Application of Lean Principles to an Enterprise Value Stream

A Lean Analysis of an Automotive Fuel System Development Process

by

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Submitted to the System Design and Management Program on January 14th, 2000 in partial fulfillment of the requirements for the degree of
Masters of Science in Engineering and Management

ABSTRACT

This thesis shows that lean principles that have been successfully applied in manufacturing can also be successfully applied across an entire enterprise. Established lean principles and lessons learned in lean manufacturing environments are applied across an automotive fuel system enterprise. This enterprise includes all major activities used in developing and delivering fuel systems to customers from the initiation of the systems concept to final production manufacturing.

The value of the enterprise's product (fuel systems) is specified in terms of enterprise customers. The value stream of the fuel system enterprise is identified and analyzed using process mapping, input/output information flow diagrams, and other techniques. Major issues in terms of waiting time, rework time, and excessive need for validation are identified using these techniques. Countermeasures against these issues are offered to facilitate a transition to a leaner state. The goal is to develop a systemic understanding of the fuel system enterprise such that lean principles and tools can be applied to its processes to improve efficiency, throughput, and value for customers.

Recommendations for further study are also listed in an effort to pursue perfection by continuously improving the lean enterprise. Finally, a transition to lean implementation plan is outlined.

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Table of Contents

ABSTRACT 3

TABLE OF CONTENTS 4

TABLE OF FIGURES 6

CHAPTER 1: INTRODUCTION 7

CHAPTER 2: UNIFYING VISION 9

2.1 The Enterprise Perspective 9

CHAPTER 3: BACKGROUND ON LEAN PRINCIPLES 11

3.1 Thinking in Terms of Lean 11

3.1.1 Specifying Value 12

3.1.2 Identifying the Value Stream 13

3.1.3 Making Value Flow 14

3.1.4 Letting the Customer Pull Value 15

3.1.5 Pursuing Perfection 15

CHAPTER 4: SCOPE OF ANALYSIS 16

4.1 System Perspective 16

4.2 The Fuel System Enterprise 17

4.3 Applications to Other Systems and Enterprises 18

CHAPTER 5: APPLYING LEAN PRINCIPLES TO MANUFACTURING 19

5.1 Historical Perspective of Lean Concepts in Manufacturing 19

5.2 Lean Manufacturing Implementation 22

CHAPTER 6: APPLYING LEAN PRINCIPLES TO A FUEL SYSTEM ENTERPRISE 28

6.1 Specifying Fuel System Value 28

6.1.1 Defining Customers 30

6.1.2 Customer Values 34

6.2 Identifying the Value Stream of the Current State Fuel System Enterprise 37

6.2.1 Process Mapping 38

6.2.2 Resource Mapping 42

6.2.2.1 Enterprise Resource Assumptions 44

6.2.2.5 Identifying High Priority Resource Opportunities 45

6.2.3 Input/Output Information Flow Diagrams 46

6.3 Making Value Flow in the Fuel System Enterprise 55

6.3.1 Insights into Non-lean and Flow Issues 55

6.3.1.1 Formal vs. Informal Flow Rates 58

6.3.1.2 Information Version Control 58

6.3.1.3 Reliance on Hardcopy 59

6.3.1.4 Flow Issues Typical at the Production and Enterprise Level..... 59
6.3.1.5 Tools and Technologies.....63
6.3.1.6 Metrics and Incentives.....68
6.3.2 Prioritizing Major Flow Issues.....68
6.3.2.1 Waiting Time.....70
6.3.2.2 Rework Time.....71
6.3.2.3 Validation Time.....73
6.3.2.4 Process Time Summary.....75
6.3.3 Countermeasures to Reach a Leaner Enterprise State.....77
6.3.3.1 Implementing Continuous Flow - Avoiding Multi-tasking.....78
6.3.3.2 Gradually Eliminate Safety Nets.....78
6.3.3.4 Align Clear Decision Points (Instead of Tasks) with Process Milestones.....79
6.3.3.5 Add an "Andon Cord" System to Pre-program and Product Development Phases..... 80
6.3.3.6 Utilize More Tightly Integrated Product/Process Design.....80
6.3.3.7 Implement Common Computing and Data Storage Systems (ERP) 81
6.3.3.8 Implement "Standard Work" Processes.....81
6.3.2.7 Implement Enterprise-wide Metrics and Incentives..... 82
6.4 Letting Customers Pull Value..... 89
6.5 Pursuing Perfection.....93
6.5.1 Future State Process Map 93
6.5.2 Opportunities for Further Analysis..... 96
6.5.2.1 Increasing the Scope of the Lean Analysis.....97
6.5.2.2 Specifying Processes and their Interconnections so that they are Self-Diagnostic.....97
6.5.2.3 Controlling Variation..... 98
6.5.2.4 Further Systemic Insights through the Utilization of Design Structure Matrices.....99
BIBLIOGRAPHY.....100
APPENDIX A: IMPLEMENTATION PLAN FOR A LEANER FUEL SYSTEM ENTERPRISE.....102
A.1 Transition to Lean.....102
A.2 Implementation Roadmap.....104
A.3 Barriers to Implementation.....107
A.3.1. Overcoming Mental Models.....107
A.3.2 Breaking Down Functional Chimneys..... 107
A.3.3 Managing (eventual) Reduction in Workforce.....108
A.3.4 Leadership Commitment.....108

Table of Figures

Figure 2.1: Systemic View - A Comparison of Manufacturing and Product Development Systems.....10
Figure 5.1: Linking Lean Thinking with Lean Manufacturing..... 25
Figure 6.1: Value Framework..... 29
Figure 6.2: Value Chain for Fuel System Enterprise - Customer Relationships and Links.....31
Figure 6.3: Current Enterprise Structure.....33
Figure 6.4: Fuel System Enterprise Customer Values.....34
Figure 6.5: Fuel System Enterprise Current State Process Map.....41
Figure 6.6: Enterprise Resources Mapped to Processes.....43
Figure 6.7: Process Times..... 45
Figure 6.8: Input/Output Flow Diagram "Black Box" Model..... 47
Figure 6.9: Input/Output Flow Diagram.....48 - 52
Figure 6.10: Tool Glossory.....53
Figure 6.11: Tool and Technology Compatability..... 65
Figure 6.12: Process Time Summary..... 75
Figure 6.13: Countermeasures to Address Major Non-lean Issues..... 77
Figure 6.14: Push and Pull within the Enterprise.....90
Figure 6.15: Future State Process Map.....94
Figure A.1: Transitional Enterprise Model..... 103
Figure A.2: Fuel System Enterprise Lean Implementation Roadmap.....105

Chapter 1:

Introduction

For years, lean principles have been effectively applied to manufacturing facilities to successfully cut wasteful activities and streamline production processes. These processes include all of manufacturing activities that transform products from raw materials to valued products in the hands of customers. Pratt & Whitney, Toyota, Sikorsky Aircraft, Delphi, Ford Motor Company, and many other companies have reported savings of billions of dollars associated with the implementation of lean principles. Lean initiatives have also slashed lead-times, cut cycle-times, and increased manufacturing throughput - often with very little investment required.

Despite its success in manufacturing, few case studies have been documented on the application of lean principles across an entire enterprise. An industrial enterprise typically encompasses not only manufacturing, but also product development, marketing, human resources, finance, research and other support organizations needed to develop and produce products for customers. The fact that little work has been conducted on extending lean principles to the enterprise level is likely due to the relative difficulty of viewing non-manufacturing elements of an enterprise as a system of processes in the same way that is intuitive in manufacturing. However, both are systems in which lean principles could be applied to improve design throughput, efficiency, and value to the end customer.

This thesis will show that the same lean principles that have been successfully applied in manufacturing can also be successfully applied across an enterprise. Established lean principles

and major lessons learned in lean manufacturing environments will be applied across an automotive fuel system enterprise. This enterprise includes all major activities used in developing and delivering fuel systems to customers from the initiation of the systems concept to final production manufacturing.

