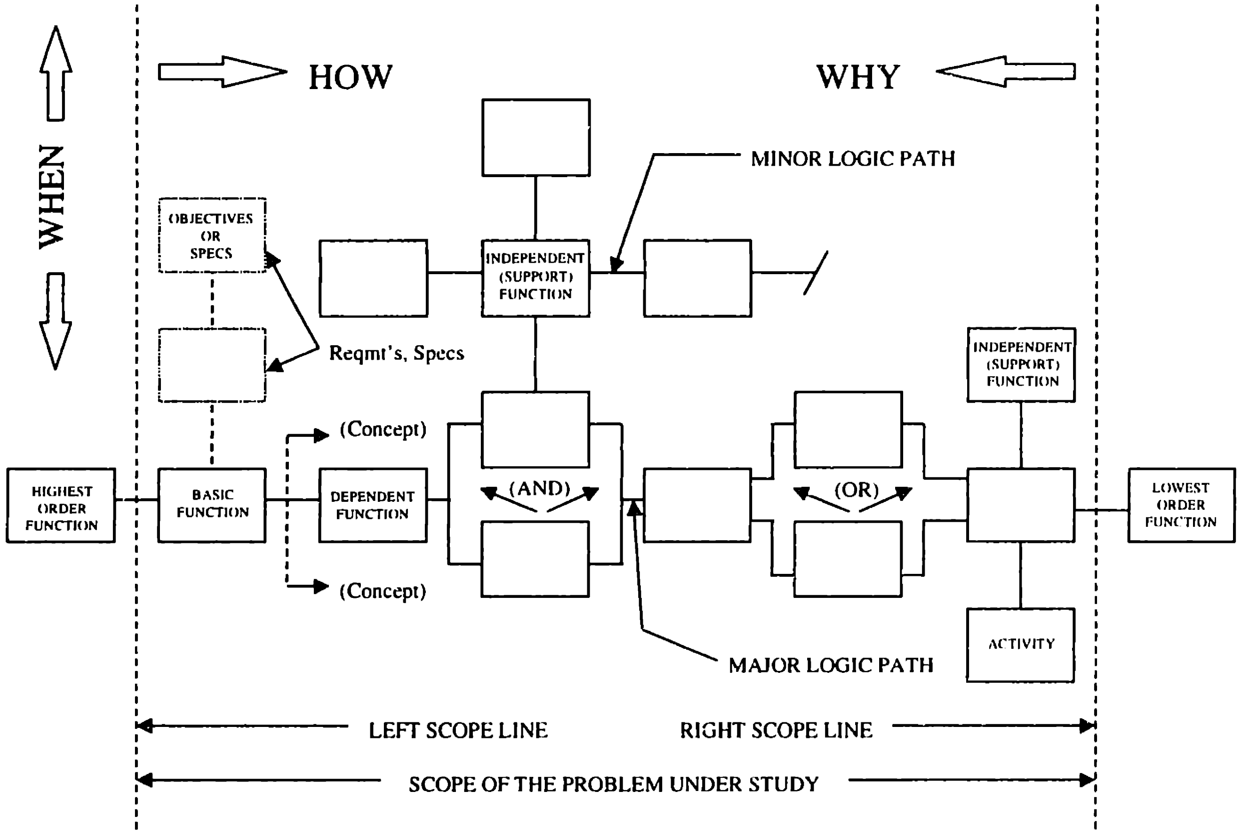

Figure 7.2. Basic FAST Model

CHAPTER EIGHT

F119 Jet Engine Product Development Case Study

Background

The F-22 Industry Team has made a decision to implement Lean Principles across the F-22 program. The F-22 Industry Team in the context of this paper comprises the U.S. Government, the airframe contractors and the engine contractor. This industry team has selected the Value Management methodology to facilitate this transition to Lean. This methodology involves the utilization of the Function Analysis System Technique (FAST) to value stream map and streamline processes. The ultimate goal of the process streamlining is overall program cost reduction. The technique has been used to create an overall F-22 Enterprise map and a Pratt & Whitney (P&W) F119 Engine map. These maps are being used as frameworks to initiate lean pilot projects involving value stream mapping on selected process areas of the enterprise.

One of the first pilot projects selected is to map the technical information flow processes between P&W, the engine contractor and the Air Force System Program Office (SPO). Technical information flow includes both product and project information as previously defined in Chapter Four, but does not include process and business information flows. The P&W/SPO technical information flow process was selected for several reasons, the first being that information which flows to the SPO, can be considered to be at the downstream end of the customer value delivering process. Thus identification of value at this organizational boundary will assist in identifying the pertinent value streams within all P&W development processes and subsequently working the mapping process upstream. Secondly, Air Force management has established the need for a paradigm shift in the manner in which the program is managed by the SPO from "oversight" to "insight". Implementing lean principles to the P&W/SPO information flow process will provide the mechanism to redefine these processes from one involving day to day detailed understanding of all issues (oversight), to one of providing the right information at the right time (insight). Attachment 1 contained in the Appendix to this report shows the overall Engine FAST model and the portion of this model that is involved in the lean information flow improvement effort. This model provides the 'bounds' of the product development value stream to be considered in this effort.

Organizational Framework

P&W fits the model of the "new organization" as described by Deborah Ancona, et al, in *Managing for the Future*. P&W has become progressively lean, flat, flexible, team based, networked with customers and suppliers, quality focused and globally oriented.[32] These organizational characteristics have an impact on the product development value stream flow. These characteristics, the flat and networked characteristics in particular, have presented challenges to information flow processes.

The company is highly networked with cross-functional integrated product teams being the organization's building blocks. A three-tiered hierarchy of teams is used to manage the complexity of the jet engine product; component level teams, subsystem level teams and engine system level teams. These teams work within an organizational structure that has evolved over the years from a purely functional one, to a strong program oriented matrix organization, and finally recently to a strong product oriented matrix organization. The move from a functional aligned organization to the strong program oriented structure broke up islands of expertise and distributed them to the programs in an effort to better integrate this knowledge into the products. A down side of this organizational structure was the erosion or loss of discipline and functional expertise due to this dispersion. An additional weakness of the strong program structure used was the continued organizational separation of engineering and manufacturing. The move to the strong product organizational structure addresses these weaknesses by grouping disciplines around specific subsystem products (compression systems, turbines systems, etc.) instead of by program. This orientation increases the 'mass' of expertise for each product. The other major motivation for this organizational configuration is the merging of engineering and manufacturing functions in product business centers.

These different organizational network configurations move the information flow challenges around between different organizational interfaces. The islands of functional expertise were broken up because this information wasn't getting to all programs. The strong program orientation was abandoned because information and expertise did not flow between the experts spread out amongst the programs. And despite the strong integrated product development team culture, information weakness between engineering and manufacturing still existed. And finally, the move to merge product engineering and manufacturing is likely to challenge the information flow processes between the various engine subsystem business centers, and between these centers and the systems engineering functions.

Finally, P&W's relationship with the Air Force customer has changed drastically over the years to where today the customer is invited and involved to participate in all activities and decision making in the product development process. The Air Force customer is treated as an integral team member at all levels throughout the organization. This integration of the customer role has also presented challenges in providing the right information, at the right time to the customer. This high degree of networking is overlaid on a flat, lean

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[32] Deborah Ancona et al., *The "New" Organization*, Module 1 of *Managing For The Future: Organizational Behavior & Processes* (Cincinnati: South-Western College Publishing, 1996), 6-10.

organization. The need to move information though this organization can place a significant burden on a lean team if the right information technologies and systems are not in place.

Program Framework

The F-22 program is currently in the Engineering and Manufacturing Development (EMD) phase. Demonstration and Prototype phases have been completed, and Low Rate Initial Production has not yet started. The value stream mapping effort was focused on information flow processes within the EMD program only. A diagram showing the EMD phase in the context of the overall program life cycle is shown in Figure 8.1.