A background on lean principles is given in terms of specifying value, identifying the value stream, making value flow, letting customers pull value, and pursuing perfection. Lean principles and methodologies typically used in manufacturing settings are outlined and their correlation to an enterprise and particularly product development are described.

The value of the enterprise's products (fuel systems) is specified in terms of the enterprise's customers. The value stream of the fuel system enterprise is identified and analyzed using process mapping, input/output flow diagrams, and other techniques. Non-lean issues are defined and recommended countermeasures offered.

The goal is to develop a systemic understanding of the fuel system enterprise such that lean principles and tools can be applied to its processes to improve efficiency, throughput, and value for customers. The same lean process approach used in the case study of the fuel system enterprise can be extended to other enterprises.

Finally, an analysis of the lean procedures used in the enterprise case study is examined. The utility of the lean framework and analysis tools is examined. Major lessons learned and recommendations for further study are listed.

Chapter 2:

Unifying Vision

2.1 The Enterprise Perspective

Despite the many successes reported by manufacturing facilities that applied lean principles to their production processes, little work has been done on extending the application of these lean principles across an enterprise. Currently, the biggest obstacle in extending the application of lean principles appears to be that of vision. It is relatively easy to follow materials through a manufacturing facility and visualize the steps that add value for customers. Manufacturing engineers commonly track the flow of materials, decompose the processing steps, and measure their associated costs and times. It is relatively more difficult, on the other hand, to follow other parts of the enterprise such as product development's in-process product (information) and visualize the steps that add value for customers. Product engineers do not commonly track the flow of information, decompose the processing steps, or measure their associated costs and times. These differences make it relatively more difficult to extend the application of typical lean principles across an enterprise.

An analogy, however, can be drawn, between manufacturing systems (factories) and enterprise level systems (processes) to help broaden the application of lean principles. In manufacturing systems, raw materials are input, manufacturing processes add value to these materials, and finished products are output. In enterprise systems, information is input, processes add value to this information, and finished designs are output. For example, Figure 2.1 directly compares system characteristics of manufacturing with the system characteristics of another part of the enterprise, product development.

	Manufacturing	Product Development
Inputs:	Raw Materials	Unprocessed (Raw) Information
Processing Modes:	Tools, Machines, Automation	Procedures (FMEA, DVP&R, CAD, FEM)
Flow:	Material Control	Information Technology, Program Timing
In-process:	Inventory	Data
Outputs:	Finished Product	Finished Design

Figure 2.1:
Systemic View - A Comparison of Manufacturing and Product Development Systems

A higher level view can be used to perceive both manufacturing and product development as systems of processes that add value to raw input to create final products for customers. With such a view, it is possible to imagine that the same lean principles that have been successfully applied to manufacturing could also be extended to other parts of the enterprise. In fact, the greatest efficiencies can be gained by applying systemic lean principles to the entire enterprise.

Chapter 3:

Background on Lean Principles

3.1 Thinking in Terms of Lean

The goal of applying lean principles to an enterprise is to eliminate waste and improve the value-added throughput of the enterprise viewed as a system. The system is made lean by eliminating processes that do not add value for the customer and do not generate money through sales. All processes in a lean system are linked in a smooth flow such that one process produces only what the next process requires when it requires it. Wasteful detours in the development flow are eliminated so that the system generates value with the shortest lead and cycle time, lowest cost, and highest quality.[1]

The application of lean principles benefit the companies that use them because they provide a means to do more with less while coming closer to providing customers with exactly what they want.[2]

In his book *Lean Thinking*, James Womack outlined an approach to applying lean principles to systems. His approach was to:

- Specify Value
- Identify the Value Stream
- Make Value Flow without Interruptions
- Let the Customer Pull Value
- Pursue Perfection[3]

[1] Rother, Mike and John Shook, *Learning to See*. Brookline, MA: The Lean Enterprise Institute (1999), p. 43.
[2] Womack, James and Daniel Jones, *Lean Thinking*. New York: Simon & Schuster (1996), p. 15.

3.1.1 Specifying Value

To think in terms of lean principles, the focus of company decision-makers must be shifted from their existing organization, technologies, and assets to the value stream so that value can be differentiated from waste. The value stream should be viewed downwards from customers' perspective, not up from a company's perspective. Value should be defined from customers' standpoint. Value is usually a solution to customers' problems rather than an isolated object or service. "Rethinking value is often the key to growth and use of assets."[4]

For example, automobile manufacturers have typically thought of the value that their enterprises created in terms of their products - automobiles. However, such a narrow definition of value may hide bigger opportunities for the companies and make them less flexible to market changes. These manufacturers could think of value in terms of providing solutions to customers' transportation problems, not just providing cars. By rethinking value with such a customer perspective could unlock great potential for automobile companies' growth and use of assets.

Many aerospace companies have already adopted such a perspective and have been successful at managing customers' transportation needs. These aerospace companies do not make their entire profits from the first time sales of products like automotive OEM's. They have grown by addressing customers total transportation needs. They make most of their profit by maintaining and refurbishing planes. For example, Lockheed Martin actually doesn't typically sell planes to the military. Instead, they sell tactical capabilities and the U.S. military doesn't actually own the fighter planes they use to achieve these tactical capabilities. Lockheed Martin leases aircraft and maintains tactical capabilities to the military's changing needs. Similar opportunities likely exist for automobile companies.

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[3] Womack (1996) p. 10.
[4] *Lean Thinking for Process Development* presentation by James Womack to MIT SDM class (1999).

The application of lean principles starts by precisely defining value in terms of customers. This is done by ignoring existing assets, processes, and technologies and re-addressing companies on the basis of product lines with strong and dedicated product teams. Defining value accurately is a critical first step since providing the "wrong" good or service the "right" way is still a waste.[5]

3.1.2 Identifying the Value Stream

Activities that can't be measured can't be properly managed. This is why the identification of the value stream is a key step in the application of lean principles. "The activities necessary to create, order, and produce a specific product which can't be precisely identified, analyzed, and linked together cannot be challenged, improved (or eliminated altogether), and, eventually perfected. The great majority of management attention has historically gone to managing aggregates - processes, departments, firms - overseeing many products at once. Yet what's really needed is to manage whole value streams for specific goods and services."[6]

To identify an enterprise's value stream, a value stream map is typically created. Such a map identifies all the actions that are required to design, order, and produce specific products. An initial objective in developing a value stream map is "to sort these actions into three categories: (1) those which actually create value as perceived by the customer; (2) those which create no value but are currently required by the product development, order filling, or production systems and so can't be eliminated just yet; and (3) those actions which don't create

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[5] Womack (1996), p. 19.
[6] Womack (1996), p. 37.

value as perceived by the customer and can be eliminated immediately. Once this third set has been removed, the way is clear to go to work on the remaining non-value-creating steps through use of the flow, pull, and perfection techniques."[7]

3.1.3 Making Value Flow

After customer-defined value has been specified, the value stream identified, and obviously wasteful activities eliminated, the next step in the application of lean principles is to make the remaining value-adding steps flow. Activities flow when one follows another in succession without interruptions. Interruptions frequently occur and inventories are commonly built-up when components of products are made in batches instead of in a continuous flow.

Thinking in terms of flow tends to be counterintuitive since most people are used to thinking in terms of organizing by departments and producing by batches. Once an enterprise is organized by departments, however, specialized equipment for producing high speed batches are typically implemented. Employees then tend to think of their careers in terms of departmentalized specialties and accountants tend to base their calculations on departmentalized tasks. But, customers do not value an enterprise's departments for the departments' sake. They also do not value the delays and wastes associated with batch production. Often batches and departments were created to simplify an organizational or resource issue, but they can add tremendous waste and strip value from customers. For this reason, these structures should be scrutinized. Thinking of a process in terms of continuous flow forces this discipline. Activities are also almost always accomplished more accurately and efficiently when produced in a continuous flow. In summary, large gains in efficiency and value can be achieved by focusing

[7] Womack (1996), p. 38.

on the customers' needs rather than the organization or production equipment so that all tasks occur in a continuous flow.[8]

As value is made to flow through an organization, special care should be given to the control of variation within the value stream. If variation is not adequately controlled, a continuous flow of information or materials through the enterprise will be impossible. Controlling variation in a value stream often means that the correct information and material must be available in the correct amount at the place it is needed when it is needed. In-process controls for variation are typically required before an enterprise can realize continuous flow.

3.1.4 Letting the Customer Pull Value

Applying the lean principle of "pull" means that no upstream process produces a good or service until a downstream customer requests it. This eliminates waste associated with inventories and "pushing" unwanted products (typically at a discount to adjust for their lower value) on to customers. Customer demand also becomes more stable as customers feel assurance in being able to get what they want when they want it and producers stop discounting prices to sell products that no one wants, but were already produced.[9]

3.1.5 Pursuing Perfection

As an enterprise successfully specifies value, identifies its value stream, makes value flow continuously, and lets customers pull value, it will further see where additional waste could be removed and how products could be changed to more accurately provide what customers value. The pursuit of perfection is the last important lean principle.

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[8] Womack (1996), p. 22.
[9] Womack (1996), pp. 24 & 67.

Chapter 4:

Scope of Analysis

4.1 System Perspective

The biggest bang-for-the-buck in applying lean principles is achieved when they are applied to an enterprise as a whole. Optimizing individual parts of an enterprise does not yield as great of a benefit as optimizing the entire enterprise (with all value streams represented) as a system. In fact, by optimizing a complete enterprise, it may be determined that a part is no longer even needed and should be eliminated!

The optimization of any subsystem typically leads to sub-optimization of the greater system above it. For example, a company that makes several products will not benefit as much by optimizing individual products as it would by viewing all its products in a portfolio and optimizing its enterprise as a complete system.

By focusing on subsystems, true system constraints may be missed. This prevents maximum throughput. Working on non-bottleneck processes is in itself wasteful.

Logistical and practical issues often arise, however, when an effort is made to apply lean principles in a grand and sweeping manner to an entire enterprise. Usually, the complexities of most enterprises make them difficult to understand and work on in their entirety. The lean practitioners in this case may get bogged down in overwhelming details that ultimately prohibit improvement actions.

One practical way to address this issue is to apply lean principles only to the parts of the enterprise that practitioners can reasonably manage. Once lean principles have been applied to subparts across the entire enterprise, further optimization can be achieved by combining the parts

and applying lean principles once again to these larger chunks. This process is continually repeated and greater efficiency gains are attained as the process is applied to ever-greater enterprise systems.

In the scope of this thesis, lean principles are applied to Ford's fuel system value stream with particular emphasis on the product development process. Defining the enterprise boundaries for the lean analysis around Ford's fuel system value stream limits the greater efficiencies that could be discovered by analyzing Ford's complete business enterprise. However, this tighter focus will allow a more concentrated and clearer example of the application of lean principles within the scope of this thesis.

4.2 The Fuel System Enterprise

The fuel system of an automobile is the system that contains, measures, and delivers fuel to an engine. It includes such components as fuel injectors, fuel rails, regulators, tubes, dampers, sensors, and valves. The fuel system enterprise includes all the organizations and processes involved in developing and producing fuel systems for customers (customers are more clearly defined in the next chapter). In the scope of this thesis, the fuel system enterprise value stream begins with the identification of a fuel system need and proceeds through the generation of fuel system concepts, component and system design, manufacturing, and the ultimate delivery of fuel systems to customers.

4.3 Applications to Other Systems and Enterprises

Although this thesis utilizes fuel systems as the value stream for lean analysis, all other vehicle systems could benefit from similar analysis. The approach to lean analysis and the recommendations developed in the concluding sections can be extended to other vehicle systems. In fact, they can be extended to other enterprises.

Chapter 5:

Applying Lean Principles to Manufacturing

A historical perspective is helpful in understanding how the application of lean principles can achieve significant gains in productivity. Lean initiatives have their roots in manufacturing. The automotive company in this analysis has already successfully applied lean principles to its manufacturing processes. This section reviews major historical events affecting the development of lean principles. It also examines the automotive company's current interpretation of lean principles and their implementation in its manufacturing processes. An understanding of the application of lean concepts to manufacturing will facilitate the extension of the same concepts across the entire fuel system enterprise.

5.1 Historical Perspective of Lean Concepts in Manufacturing

An insatiable demand for affordable automobiles in the early 1900's drove Henry Ford and other early automotive pioneers to look for innovative ways to produce vehicles in high quantities and low costs. At this time, direct labor accounted for over half of the product cost. The number of different vehicle types offered by each automobile manufacturer was very limited. Several innovations were introduced to the automotive industry in order to produce high volumes of the same type of vehicles while reducing the costs of direct labor. These innovations included interchangeable parts, division of labor, and moving assembly lines. Mass production techniques drove economies of scale in which expensive and specialized machine tools were used to lower unit production costs.

In 1911, Frederick Taylor popularized the notion of "Scientific Management." Taylor used a scientific approach to study industrial work and optimize it in terms of maximizing the work output of laborers at the lowest expense. These scientific studies drove efficiency and industrial productivity at a time when labor accounted for the majority of manufacturing expenses. Likewise, the focus of vehicle manufacturing facilities at this time was on increasing the number of units produced per investment in labor, materials, and overhead.

With low product variety, vehicle manufacturers still maintained relatively lean facilities that supplied only what was needed, when it was needed, to the place where it was needed (reference Ford Highland Park facility circa 1915). But, as the automobile companies grew, they began to offer multiple vehicle types using varied technologies for varied customers. In an attempt to control production costs, the companies organized their production facilities by specialized processes. For instance, one production area would be highly specialized for metal stamping, another for assembly, etc. (reference Ford Rouge facility circa 1950's). To drive down unit costs in such specialized production areas, manufacturing management focused on improving the variable costs of these operations.

Over the years, automation was increasingly used to lower direct labor costs. Management attention in such manufacturing facilities focused more on the existing company assets, organization, and technologies instead of the product itself. Value tended to be defined in the product itself rather than a solution to customers' problems.[10]

Following World War II, Toyota had a different experience than its American counterparts had experienced earlier in the century. With extremely limited capital, it was faced with producing multiple varieties of highly sophisticated vehicles for a low volume of demand.

[10] *Lean Thinking for Process Development* presentation by James Womack to MIT SDM class (1999)

Instead of competing in terms of mass production at lowest cost, this scenario drove Toyota to compete in terms of quality, flexibility, speed to market, and price. This in turn inspired Toyota to adopt lean behaviors of producing only what was needed, when it was needed, where it was needed. During this time, Toyota adopted lean innovations such as fast change-overs of equipment, just-in-time supply chains, manufacturing cells, pull, Andon and Kanban systems, as well as a corporate culture that embraced continuous improvement. This culture fostered structured problem solving in which workers designed, operated, and improved individual activities, connections linking activities, and the value streams over which materials and information take form. Toyota's structured problem solving methods allowed its production systems to be made up of highly modular and nested subsystems with self-diagnostic interfaces and components.[11]

By the 1980's, lean techniques could be seen to have significant effects as the productivity differences between Japanese and American automakers became more and more apparent. In 1990, James Womack and Daniel Roos published the influential book; *The Machine that Changed the World.* This book detailed many of the lean behaviors of Japanese automakers (particularly Toyota) and their differences compared to their American counterparts.

In their report published in 1995, Clark, Ellison, Fujimoto, and Hyun reported data from the late 1980's showing that the Japanese spent about 50% less engineering hours on each new car on average as compared to their American counterparts. The report also showed an average of 26% less development cycle time per each new vehicle and 45% less prototype lead-time.[12]

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[11] Spear, Steven and H. Kent Bowen, "Decoding the DNA of the Toyota Production System,"*Harvard Business Review*, September-October, 1999, pp. 97-106.