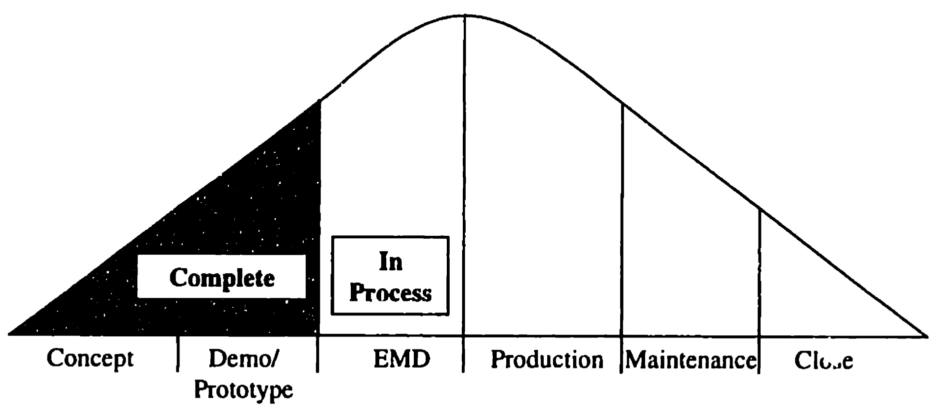


Figure 8.1. EMD Phase In Context of Program Life Cycle

Information Flow Team Composition

Initial actions in support of this effort involved establishing the team composition and working norms. An early decision was made to include the customer in the value stream analysis process. This decision was made for several reasons; one, because of the integral nature of the customer relationship, two, because of the uncertainties in just what is meant by "value" in these processes, and finally three, because the selected processes are customer boundary processes. Inclusion of the customer would ensure upfront agreement on the current process and would ensure a full understanding of what the customer values in these processes. This approach differs from that outlined in *Lean Thinking* where customer value is identified through alternate means (i.e. interviews) as opposed to actual customer participation in mapping and improving the value stream. During initial planning, P&W and customer team leaders were selected, and specific team members were identified. These included owners of the selected processes, owners of the processes just upstream, and facilitators.

One concern became evident during the initial team discussions. The transition from oversight to insight has yet to occur and because it is a significant operating and cultural change, it would be necessary for all team members to embrace this direction for establishment of the envisioned future state. Additionally, discussion revealed that just like other problem solving processes, one has to consciously avoid jumping to the future state prior to completing the analysis phase.

The team was comprised of members from the key P&W and customer organizations involved along the information flow interface. Included were P&W Component Integrated Product Team (CIPT) Leaders and a representative from each of the three Systems Engineering Functions. On the government side, team members included the local DCMC representative, Flight Leads and a Configuration Management representative. Additionally, the team included both P&W and government F22 Lean Transition Facilitators. The team thus had the benefit of having two members who participated in previous F22 lean events. Finally, a P&W facilitator was used to assist the team in working through issues during the value stream mapping process.

Reasons for Change

Besides the overarching program need expressed by the F22 Management Team, the information flow team unanimously agreed that there were compelling reasons for change. P&W and SPO independent perspectives on the business reasons for change were identified to be:

P&W

- Must meet specification requirements within budget to retain F119 product line.
- Must reduce program cost, retain product quality to meet capped budget.
- Must meet shareholder expectations (ROI)
- There is a strategic interest to execute more efficiently

SPO

- Cost of the product and the program
- Fear of program cancellation
- Desire for a world class product
- National defense/FMS politics

Prior to mapping the current process state, team members provided sketches of their perceptions of problems with the current information flow process. Selected graphics follow. One perception was that the information was not flowing as it would in a work cell, rather it is haphazardly making its way to the customer:

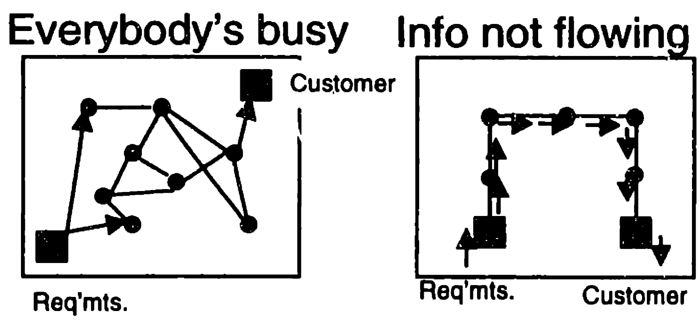


Figure 8.2. Perception Of Current Process State – Haphazard Flow

Another perception was one where the workers just do not have enough throughput to accomplish the required information tasks. The perception was that there was significant muda in the process creating this condition.

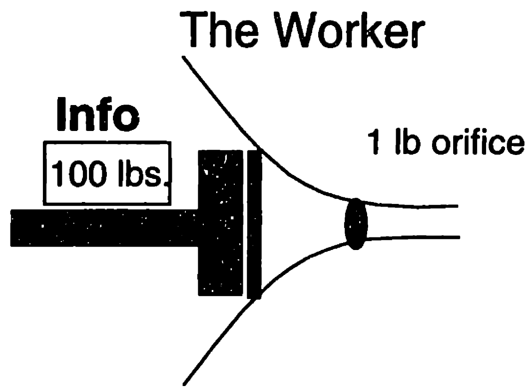


Figure 8.3. Perception of Current Process State – Bottlenecks

And finally a third sketch shown in Figure 8.4 provides a rendition of the batch and queue information process which tends to occur at major program milestones where the bulk of the required information is dumped at the last minute on the customer. This approach leads to time lag muda, where if there is a problem with the delivered information, it is not recognized until the eleventh hour of a program major milestone.

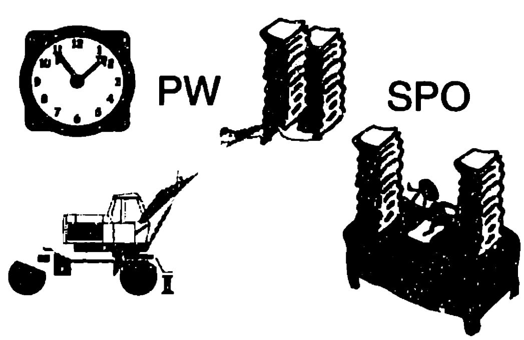


Figure 8.4. Perception of Current Process State – Batch & Queue

These perceptions were real and being felt by the team members. The team's goal was to identify potential process changes to eliminate the muda associated with these perceptions and to ultimately provide the right amount of the right information at the right time and at the right place for both internal and external customers. These perceptions indicate current information flow processes are not lean, and that they have led to duplication of meetings, data repackaging and ultimately a subpoena relationship with the customer. A solution to the current information flow problem was also deemed important at this juncture due to the fact that the EMD program technical staffs are being reduced over time as the program progresses towards production. Information flow requirements will continue as the program matures, but the remaining staff must focus on technical transformation tasks and reduce the effort associated with technical information transaction tasks (non-value added).

Overview of Current Process State

A significant amount effort has been expended over the years of the program to improve processes. Additionally, a significant amount of effort has been expended on program restructuring to reduce program costs while satisfying requirements. The current process state was therefore perceived to be quite lean (that is, lean from the standpoint of the amount of resources allocated and work scope to accomplish requirements, but not in terms of lean principles), as well as on a path of continuous improvement. Current expectations were that a customer value framework would provide unique insights and opportunities to enable a "lean leap". The current EMD program development processes were also deemed to be mature because they had been in use from program inception through Initial Flight Release (IFR), and considerable learning and improvement has occurred over this time frame. Looking at a generic life cycle of a process as depicted in Figure 8.5, the consensus was that we were currently operating in the Maintain – Improve region. That is, the EMD product development process was fully stabilized, in use, and maintenance and improvement actions were routine.

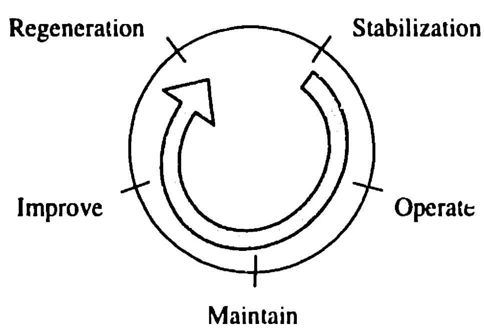


Figure 8.5. Generic Life Cycle Of A Process

Given where we had been operating, and the above compelling reasons for change, there was team consensus that what we were looking for in this lean effort was to regenerate the process (radical change). We were looking for a significant philosophical shift in how to conduct the EMD program information flow processes. To assist in defining this philosophical shift, the team worked through philosophical non-negotiables and beliefs to bound the team's actions and guide the lean transition process.

The primary non-negotiables of interest were:

P&W – Retention of integrity, reputation and business success

SPO – Technical information must be provided to substantiate requirements are met

The set of beliefs were:

- Joint "meaning" on all requirements is a must for trust
- It is not in the best interest of both parties to have the government disappear for 12 years and then have P&W dump the data
- Feedback from the Air Force reduces back end risk
- Milestones and check-ins reduce risk
- Avoiding all risk through oversight is too expensive
- The Air Force customer wants documented verification validated by their own "inspectors"
- Changes in people require documentation of product changes even if verbally agreed to today.
- Don't repeat/Don't repackage information

An additional process perspective to be considered during this effort was the differences between commercial and military product development processes. While commercial development programs are typically funded by the business enterprise, and involve a commercial airline customer; military development programs are funded by the taxpayer, involving a military airline customer. Commercial development programs are accountable to the shareholders of the enterprise, while military development programs need to be held accountable to the public (taxpayer). On military programs, this public accountability drives government risk aversity due to the need for the program to pass public scrutiny and the "newspaper test". This risk aversity in military development programs traditionally has lead to oversight of the contractor business enterprise, while the commercial endeavor is conducted in an environment without this oversight. Additionally, while the commercial efforts are conducted in a competitive environment leaving a customer with alternate source options should a contractor not perform acceptably, many government development acquisition programs are sole source to a single enterprise, essentially leaving no options should major program issues develop. This again encourages the use of oversight to ensure the development program does not become a "technical development sink hole" with no alternatives. This military program risk aversity turns out to be a significant driver in the information flow processes between the government customer and the contractors.