[12] Ellison, David, Kim Clark, Takahiro Fujimoto, and Young-suk Hyun, *Product Development Performance in the Auto Industry: 1990's Update.* Cambridge, MA: IMVP, MIT (1995), pp. 3-35.

As the systemic benefits of the Toyota Production System became more apparent, lean initiatives gained greater popularity in an increasing number of manufacturing facilities. American vehicle manufacturers gradually turned their attention from a process/operation focus to a system focus. The lean principles of specifying value, identifying the value stream, managing the flow of value, allowing the customer to pull value, and pursuing perfection are commonly used today to improve manufacturing productivity. Lean principles have been used extensively in manufacturing environments to ensure that only the right product is made at the right time at the right place.

Lean principles have not been extensively used, however, on the enterprise level. The application of lean principles to an enterprise (specifically the fuel system enterprise) is the emphasis of this thesis. Before analyzing the enterprise, a deeper understanding of lean concepts can be gained by analyzing the automotive company's lean manufacturing behaviors. From this baseline understanding of lean, the concepts will be extended from manufacturing to the enterprise level in the next chapter.

5.2 Lean Manufacturing Implementation

Through its updated production processes, the automotive company has already been successful in applying lean principles to its manufacturing facilities and helping suppliers implement lean strategies in their manufacturing facilities. The vision behind the company's new production process is to integrate its own manufacturing with suppliers to create a system that is lean, flexible, disciplined, consistent, and stable. The system uses a set of processes and principles that depend on groups of capable and empowered employees working and learning together to consistently deliver products that exceed customers' quality, cost, and time

expectations. In this way, the company can maximize the efficient use of its assets, eliminate waste, and improve customer satisfaction.

Prior to the implementation of its new production system, the company's manufacturing philosophy was directed at producing a scheduled number of vehicles and components per day with the highest quality and lowest variable cost. With the new manufacturing system, this philosophy has evolved to producing only what customers want, when they want it. To support this philosophy, the production process is run in a more stable and predictable manner with emphasis on the lowest total life cycle cost, fastest cycle time, and highest quality.

To implement lean principles, the company's production facilities used similar steps as those recommend by James Womack in *Lean Thinking*. Womack's first step is to specify value in terms of the customer. The company's production facilities define customer value based on the quality, cost, and timing of the products they manufacture.

Womack's next step is to identify the value stream. Under its new manufacturing system, the company's and supplier's production facilities use current state mapping and the company's Metrics Implementation Process to define value streams. The time, material, and information flows of manufacturing lines are documented and the data analyzed in terms of the manufacturing system's metrics. Once the entire set of activities used in producing a product has been defined and measured, wasteful steps can be identified and eliminated.

The next steps Womack recommends to implement lean principles are to make value flow without interruptions and let customers pull value. The company's manufacturing system uses a five phase implementation approach to achieve this. These steps include:

- **Stability** - Eliminating wide production variance and producing what is planned when committed with the people, equipment, & materials scheduled.
- **Continuous Flow** - One process activity follows another in a continuous flow without interruptions typically associated with batches & inventories.
- **Synchronous Production** - Plan logistics, manage internal logistics, manage external logistics, and schedule production to deliver products just in time and just in sequence.
- **Pull System** - Production instructions are cascaded from downstream to upstream. An upstream process produces only when a downstream customer signals a need.
- **Level Production** - Reducing variations in the production system.
- **Continuous Improvement** - Perfection is always pursued. More waste is eliminated, more efficiency gained, and products meet more exactly what customers want.

These steps are supported by the company's manufacturing system principles:

- **Using Total Life Cycle Cost to Drive Performance** - Systems view of the whole business and associated costs.
- **Effective Work Groups** - Empowered, capable, motivated employees who trust and rely on one another.

- **Just-In-Time Production** - A system of making & delivering only the right materials in the right amounts at the right time. Allows single-piece flow.
- **Optimizing Production Throughput** - Maximize asset utilization.
- **Aligning Capacity with Market Demand** - Set capacity of constraint processes in alignment with customer demand. Ideally, each customer's requirements would be met and delivered without delay.
- **Zero Waste/Zero Defects** - Eliminating anything that does not add customer defined value. This takes the form of wasteful materials, equipment, space, energy, time, ideas, and defects.

Figure 5.1 summarizes the application of lean principles to the company's manufacturing sites using its new manufacturing system:

Lean Thinking Principle	Company Translation of Lean Principles	Steps - Manufacturing Sites
Specify Value	Implied the same (depends on **Effective Work Groups** trained to understand customer values of cost, time, and quality	Value in production implied in terms of quality, cost, and time
Identify Value Stream	Current state mapping which depends on Manufacturing System Metrics and **Total Life Cycle Cost** as a driver	Current state mapping/ Manufacturing System Metric Implementation Process
Make Value Flow without Interruptions	**Just-In-Time Production, Optimizing Production Throughput**	**Stability, Continuous Flow, Synchronous Production, Level Production**
Let Customer Pull Value	**Aligning Capacity with Market Demand**	**Pull System**
Pursue Perfection	**Zero Waste/Zero Defects**	**Continuous Improvement**

Figure 5.1
Linking Lean Thinking with Lean Manufacturing

Based on a set of metrics, the company's manufacturing system was designed to support lean principles, identify waste, and continuously improve toward a lean ideal. The metrics allow work groups to assess their current performance, drive for improvements, and support the manufacturing system principles. Due to its proprietary nature, however, the details on these metrics can not be disclosed in this thesis.

When a work group implements the company's new manufacturing system to their application area, they will collect data to track and analyze the system's metrics over time and drive for improvements using lean principles. To drive process improvements as measured by the system metrics, work groups first identify their current process (value stream) using the Current State Mapping (CSM) process.

Once the value stream has been identified through current state mapping, lean principles can be applied to identify opportunities to eliminate waste. All processes should be linked together such that upstream processes make only what the next process requires when it requires it. The process should be a smooth flow with the shortest lead-time, lowest cost, and highest quality.

CSM and the company's manufacturing system metrics are used to evaluate, identify, and prioritize opportunities for improvement. Based on this analysis, action plans to drive improvements are developed and stretch objectives to drive continuous improvement are set. Tools such as Visual Factory, Total Productive Maintenance, Quick Changeover, and Error Proofing are used to implement lean principles.

With a basic understanding of lean principles and the use of the company's lean manufacturing behaviors as a reference model, we are now ready to expand the application of

lean principles from manufacturing to the complete value stream associated with the fuel system enterprise. The basic lean principles of specifying value, identifying the value stream, making value flow, letting the customer pull value, and pursuing perfection will be applied to the value stream of the fuel system enterprise. Lean principles will be applied to the whole value stream, including product development, in a similar manner to that in which the company has applied lean principles to its manufacturing processes.

Chapter 6:

Applying Lean Principles to a Fuel System Enterprise

After establishing a general background for lean principles and describing their implementation in manufacturing settings, lean principles will now be applied in a similar manner to the fuel system enterprise. Most of the lean concepts explained in the previous chapters can be readily extended to the enterprise level. These lean concepts include specifying value, identifying the value stream, making value flow without interruptions, and pursuing perfection. The one exception is in the lean concept of letting the customer pull value. In section 6.4, pull is shown to be of limited value in applying lean concepts to the fuel system enterprise.

6.1 Specifying Fuel System Value

Successful companies provide value for all stakeholders such that win-win situations create enough value for all to prosper. The company itself will not prosper unless enough value is created for the prime stakeholders such that customers don't go to competitors, investors don't invest elsewhere, and employees don't seek employment in other companies.[13]

In *Lean Thinking,* Womack approaches value as a measurement relative to perfection – an idealized state without waste.

[13] Donovan, John, Richard Tully, and Brent Wortman, *The Value Enterprise.* Toronto: McGraw-Hill Ryerson (1997), p. 18.

In his 1999 MIT thesis; *The Application of Lean Principles to the Military Aerospace Product Development Process*, Robert Slack not only defined what customer value meant in a lean framework, but also developed a formulation to quantify it:

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

Where:

N = the need for the product or service

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

f(t) = time function

C = the cost of the product or service

This formula allows quantitative measurement of value. It is based on Slack's framework given in Figure 6.1:

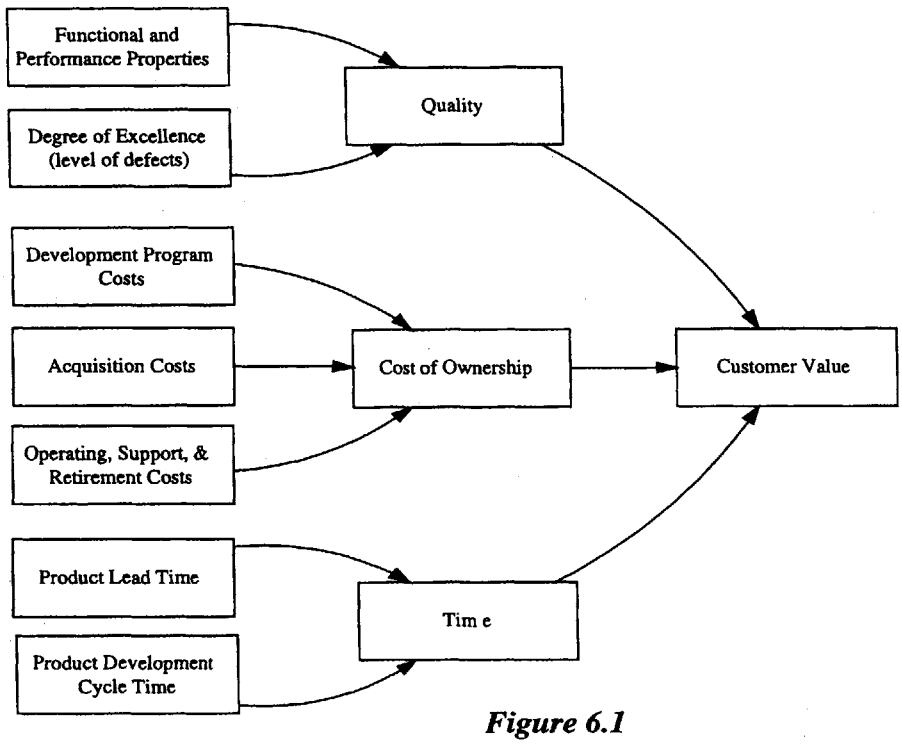


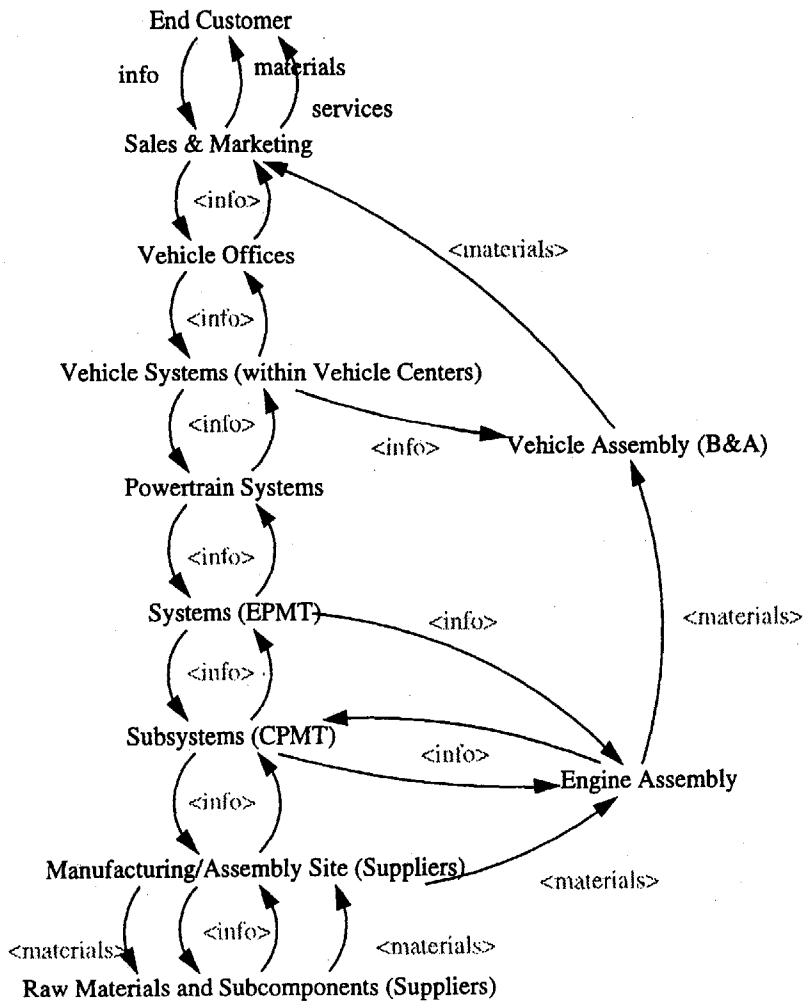
Figure 6.1
Value Framework

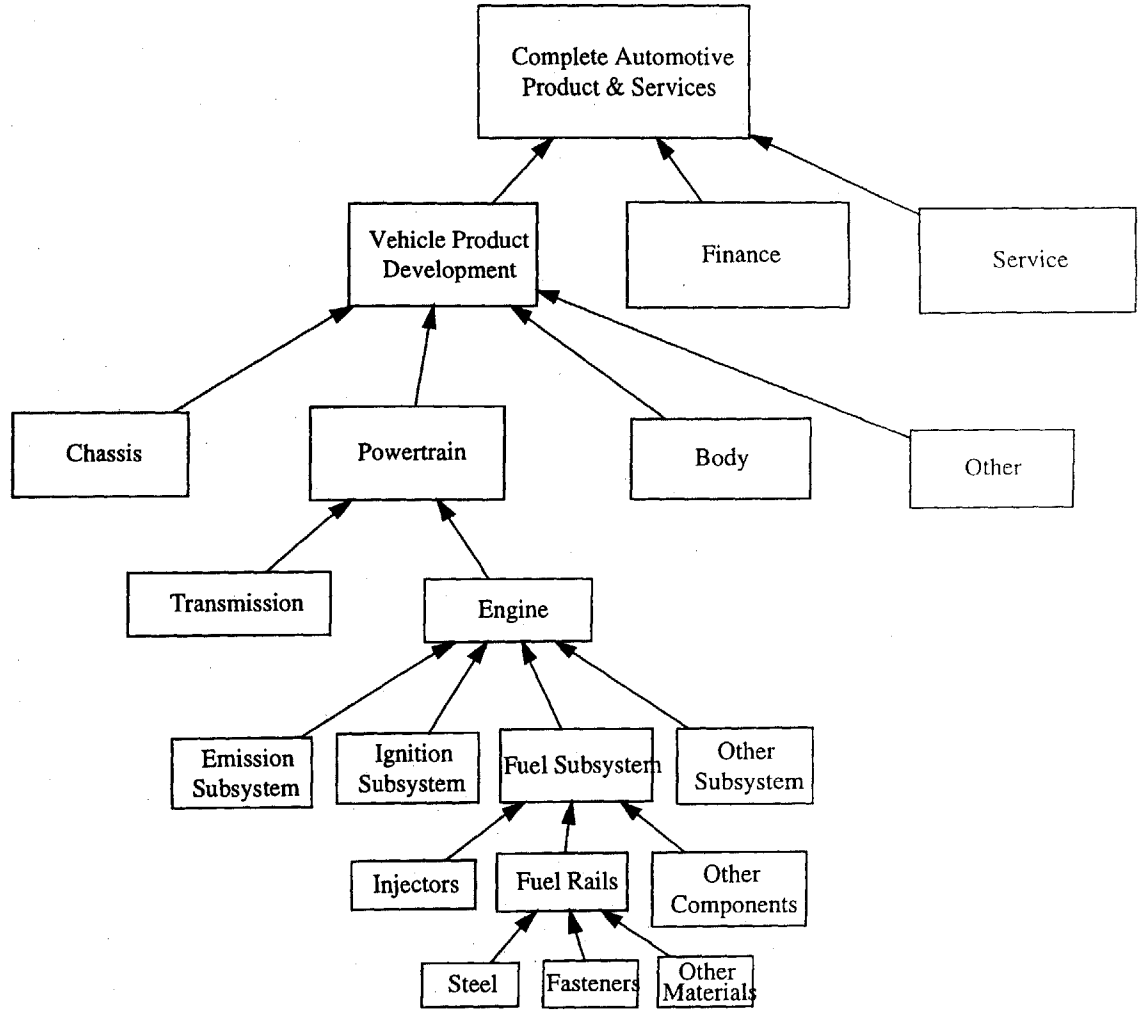
6.1.1 Defining Customers

In applying lean principles to an enterprise, multiple value perspectives must be considered. The customer for whom value is defined depends on the scope of the analysis. Different sets of customers define value for different levels of enterprises. When defining value for the highest organizational level, the extended enterprise (which includes the entire company, its suppliers, and environment), value is specified for the final customer purchasing the end product. Specifying value for the end customer yields a high level perspective that is most beneficial for the company.

The value chain for a product can be unclear, however, when the scope of the analysis is narrowed to the level of subsystems and components for a final product. For example, when the enterprise is defined as the fuel system enterprise as opposed to the complete vehicle. In the subsystem case, different organizational layers within the company overlap and act as surrogate customers. Lower level organizations within the company supply higher level organizations with components. These components are built into higher level systems and then passed on to the next higher level organizations to build even greater systems until the final product is complete. The different layers within the organization typically have different scopes and define value in terms of the next layer of the organization that they provide product for. To further complicate matters, lower level organizations often supply products for several different higher level organizations. As an example, Figure 6.2 shows the value chain that exists for a fuel system enterprise within the automotive extended enterprise and how customer relationships link to products.

Figure 6.2:
Value Chain for Fuel System Enterprise – Customer Relationships and Links





This thesis limits the scope of the lean analysis to the enterprise responsible for fuel subsystems. It is assumed that the highest level organizational layer has correctly interpreted final customer values and has cascaded this information to the next lower organizational layer. Each successive organizational layer translates the values cascaded from the next higher organizational layer and further cascades value information to the next lower organizational level. In this way, the assumption can be made that the fuel system organization must only consider the value of its product from the perspective of the next higher level organization within the company that it provides product for.

The results of this analysis will, therefore, be limited to benefiting the fuel subsystem organization and the next higher level organizations it provides products for. In theory, the same approach could be applied to higher levels of the organization with greater scope to further benefit the company.