Customer Information Requirements

In an effort to provide P&W with a full understanding of the information requirements of the 'customer', the government team provided a top level organization chart. This chart was used to describe the information demands of the various arms of the Air Force organization and how these demands flow to the SPO/P&W organization interface. This organizational diagram is shown on Attachment 2 of the Appendix. This organization diagram highlights the varied customers involved in the program that ultimately drive a diversity of information needs. Directly at the organizational interface, most information flow occurs at the WBS Manager and Flight Lead interfaces. The information required at this level is highly influenced by the information demands at the next level, the Home Office and the Engine Leads. These two organizations have varying requirements, the Home Office acting more as an independent team assessing the program, while the Engine Leads are involved in the daily execution of the program. At the highest level, information is required by the Washington arena. This information is channeled through three separate Air Force organizations, the Aeronautical Systems Center, the System Program Office and Air Combat Command, which each have their own information needs. This customer organizational view gave the P&W team an appreciation for the source of the customer information demands and an appreciation for the need for seamless information flow.

When requested to outline development program information requirements, at the top of the government customer representative's list was the familiar Technical – Cost – Schedule triangle. This triangle represented the information required for the SPO to assess risk in these three program areas. This input was a direct validation of the previous proposed model of the attributes of Customer Value in the product development environment discussed in Chapter Two and shown in Figure 8.6.

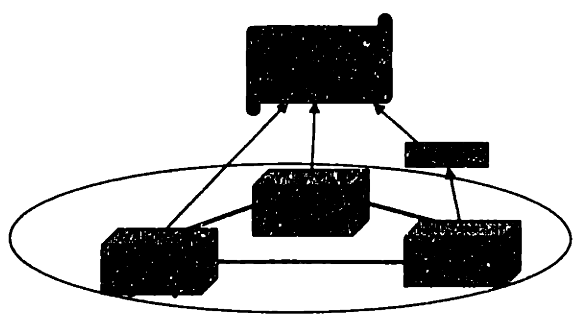


Figure 8.6. Customer Information Requirements – Technical/Cost/Schedule

Moreover, risk became a central theme to the information requirements of the customer. Risk was identified as a key element in determining the degree of oversight to be exercised by the government customer. If the customer perceives high risk in the development program, then oversight is used to drive action by the contractor to manage this risk. Or if the information is not available for the customer to adequately assess risk, perceived risk increases, and again oversight is used by the customer to gain access to the information such that an independent risk assessment can be accomplished. This relationship between customer oversight and perceived risk is generalized in Figure 8.7. The information flow model shifts as a function of program risk as perceived by the customer.

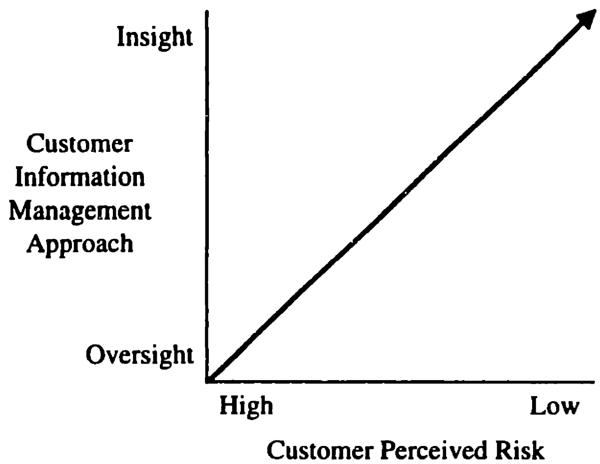


Figure 8.7. Customer Information Management Approach Versus Perceived Risk

Similarly, if the customer does not have confidence in the integrity of the contractor's processes, this again raises the customer perceived risk level and hinders the drive towards insight.

The current oversight approach to information flow between the customer and the contractor is driven by the customer's desire to maximize the value of the product development process by minimizing the risk (R) of the final product not meeting functional requirements or needs (this discussion also pertains to cost and schedule risk). This recognition of the role of risk substantiates the inclusion of risk in the equation for customer value derived in Chapter Two:

$$\text{Customer Value} = \frac{N \times (1 - R) \times f(t)}{C}$$

The customer has a need to understand in real time what the current program risks are. This value assessment need is essentially continuous in nature throughout the EMD program. The information value stream to be studied therefore needed to include that information which is required by the customer to adequately assess this program risk. At a top level, these needs were identified by the customer to be design information, plans, and results as compared to requirements. A more detailed bulletized summary of these information needs is shown in Attachment 3 of the Appendix.

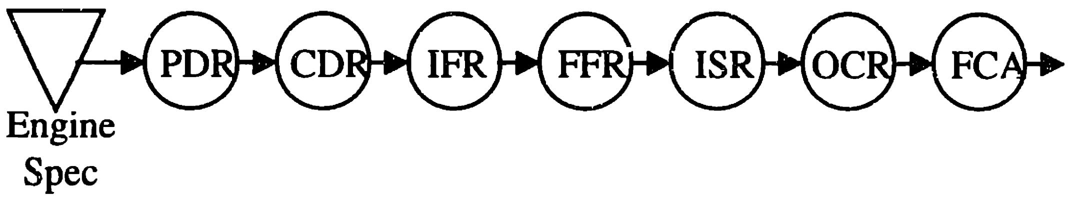
To further get an understanding of the customer information requirements, the customer representatives on the team identified the required attributes of this information other than content. The attributes identified were:

- ➢ Timely – this is now a familiar value attribute. Timely implies not only delivering information when required, it also means not waiting till the last moment (eleventh hour syndrome) to complete a data dump.
- ➢ Complete – this is consistent with the meeting requirements attribute.
- ➢ Contractor format acceptable – The customer preference is to work within the framework of contractor processes. This is a flexibility which has arisen as a result of acquisition reform. This should facilitate utilizing existing process data to satisfy data needs without recreating the information to meet a specific format requirement.
- ➢ Accessible – the information needs to be physically provided to the SPO in some cases, and in other cases, just having access to the data at P&W is acceptable.
- ➢ Include Conclusions/Recommendations – in general the data needs to include a summarization, again the SPO is not interested in data dumps. This summary information should include conclusions and recommendations as a minimum.
- ➢ Readable/Compatible/Legible – readable and legible are pretty self explanatory. Compatibility can be an issue, particularly when the information is in electronic format.

Technical Information Value Stream Mapping – Traditional Model

The team had two mapping techniques readily available for use based on the skills of the team members, a traditional flow mapping technique and the FAST model technique. Due to the simpler nature of the traditional process flow mapping technique, this method was chosen to initiate the mapping activity with the team supporting applying the FAST technique as a secondary technique to gain additional insight on a time available basis. This approach would provide an opportunity to contrast the techniques for mapping information flow type processes.

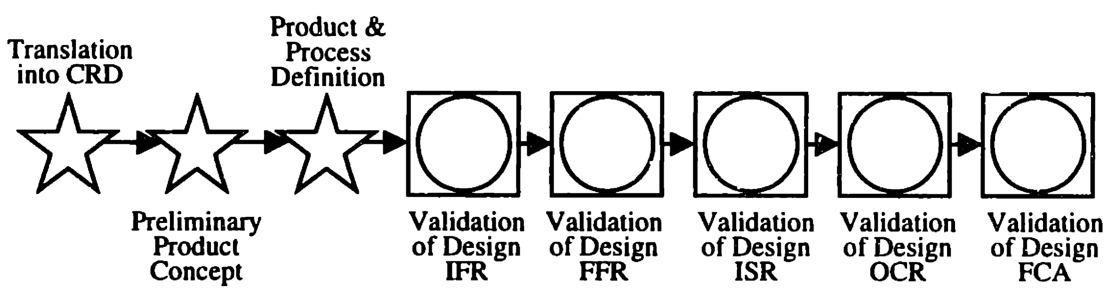
Although the information flow between the SPO and P&W was of primary interest, the entire product development value stream flow was mapped at the highest level to get an understanding of the overall process flow. Consistent with the lean approach of considering the entire value stream to prevent sub-optimization, the team started with the overall F119 Engine FAST model as a framework and decomposed the product development portion. This decomposition of the EMD product development process then would provide the means to understand the specific technical information flow processes of interest in this case study. The approach used involved starting at the very highest level of abstraction for the development process and then "drilling down" to lower levels to achieve process definition and insight. The EMD program Specification Definition and Functional Configuration Audit milestones formed the boundaries of the process to be mapped. Interim milestones provide insight into the activities occurring in the EMD program as a function of time as shown in Figure 8.8. Note the symbology used for this flow mapping is defined in Attachment 4 of the Appendix.