Figure 6.3 models the automotive fuel system enterprise used for analysis in this thesis. Component Program Module Teams (CPMT's) are organizations responsible for the development and care of engine subsystems such as fuel subsystems. CPMT membership includes internal engine system and subsystem design and release engineers, manufacturing engineers, purchasing agents, and on-site component supplier engineers. The direct customers of CPMT's are Engine Program Module Teams (EPMT's) who assemble the various engine subsystems to create automotive engines. EPMT's are internal teams with overall responsibility for engine programs within the automotive company. EPMT membership includes vehicle system engineers, engine system engineers, and vehicle level purchasing agents. In a similar fashion, EPMT's interact

with teams responsible for Powertrains. These teams interact with higher level groups responsible for vehicle programs.

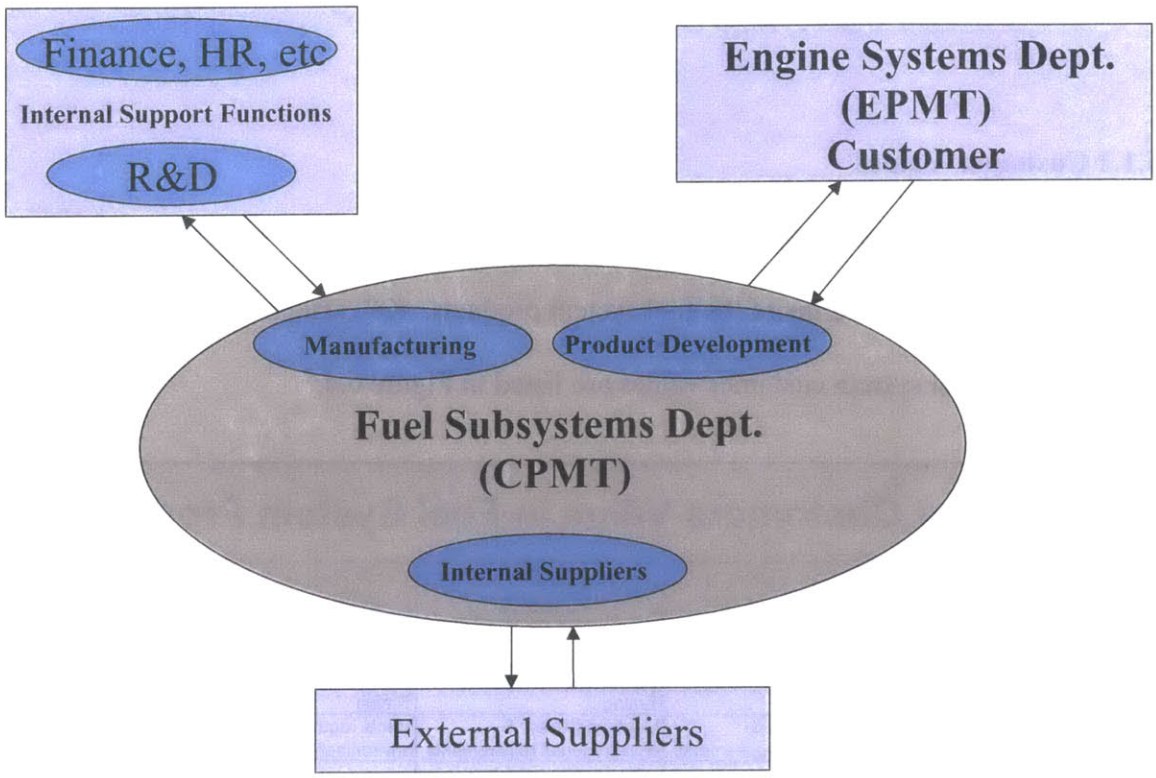


Figure 6.3
Current Enterprise Structure

Fuel system enterprise stakeholders include:

- Subsystem manufacturing plant (component & subsystem) - one organization level down from fuel subsystem organization
- Engine Assembly Plants - equal level
- Engine System Engineering (EPMT) - one level higher
- Vehicle Office and Vehicle Centers - two levels higher
- Vehicle Assembly Plants - two levels higher
- End customers purchasing vehicles - several levels higher

- Company shareholders - several levels higher
- Government and other regulatory bodies - several levels higher
- Company employees

6.1.2 Customer Values

As customers of the fuel system enterprise, the various fuel system stakeholders have multiple values in terms of the fuel system products. Key stakeholders and their most relevant fuel system customer values are listed in Figure 6.4.

What Customers Value in Fuel System Products

Engine Assembly Plant	Engine Systems Engineering	Vehicle Offices & Centers	End Customers	Shareholders
Cost / Profit	Cost	Cost / Profit	Cost	Return on Investment (profit/cost)
Ease of Manufacturing	Functional Performance	Functional Performance	Functional Performance	
Timing	Timing	Timing	Timing	
Problem Support	Meets regulatory & environmental requirements	Meets regulatory & environmental requirements	Meets regulatory & environmental requirements	
Quality, Reliability, Durability	Quality, Reliability, Durability	Quality, Reliability, Durability	Quality, Reliability, Durability	
Robust, Stable Design	Safety	Safety	Safety	
	Seviceability	Serviceability		
	Robust, Stable Design	Robust, Stable Design		

Figure 6.4
Fuel System Enterprise Customer Values

Several of the customer values are typical across most stakeholders such as cost, timing, functional performance, and quality. The differences are important to note, however, because they often yield clues to sources of waste. When value is not cascaded correctly from the highest organization level (in terms of the final customer) down through the organization, wasteful effort often results. Lower level organizations can expend valuable resources to create products for higher level organizations that can not be traced back to the final customer. In this case, organizational policies have been

created for the sole purpose of the organization or to utilize existing assets. But, these types of wasteful products do not support the value chain to the final customer and ultimately waste precious resources. The flow of values must, therefore, be carefully cascaded and aligned to avoid wasting resources on products that serve only organizational policy needs, but do not add value to the end customer.