Where: PDR – Preliminary Design Review
CDR – Critical Design Review
IFR – Initial Flight Release
FFR – Full Flight Release
ISR – Initial Service Release
OCR – Operational Capability Release
FCA – Functional Configuration Audit

Figure 8.8. Product Definition and Validation Flow

The above map is nothing more than a series of milestones and does not give any insight into what is flowing in this process. Translating these milestones into top-level activity titles yielded the flow shown in Figure 9.4.



Where: CRD – Component Requirements Document. This document is used to decompose engine specification requirements into major engine subsystem requirements.

Figure 8.9. Map Of Top Level Activities

This flow level was also found not to be of sufficient level of detail for analysis. Since the current status of the EMD program under study was between the IFR and FFR stages, the team decided to focus on the Validation portion of this map and not on the up-front requirements definition and preliminary and detail product definition processes. At this level, the validation processes between the major program milestones (IFR, FFR, ISR, OCR and FCA) are identical. During each stage of the program, specific verification activities are required to satisfy specific program requirements unique to that phase. Additionally, due to design changes between these milestones, there is also re-verification activity to be accomplished. Improvements made to this verification and re-verification work flow would therefore benefit the program for each one of the remaining program milestone cycles.

After developing the above, the team recognized that it does not capture as much of the underlying information processes as necessary to get an understanding of the muda in the process. The next step in the mapping process involved "drilling down" into this validation work flow to define the specific work steps, the value stream. This "drill down" map is not shown here, rather it is shown on Attachment 5 of the Appendix due to its added complexity. This map represents the value stream within each of the previously shown "validation of design" blocks. At this level, some of the details of the information flow begin showing up. Meetings, documents and information sub-systems become visible at this level. At this level there were two primary paths identified, successful validation activity, and validation activity which results in a deficiency being identified. The leg of the process involving deficiencies and re-verification activity was considerably more complex from an information flow standpoint. This leg was chosen for "drilling down" another level to further understand the details of the various value added and non-value added steps in the information flow. The map associated with this activity is shown on Attachment 7.

After mapping this work flow, it became evident that what is flowing in this validation process is the information required to populate a verification requirements matrix which ultimately is fully populated at the Functional Configuration Audit (FCA) at the end of the EMD program. This information is required to verify that all detail parts of the engine assembly have met the verification requirements of the Engine Specification. This matrix is inspected at each major program milestone to ensure that the program is on track relative to meeting engine specification requirements. An idealized future vision/pictorial representation of this flow is shown in Figure 8.10.

As we studied this model and the previous process map, it was quite evident that these do not capture much of the information flow which is actually occurring in the current development process. There are information flows that occur which for all practical purposes occur perpendicular to this core information flow. This information is the information which has to be communicated from one organization to another for status purposes or for decision making purposes. The actual work flow may actually stop, waiting for this off-axis activity to occur. A large number of meetings and plans/reports are of this nature, off of the primary development effort information flow. Often this data and information has to be packaged a certain way to facilitate communication to the intended audience. Our lean transition effort also had to address this information flow to succeed in eliminating waste.

Requirements Verification Matrix

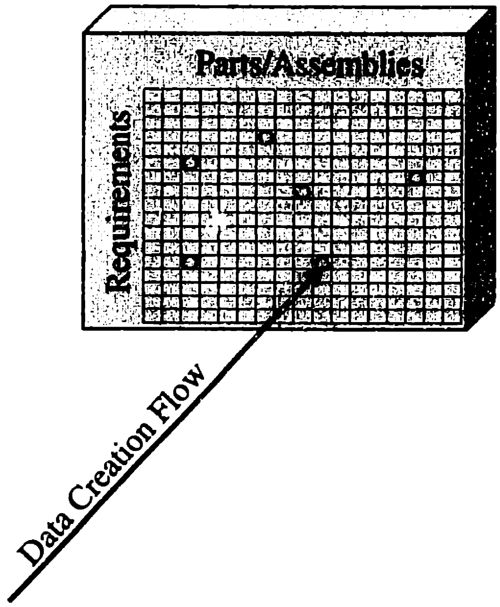


Figure 8.10. Idealized Validation Flow

The consensus was that the 'off axis' information flow was requiring an inordinate amount of effort (muda) relative to the main work flow and in fact was inhibiting the work flow value stream due to the drain on available resources. This drain has elements of both transport muda and wait time muda. As a result of this perception, the team mapped meetings and documents (information flow means) onto the high level product development process to assist in envisioning this flow. This information product map as a function of program timeline is shown in Attachment 7 of the Appendix. This map shows the multiple communications for the same program events and thus highlights the potential for muda elimination. In order to fully understand the information value stream, it was necessary to understand what communication means were being used, and what the information content of each means was. Note that this approach is similar to that proposed by Keen who suggests that when dealing with processes without well defined 'rules', that charting coordination and collaboration between people is an appropriate focus and an effective improvement tool instead of a work flow focus[33].

Meetings and documents were reviewed for opportunities for combining, improvement or elimination. Additionally, the information flow paths were reviewed by the customer to verify value-added from a customer perspective. Each team member ranked the various process steps for level of perceived muda or 'pain' and these were ranked using Pareto techniques to establish priority projects for improvement efforts. Three process areas were selected for "drill down" and further flow analysis:

- Define Design/Release Process
- Validate Design/Meet Requirements

[33] Keen, *The Process Edge*, 108-109.

- Perform Development Test Engine – Test Planning Portion

The analysis of these processes are to be accomplished by the process owners with the guidance of a champion from the lean information flow team. The "drill down" accomplished during the lean information flow event serves as a starting point for the processes to be analyzed.

Technical Information Value Stream Mapping – FAST Model

After having completed the value stream mapping exercise using the traditional process flow chart technique, the Function Analysis System Technique (FAST) was used to map the development process. The purpose of using this second technique was to contrast the two methods in an attempt to identify the strengths and weaknesses of each in value stream mapping product development processes.

The FAST model developed for the F119 engine product development process is shown on Attachment 8. The map starts with the highest level function which is to satisfy the customer, both the Air Combat Command and the Aeronautical Systems Center (ACC & ASC). The manner in which the development program accomplishes this is to satisfy the requirements of the ISR and OCR milestones. Satisfying these milestones is contingent on meeting functional, schedule, development cost and product cost requirements. Meeting or exceeding these requirements provides the customer with maximum value. Because our charter was to map the technical information value stream, the mapping focus was on the 'meet functional requirements' value stream. The value stream associated with meeting schedule and cost requirements is left for study at a later date. The "mitigate risk" function is a supporting function which addresses the higher level functions of "meet functional requirements", "meet schedule" and "meet cost". This sub-function was expanded to show the relationship of the managing risk function with the core value stream. This information flow associated with managing risk is provided to program management and the customer to allow a real time assessment of program status and risk. The varied program meetings which satisfy this function are listed. Proceeding along the primary or core value stream, starting with "meet functional requirements" in the "how" direction, are the following functions:

- validate design
- flight test engines/flight clear engines
- qualification test components
- qualification test engines
- build engines
- supply hardware/fabricate & procure hardware/order hardware
- define product/create design
- flow-down requirements
- establish requirements/interpret PIPS (customer specification)

This is the value stream along which elimination of muda and implementation of flow will result in increased customer value. This value stream ends at reviewing the customer's Prime Item Performance Specification, the lowest level function along the primary value stream. The various supporting functions and activities emanate from this core value stream.

Value Stream Mapping Results

The analysis of the traditional and FAST value stream maps and the associated information flows resulted in a project list containing technical information/decision flow lean ideas. This list is shown on Attachment 9 and identifies areas of greatest 'pain' by the process participants and areas of obvious muda. In several areas, further "drill down" and study is required to develop specific recommendations for Type One muda elimination and implementation. Three specific process areas were identified for further analysis, design package generation, the product validation flow and finally the test planning flow. In other process areas, specific actions are recommended. Examples of specific muda elimination projects include:

- Type One Muda Elimination – The team recommends elimination of the Integrated Master Schedule (IMS). The IMS was used early in the EMD program as a non-contractual means to manage the integration of schedules at all levels. Today, the IMS is no longer used to manage the program, rather it has become just a statusing tool. Alternate scheduling tools are used by the Component Integrated Product Teams to ensure consistency with program milestones.
- Type Two Muda Elimination – The team recommends elimination of the AEDC-QLA. This is a legacy test report which is to be integrated with the P&W assessment.
- Streamline the flight clearance review process by using the in-house Level V review to satisfy these customer requirements. (Type One Muda)
- Several recommendations are made to combine meetings which currently have overlapping functions. (Type One Muda)
- Streamline the F119 unique required PMI-062 (Program Management Instruction) process associated with definition of re-verification requirements for design changes. This involves the elimination of the requirement for certain classes of changes, combining the intent of this instruction with the P&W commercial standard process, and elimination of the need to specifically define rationale for similarity claims.

One aspect of value stream mapping which the team was not successful in accomplishing within the time constraints of this thesis was the quantification of savings associated with the improvement recommendations. On a broader note, a weakness of this particular team activity was that the particular process area selected for analysis (P&W/SPO technical information flow) was dictated to the team prior to mapping the value stream.

Ideally, one would map the value stream and then select to focus on a given process area based on a quantified need. During value stream mapping of the overall development process, it was evident that there are many opportunities along the primary product definition/validation value stream for muda elimination and information flow improvement.

Comparison of Value Stream Mapping Techniques

In executing the FAST technique to map the development program information flow value stream, the following strengths of the FAST approach were identified relative to the traditional process mapping technique:

- It is a rigorous technique with a consistent set of 'rules'. The rules are relatively simple which facilitates quick definition of the value stream. With some practice, the technique becomes intuitive.
- Function verb/noun naming convention promotes common terminology and effective communication.
- It forces both the "how" and "why" dimensions to be addressed. How the process is executed is captured, as well as why the process is done. Having the "why" question answered as part of the map helps identify questionable muda process elements.
- It naturally flushes out the primary value stream. Supporting functions are directed vertically on the map relative to the primary flow. This may have some benefits in envisioning the future state.
- It works well at various levels of abstraction. A top-level map can be generated for use as a guide for further "drill downs" into specific process areas.

Similarly, the FAST model technique in its current form has some weaknesses relative to value stream mapping:

- No direct insight is available into transport/movement muda types. The map does not provide definition of the location or physical nature of the value stream and flow.
- There is no one 'right' representation. The final configuration of the map is sensitive to the selected verb-noun functions. This could result in difficulty in achieving consensus on the map.

Both techniques work equally well in the team setting. The current process mapping skills and tools of the organization should also be taken into account when selecting a mapping technique. If a current mapping tool is available which can be adapted to value stream mapping as discussed in Chapter Seven, then acceptance and communication may be enhanced through the use of this familiar tool. Based on the experience with this case study, the FAST model approach is the preferred method with modifications to capture the physical aspects of process location and information flow.

CHAPTER NINE

Thesis Conclusions

One of the goals of this thesis was to broaden the understanding of lean principles as they pertain to the product development process. The primary approach used to achieve this goal was to investigate recent literature on related topics and establish similarities and differences in thought, and then to build on the available information. Additionally, the application of lean principles in the manufacturing setting was investigated to determine the viability of utilizing a similar approach in product development. Of the five lean principles, three were found to require tailoring of the manufacturing template to facilitate an understanding in the product development context; value, value stream and flow. The applicability of one lean principle, pull, to the product development setting was found to be questionable. And finally, the last lean principle, perfection, was found to be generic in nature and therefore required no expansion in understanding for application in the product development organization.

Since customer value is the primary driver in Lean Thinking, significant focus was placed on the principle of customer value. Three perspectives are offered to enhance the understanding of value; a word definition is provided, and an attribute model and a mathematical expression are developed. These perspectives provide an opportunity to explore customer value in differing ways in support of applying what is learned to the pursuit of lean processes.

Customer value is defined as:

> Value is a measurement of the worth of a specific product or service by a customer, and is a function of (1) the product's usefulness in satisfying a customer need, (2) the relative importance of the need being satisfied, (3) the availability of the product relative to when it is needed and (4) the cost of ownership to the customer.

Specific high level attributes are developed for customer value in the product development setting. The first primary attribute is quality which encompasses all non-price attributes of customer value. The quality attribute is decomposed into two sub-attributes, functional and performance properties of the product relative to customer needs, and the level of defects of the product. The second primary attribute is cost of ownership. The sub-attributes of cost of ownership are development program cost, acquisition cost and operating, support and retirement costs. Finally, the third primary customer value attribute is time. The time attribute is decomposed into two sub-attributes, product lead time and product development cycle time. The definition of specific customer value attributes facilitates the value stream mapping process and the identification of those process activities which directly contribute to customer value.

A mathematical expression for customer value was developed which includes terms for each of the primary attributes. Customer value is directly proportional to the ability of the product to satisfy customer functional and performance needs, directly proportional to the ability of the firm to deliver the product when it is needed, and inversely proportional to the cost of ownership of the product. A linkage between customer value and risk was proposed.

The existence of other value dimensions or perspectives was investigated to assist in relating lean principles and customer value to other operational considerations. The existence of two other perspectives is supported, shareholder value and employee value, and the potential linkage of the three value streams is discussed. It is reasoned that this linkage of value streams necessitates consideration of all three perspectives in the pursuit of a lean organization.

A definition was developed for the value stream lean principle. The customer value stream was defined as:

> The uninterrupted succession of product development activities along which there is continuous addition of product attributes including quality, functionality and usefulness, which directly address customer needs.

Information flow was introduced as the work flow of interest in the product development process. The primary method of developing an understanding of the flow principle in product development was through the manufacturing analogy. To assist in identifying the wastes which stand in the way of generating flow in product development, an investigation was conducted to determine if the wastes and flow techniques which have been identified in the manufacturing setting could be applied to the product development environment. A survey of product development engineers supports the conclusion that the types of wastes found in the manufacturing environment also exist in the product development environment. But a critical look at the unique value attributes in product development suggests that there is other muda types unique to these attributes and the product development process. A review of the techniques used in manufacturing to eliminate these wastes and make the work flow indicates that not all techniques have direct application in product development. Specifically, the just-in-time process control technique and single piece flow are proven methods in manufacturing to eliminate inventory and overproduction muda, but no corollary in the product development environment was identified.

The pursuit of perfection, the last lean principle, was found to deal primarily with change mobilization within organizations and as such it provides a framework within which to implement lean thinking into organizations, be it a manufacturing organization or a product development organization.

Another goal of this thesis was to demonstrate the applicability of lean principles and techniques to the product development environment through a case study. The F22/F119 engine development program was selected for use in this study. To ensure that customer value was fully understood, the customer was involved in the process of identifying customer value attributes. In light of the more complex nature of customer value when compared to the manufacturing setting, this approach is recommended for lean product development efforts.

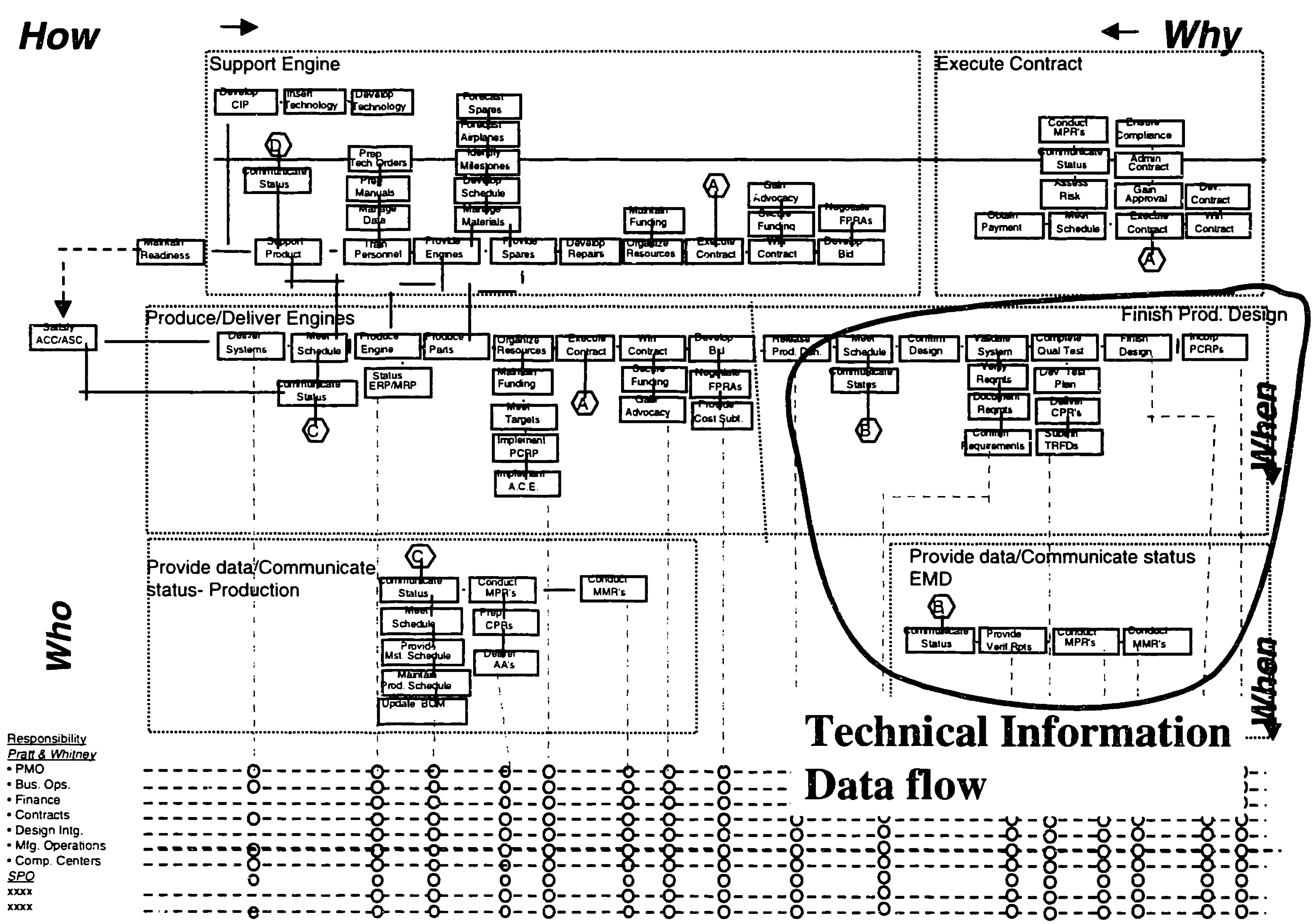
Two methods of value stream mapping were utilized in the case study to evaluate the advantages and disadvantages of each in facilitating lean implementation. Both traditional process flow-charting and the Function Analysis System Technique (FAST) were used to generate value stream maps. The FAST technique's inherent functional slant which provides the 'why' as well as the 'how' perspectives on the process map is the more sophisticated tool and ultimately may be the better choice with some tailoring to address its shortfalls, like the lack of physical location and movement definition. But ultimately, the best choice for a mapping tool is the one which the lean implementation team is comfortable using and the one which best communicates the current and future process states to the firm's power brokers.