An example of such a waste can be seen in the multiple documents suppliers are typically required to create for the various levels of the automotive company. Often the same data must be reformatted into different documents for the various levels of the automotive company. Although this information may help the enterprise track and meet important customer values such as timing or costs, no stakeholders value redundant data for the data's sake. The redundant data can, therefore, be considered wasteful since it is serving only an organizational policy, but not adding value for end customers. A much better solution would be to generate and use the data once for the entire enterprise and not create redundant documents.

To provide value to its customers, Fuel System CPMT's produce the following products:

1) Processed information
    a) Fuel subsystem designs that:
        i) Are validated to meet subsystem functional, quality, timing, and cost targets
        ii) Integrate subcomponent designs
        iii) Fit and function with other engine subsystems
    b) Convey information

i) Cascade requirements to component level

ii) Release designs to plants that can be manufactured

iii) Report functional, quality, timing, and cost information to EPMT

2) Fuel Systems that:

a) Meet functional, quality, timing, and cost targets

b) Can be built into engine systems

3) Services

a) Support Field Concerns

b) Support Manufacturing Concerns

6.2 Identifying the Value Stream of the Current State Fuel System Enterprise

Since activities that can't be measured can't be properly managed, identifying the fuel system enterprise's value stream is a key step in the application of lean principles. Once the enterprise's processes, resources, flow of information and materials, tools, technologies, metrics, and incentives have been identified, they can by analyzed in a lean context.

To identify the current value stream of the fuel system enterprise, several lean analysis techniques were employed. These techniques included process mapping, resource mapping, and input/output flow diagrams. Using process mapping for an enterprise is similar to using value stream mapping typically found in manufacturing settings. Process mapping is used to identify all major processes in the enterprise from concept initiation to final sales and service of the product. Process maps can be made to define the current state of the enterprise and also the desired future state of the enterprise after lean initiatives have been implemented.

Resource mapping was also used to identify the current state of the enterprise. Resource mapping identified the time, cost, and worker headcount associated with each process as defined in the process map.

Finally, input/output flow diagrams were used to identify the flow of information and materials through the enterprise. In addition, the tools and technologies used to transfer information and materials are defined in the input/output flow diagrams.

The goal of this analysis was to gain a systemic understanding of the enterprise's processes and their interconnections so that areas of waste and inefficiency can be identified. These problem areas which show potential for lean improvement will be viewed through the value perspective of the enterprise customers developed in the previous section. Once non-lean issues have been identified, they can be measured, and addressed.

6.2.1 Process Mapping

Figure 6.5 identifies the major enterprise elements that comprise the fuel system development process. This process map was developed by interviewing several CPMT members and integrating this information with the personal experience of the author.

The process begins with Marketing personnel identifying end customer needs at the vehicle level. A Program Direction Letter (PDL) addressing market opportunities is then formulated to authorize company resources for a vehicle program. The PDL integrates input from Marketing, Advanced Engineering/R&D, Strategy/Planning, and Finance and must be approved by top management.

Once the PDL has been kicked-off, a timeline is developed for a vehicle program (new vehicle development, or existing vehicle 'freshening') to meet this perceived customer demand. Resource requirements are analyzed and provided for the program. High level information is cascaded down through the respective vehicle super-system 'chunks' (in our case, Powertrain to Engine System to Fuel Subsystem) where the needs and timing are decomposed into system level specific requirements. Concept generation takes place at each system level. As concepts that require enhancements to the Fuel Subsystem are identified, appropriate teams are formed to investigate. These (sub-system) teams further refine the previously identified needs into Functional Requirements/Specifications. Based on input from Purchasing and Engineering, key suppliers will be selected at this time to participate in the development. While selection at this time is no guarantee, it does put a supplier in a preferred status (where it is 'their business to lose'). With the aid of supplier involvement, component selection of the design takes place. This purchasing led stage is completed with cost/timing estimates in the form of target agreements for all critical components.

Design options are then evaluated through a D-FMEA (Design Failure Modes & Effects Analysis) process that analyzes failure modes and their effects. Selected design options are further detailed in CAD/CAM and a subsystem design is developed to integrate the various fuel components into a functional system. A corresponding Bill of Materials (BOMs) is generated from the subsystem design. The 'design weighted' phase ends with the validation testing of prototypes (and corresponding updates to the D-FMEA documentation). Failures in validation testing lead to iterative loops through the D-FMEA process, redesign, generation of new part numbers, and revalidation. The 'manufacturing weighted' phase begins with the formal process in which manufacturing representatives of the CPMT investigate and judge the feasibility of manufacturing a design. Once manufacturing feasibility of a design has been approved, manufacturing options are evaluated through a P-FMEA (Process). Upon completion of the manufacturing process development and a validation build (including test), the sub-system is 'PSW' (Product Submission Warrant) certified and P-FMEAs are correspondingly updated. PSW signifies that the design functions as intended and that it can be reliably manufactured. The sub-system design is then officially 'released'. This triggers Purchasing to order (and suppliers to build) components in predetermined volumes. Next, Fuel sub-systems are assembled. Depending on the design, this is typically done either at a major supplier, or at an Engine plant. The fuel systems are delivered with the Engine to the Vehicle assembly plant. Following the sale of vehicles through the dealership network, several ongoing actions take place throughout the life cycle of the product. These ongoing actions include:

- Tracking field performance through warranty monitoring,
- On-going improvement (including cost reductions to designs), and
- Supplying parts to service depots for field replacement