The value stream mapping effort was successful in identifying process muda, both type one and type two and resulted in a project list for future analysis and implementation. Although this case study identified significant waste, the radical change, which was sought initially by the team, has not been accomplished to date. There were several factors for this including the fact that this thesis had a specific time window within which to accomplish the lean effort. This was the first detailed lean effort on development processes within the organization, and as such, took longer to accomplish than is expected in the future as learning takes place. The lean premise that specifies the need to consider the entire value stream also drove the team to map the entire product development process, thus expanding the task beyond the particular processes of interest and expanding the mapping task. Finally, in this case study the process focus on P&W/SPO information flow was selected up-front prior to the mapping exercise. This early identification of focus may have resulted in the selection of a process area which will not provide the greatest benefit from the application of lean principles. But the team did identify future state concepts for the core validation flow processes, which will be pursued as follow-on activity.

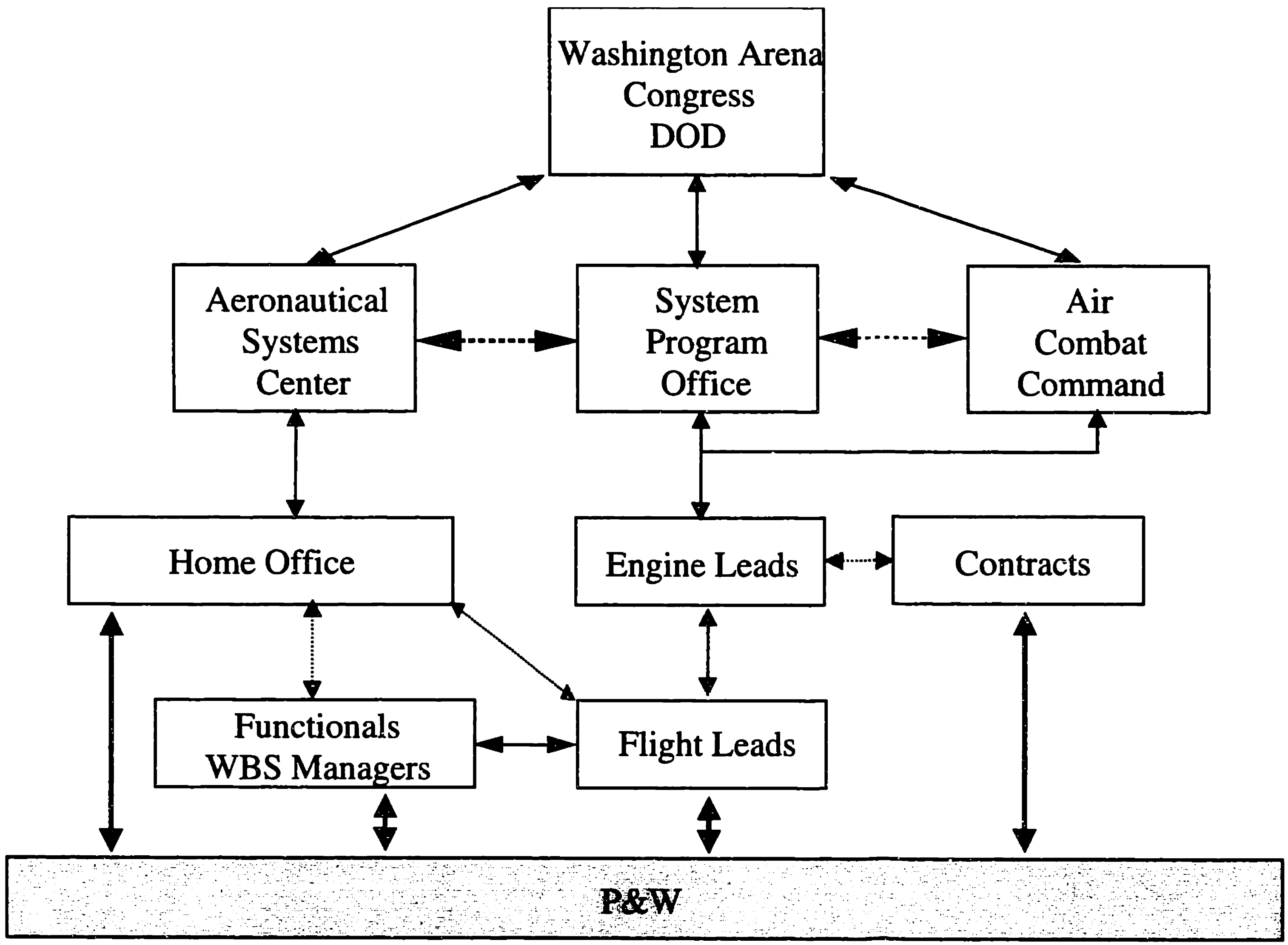
Finally, based on this research and the case study, one can conclude that lean principles as they have been applied in the manufacturing setting can be applied successfully to the product development process. But for maximization of customer value in product development, our understanding of these principles requires expansion. Customer value takes on new attributes in product development. The current set of flow techniques used in manufacturing only addresses the customer value attributes associated with the 'how' domain, the process domain. They are focused on improving the execution of how the manufacturing or product development processes are accomplished. But as shown in the customer value attribute discussion, customer value in product development extends beyond the 'how' domain into the 'what', or product domain. This extension in the product domain involves the decisions made by product development firms as to what product functions and performance are to be provided to a meet specific set of customer needs. These decisions of course affect the other primary customer value attributes, both cost of ownership and time. Therefore a lean effort in product development, to be truly effective, needs to address this decision making.

Lean product development decision making has to involve the full understanding of customer needs and requirements, real time, as the product development program is progressing such that maximization of customer value is attained. It involves a full understanding of the cost of ownership, not only product cost, but operating and support costs, again throughout the decision making processes of the program. Lean tools for product development are different than the manufacturing set, and must include techniques to keep the primary customer value attributes in focus and properly considered throughout the development program.

APPENDIX – CASE STUDY ATTACHMENTS



Attachment 1. F119 Engine FAST Model



Attachment 2. Air Force Customer Organization Structure

Risk Information : Technical – Cost – Schedule

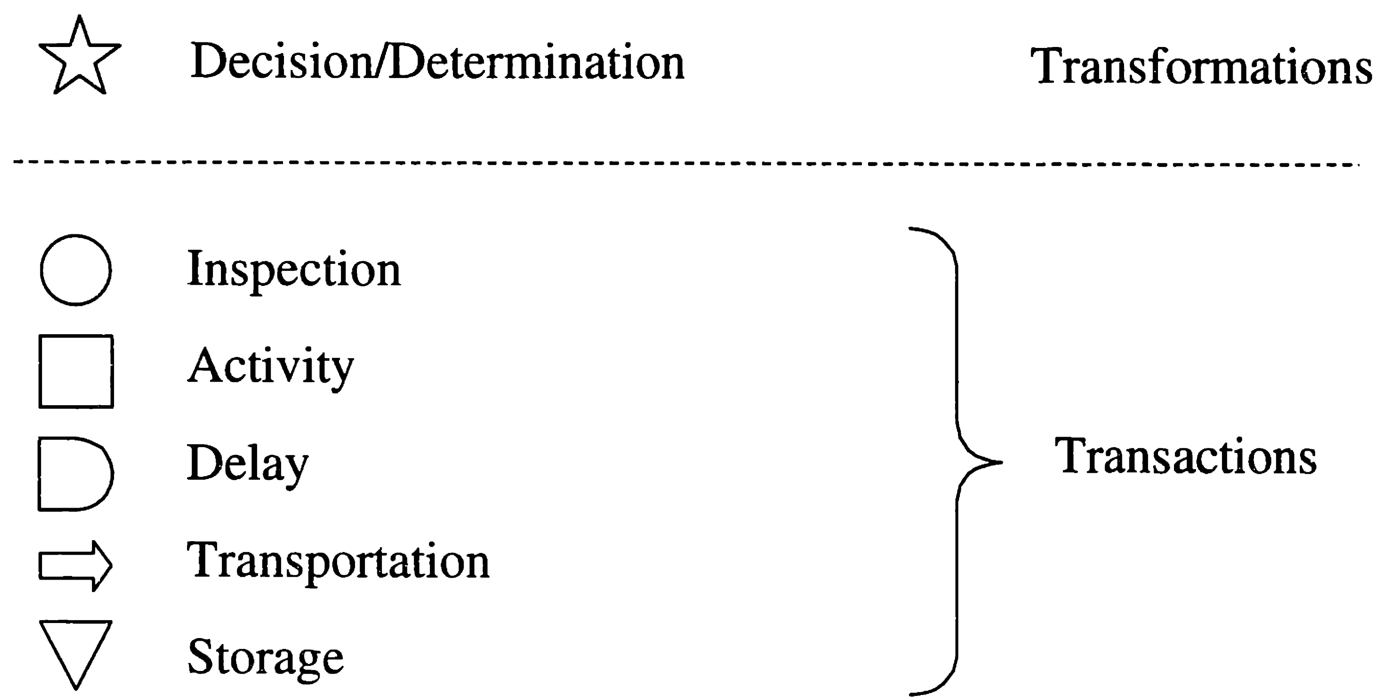
Design Information: Design Description
- Summary Analytical Results
- Producability
- Development Cost
- Product Cost

Plans:
- Master Plan
- Test Plans
- Rationale for Deviations
- Configuration Management
- Data Management
- Engine Deliveries
- Safety, ...

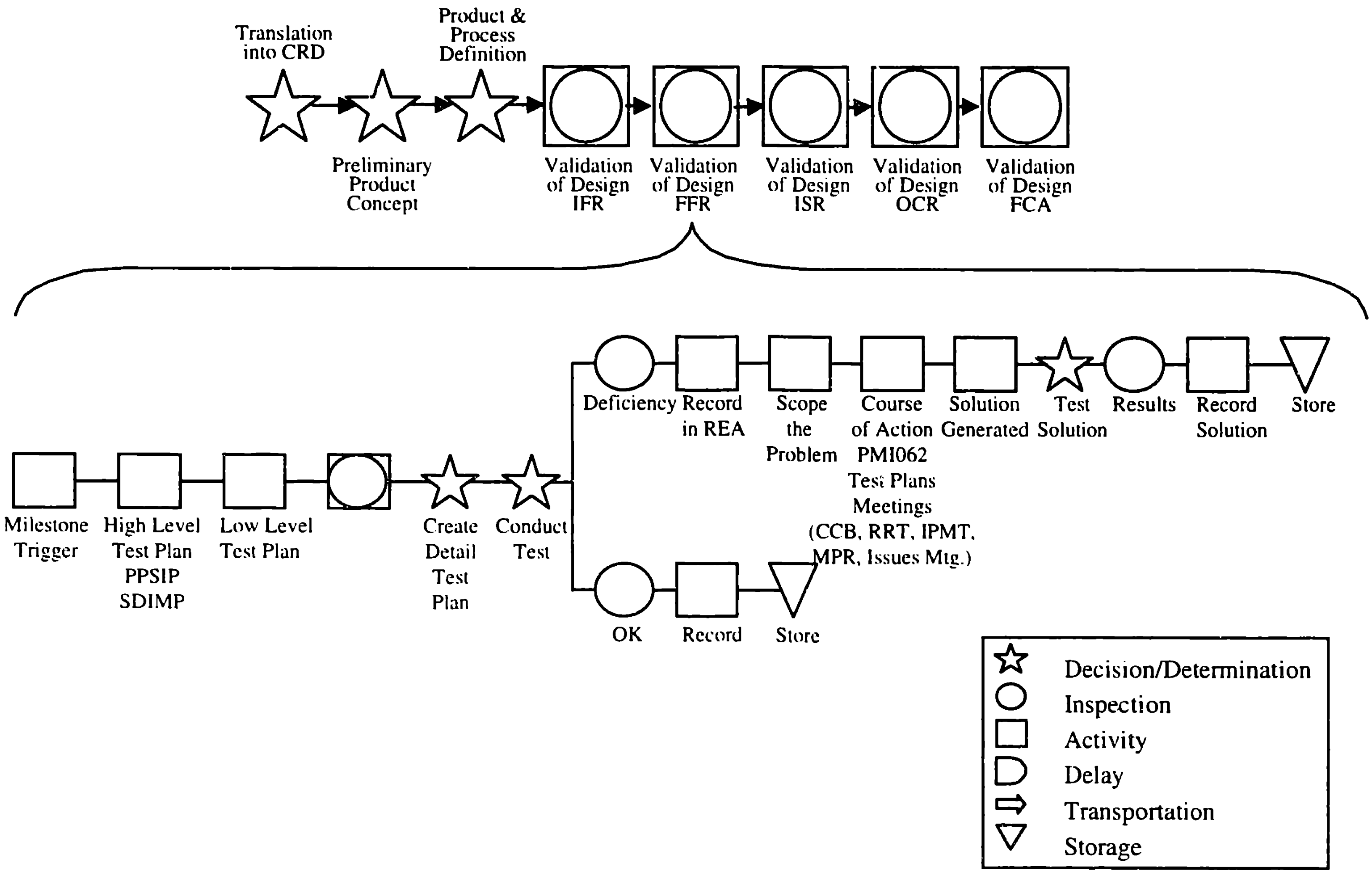
Results as Compared to Requirements: Status /Reporting
- Technical Performance Measures
- Failure Malfunction Reports
- Program Progress
- Development/Validation Results – Success/Shortfalls

Final Reporting
- Summary level with Conclusions & Recommendations
- Access to Supporting Documentation
- P&W Program Office Acceptance

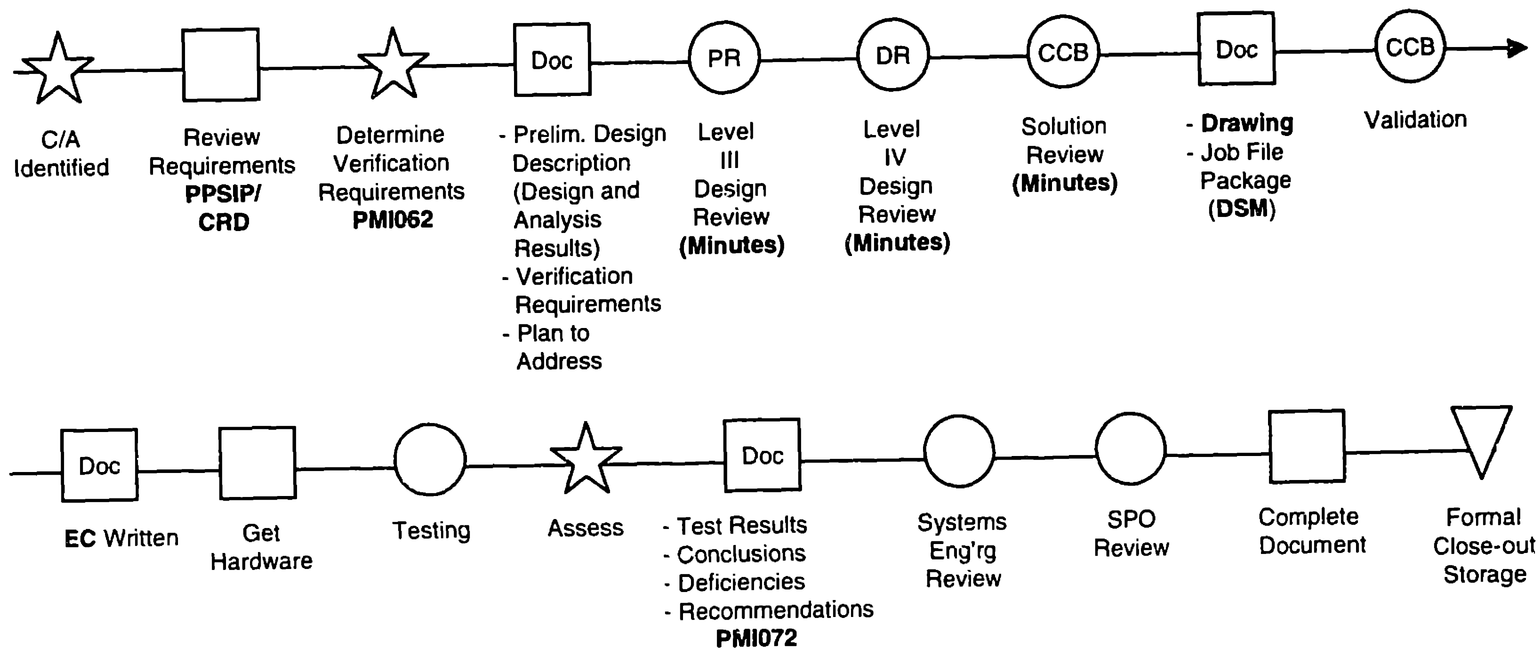
Attachment 3. Government Customer Information Needs Summary



Attachment 4. Definition of Flow Mapping Symbols



Attachment 5. Second Level Validation Flow "Drill Down"



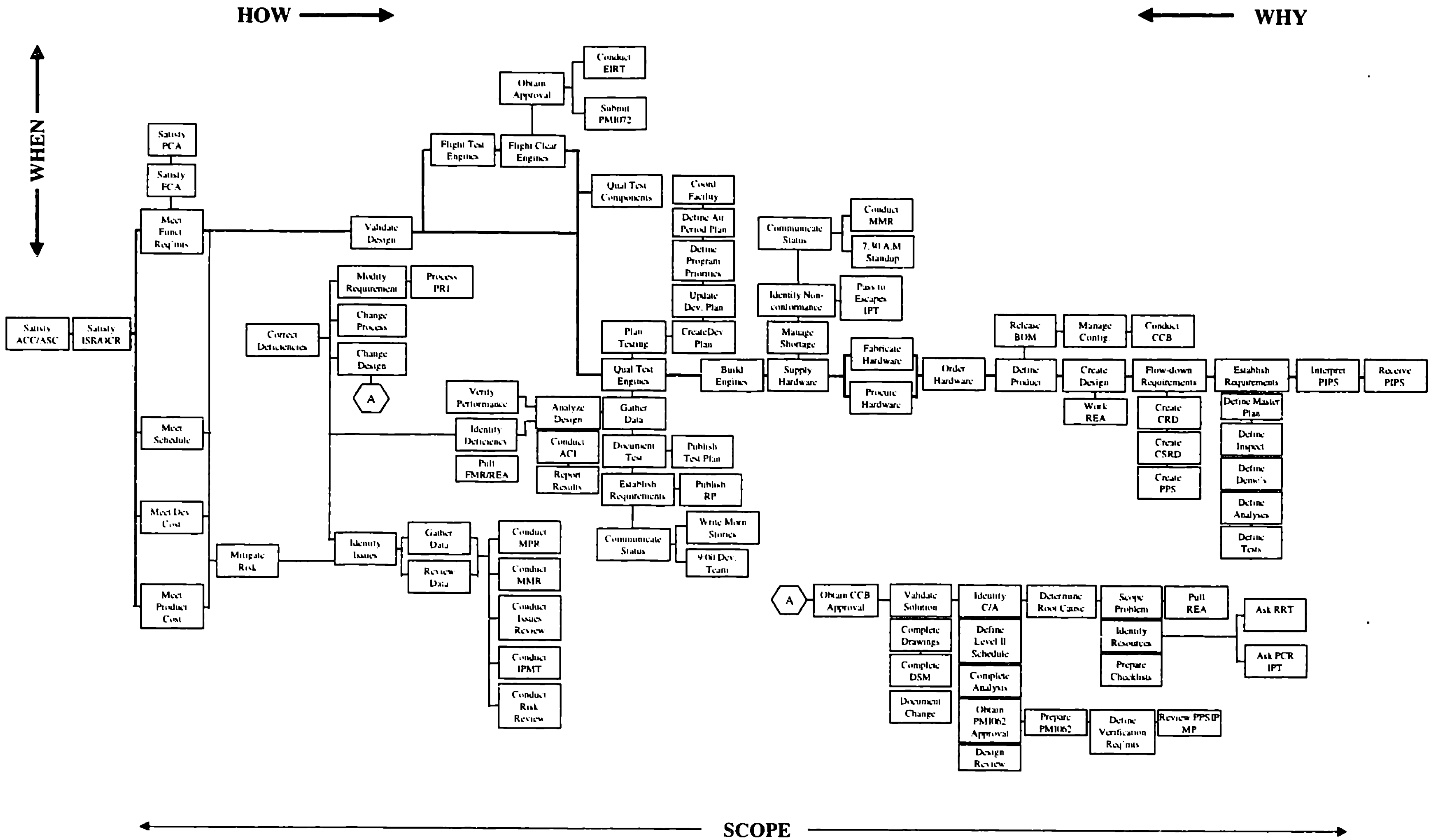
Attachment 6. Third Level Validation Flow "Drill Down"

Identify Requirements →	Flow Requirements →	Define Master Plan →	Create Engine Development Plan →	Define Design/ Release →	Execute Configuration Control →
SPEC [1,2]	CRD [4,5] CSRD [4,5] PPS MPR [1,5]	PPSIP [1] - Vol I - Vol II Program Milestones [1]	EDP [1] Product Definition [1,4,5] Engine Configuration Summary [1,4,5] High Level Plans [1,5] (AMT, Alt Dev't, Ingestion, etc.) ETWG Minutes [1,5] FTWG Minutes [1,5] Facility Improvement Plans	REA [1,4,5] (problem, solution, validation) Job File (DSM [1,4,5], analysis, IPT checklist, lab reports, PMI062 [1,4,5], etc.)	Cost Status [1,5] Weight Status [1,2] BOM Release [4,5] Add/Deletes [4,5] Inspection Requirements Pedigree Review Report [1,4,5], Pilot Lot, Used Hardware [4,5]

Perform Development Test Engine →	Validate Design/ Meet Requirements →	Define Deficiencies →	Closeout Deficiencies →	Pass ISR/ Deliver Systems →	Satisfy Warfighter/ Congress
ACI [1,4] Low Level Test Plans [1,4,5] TJR [1,5] Air Period Plans [1,5] Pre-test Predictions Run Programs [1,4,5] Morning Stories [1,4,5] Test Results [1,5] Test Report [1,5] AEDC QLA [6] Flt Test Letters, Results & Report [1,5] ATP Results/ Report/DD250 [1,4] QT/FTE Teardown Audits [1,4,5]	TPM [1,4,5] PMI072 [1,4,5] PPSIP Integrity Report [1,4,5] SPEC IMP Closeout [1,5]	REA [1,5] (EC tracking FRACAS) FMR [1,4] Issues List and Minutes [1,4] IPMT Minutes [1] PCR Minutes [1] MPR [1,5] (eliminate technical)	Same as Loop Starting with Define Design	Flight Clearance Report [1,4,5] Functional Configuration Audit (FCA) [1,4,5] Physical Configuration Audit (PCA) [1,4,5]	REA [1,4,5] Deficiency Definition [1,4] Flight Test Report [1,4]

[1] SPO needs
[2] No Change Required by SPO - good as is
[3] SPO Does Not Need
[4] Can Combine w/Other Information Product
[5] P&W Should Improve or Streamline
[6] Eliminate

Attachment 7. Information Output/Products as a Function of Program Timeline



Attachment 8. F119 EMD Technical Information Flow FAST Model

Project List	Owner	Champion
I. Product Information Flow Process A. Streamline design package B. Kaizen product validation process C. Streamline test planning		
II. Redundant Meetings A. Combine RRT and issues meeting B. Combine CCB and PCR IPT C. Don't distribute RRT funds @ MPR D. Review development status meetings E. Eliminate / streamline ESIT, FT analysis team, data review meetings		
III. Flight Clearance Review A. Consider independent P&W process modulated on commercial practice		
IV. Specification Verification Planning and Documentation A. Define exceptions to Class I EC plans B. Create one document C. Define, redefine S, E & V D. Consolidate TJR, PMI-062, PMI-072, DSM's E. Reduce necessity for face-to-face meetings F. Eliminate hierachy for document approval		
V. Create new or modify existing system that stores and tracks future F119 documentation that suports closure of contractural SOW requirements		
VI. Delete IMS		
VII. Eliminate AEDC - QLA		
VIII. Streamline FFR, ISR, OCR Review - Timeliness of Data Precludes Meetings		
IX. Train CIPT's		

Attachment 9. F119 Information Flow Lean Event Project List

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