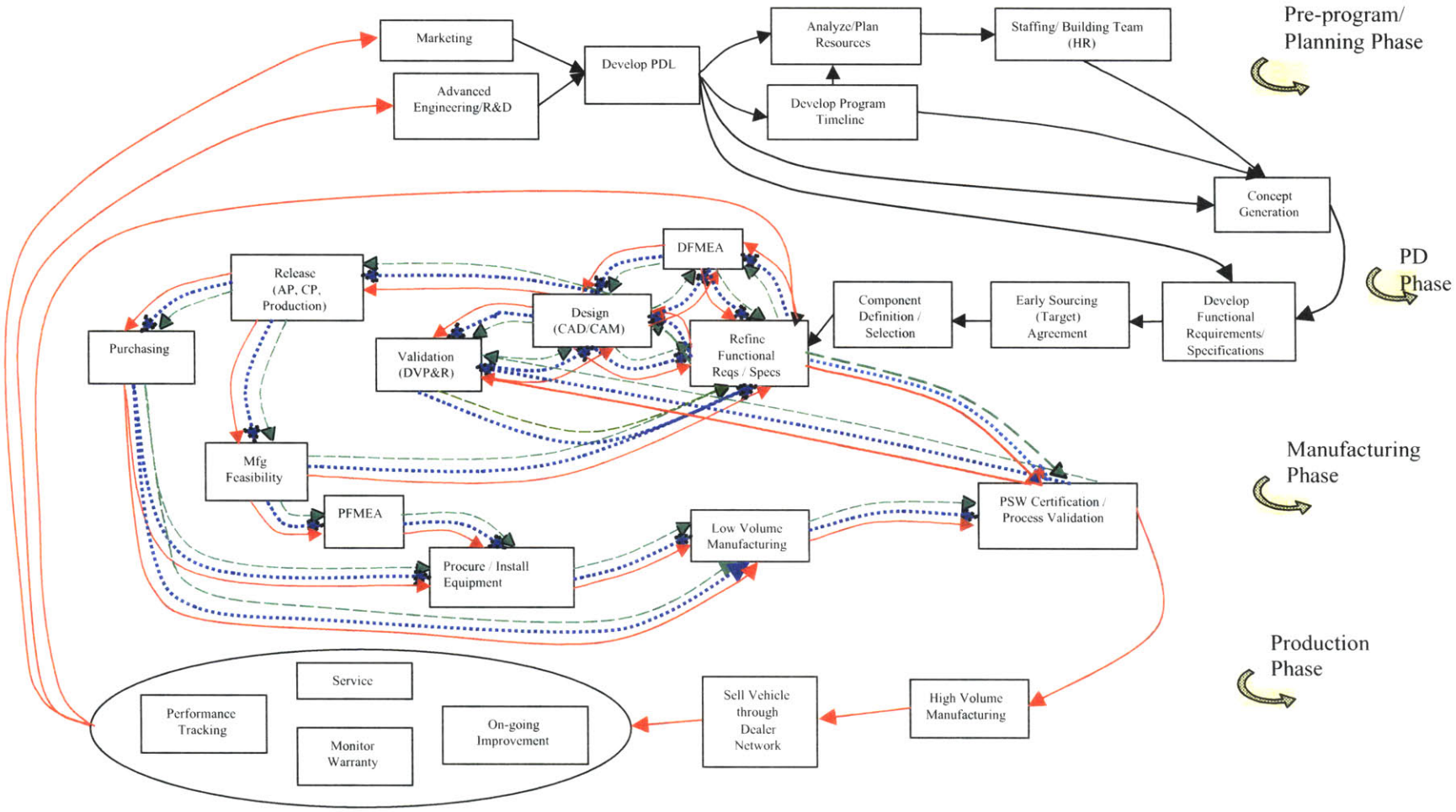
Information collected from these activities is fed back into the concept generation process for future programs thereby completing the main loop.

Several smaller iterative loops occur during the process. Since the overall automotive vehicle is very complex, it is very difficult to know if a design will truly work until the entire super-system is assembled and tested. The automotive company conducts a series of full vehicle level builds in order to gain this knowledge and identify any system level conflicts. Three main builds occur during a vehicle program and are supported with hardware as follows:

- Advanced Prototype (AP): Corresponding to 'design intent' (DV) prove-out
- Confirmation Prototype (CP): Corresponding to 'process intent' (PV) prove-out
- Production (Job 1): High volume manufacturing (PSW parts)

Advanced prototypes are typically tested in lab mock-ups or workhorse vehicles. They are intended to test functional performance to expectations, but may be built from prototype processes with prototype materials. They are intended to give quick directional validation information. Confirmation prototypes are intended as a final validation that designs function as expected when tested on hardware built from the intended manufacturing process. The final production validation is intended to confirm that manufacturing facilities can produce hardware to expectations in higher production volumes. In the current state process map, the AP loop is designated by dashed green lines, the CP loop is shown by blue dotted lines, and the Production loop appears as red solid lines.

Figure 6.5
Fuel System Enterprise Current State Process Map



Iterative loops for Advanced Prototype (AP), Confirmation Prototype (CP), and Production (Job 1) series and failures.

A second tier process map can be drawn for each individual box shown on the first tier current state process map. Second tier maps help further analyze individual process steps in greater detail. For example, if a particular problem was thought to exist with one of the processes internal to the enterprise (such as DVP&R or Low Volume Manufacturing, etc.), this process could be analyzed in greater depth with a process map that further defined the process's internal steps. But, since this analysis is on the enterprise level, no second tier maps were utilized.

The current state process map identified the key processes that occur within the fuel system enterprise and how they connect to one another. It will serve as the basis for understanding how the fuel system enterprise operates as a system.

6.2.2 Resource Mapping

Continuing with the notion that what can not be measured can not be properly managed; a means of measuring the enterprise's resources must be established in order to improve them. In the last section, the enterprise processes were identified through current state process mapping. In this section, resources associated with enterprise processes are quantified in order to better understand and improve them. Resources are defined in terms of the time, money, and headcount associated with the development of a typical fuel system.

Figure 6.6 shows the typical enterprise resources required for the development of an average scale "6" level (see design scaling below) fuel system. The resource data was generated through multiple interviews with CPMT team members and the author's first-hand experience. Due to proprietary reasons, the actual data has been disguised, but relative numbers remain proportional.

Process Number	Process Description	Times*			People*			Money*		
		- AP-	- CP-	- Prod-	- AP-	- CP-	- Prod-	- AP-	- CP-	- Prod-
1	Marketing	48	-	-	20	-	-	N	-	-
2	Advanced Engineering/ R&D	72	-	-	10	-	-	240	-	-
3	Develop PDL	12	-	-	20	-	-	N	-	-
4	Analyze/Plan Resources	4	-	-	10	-	-	N	-	-
5	Develop Program Time Line	4	-	-	10	-	-	N	-	-
6	Staffing/Building Teams	8	-	-	10	-	-	N	-	-
7	Concept Generation	4	-	-	8	-	-	N	-	-
8	Develop Functional Requirements/Specifications	6	-	-	18	-	-	N	-	-
9	Early Sourcing (Target) Agreements/Cost Estimates	24	3	-	18	12	-	N	N	-
10	Component Definition / Selection	6	3	-	18	8	-	N	N	-
11	Refine Functional Reqs/Specs	12	8	5	10	6	6	N	N	N
12	DFMEA	8	4	2	22	8	2	N	N	N
13	Design (CAD/CAM)	9	5	2	44	36	22	N	N	N
14	Validation (Plan, Test)	72	72	40	108	88	64	1,200	400	200
15	Manufacturing Feasibility	4	2	2	12	10	8	N	N	N
16	Release (AP, CP, Production)	5	3	3	24	24	14	N	N	N
17	Purchasing	4	2	2	30	24	24	N	N	N
18	PFMEA	16	8	2	22	8	2	N	N	N
19	Procure, Install, Ramp-up Production System	28	56	8	80	50	40	4,000	6,000	10,000
20	Low Volume Manufacture	40	30	20	30	60	120	6/Unit	4/Unit	0.24/Unit
21	PSW Certification / Process Validation	4	6	12	32	32	32	200	400	1,200
22	High Volume Manufacture	-	-	20	-	-	120	-	-	0.24/Unit
23	Sell Vehicle through Dealer Network	-	-	6	-	-	6	-	-	N
24	Service	-	-	24	-	-	6	-	-	0.002/Unit
25	Monitor Warranty	-	-	24	-	-	20	-	-	N
26	Performance Tracking	-	-	24	-	-	20	-	-	N
27	On-going Improvement	On-going	On-going	On-going	20	20	20	N	N	N

Figure 6.6
Enterprise Resources Mapped to Processes

* *Actual process times, number of people and amount of money were normalized due to their proprietary nature. For all three measures, a multiplier was used for relative scaling and units are assumed generic.*

N = Negligible (Less than 5% of total)

The resources defined in Figure 6.6 are based on several assumptions. These assumptions and some of their resulting consequences are listed below.

Enterprise Resource Assumptions

The process times in the development of fuel systems depends on the scope of the project. Some projects require completely new designs implementing new technologies whereas other simpler projects only require modifications to existing designs. The enterprise uses the following scaling parameters to estimate required resources:

Scaling Parameter	6	5	4	3	2	1
Change Description	All new programs in which analytical tools are not sufficiently developed	Design actions are within correlation of analytical tools	New use of Powertrain for non-structural engine actions	Minor package-driven changes	Very minor package-driven changes	No base engine, transmis-sion, or catalyst changes

For this case study, the worst case scenario in terms of length of time and amount of resources and development work was assumed. This corresponds to a scale "6" level program. Smaller projects are assumed to have cycle times that are scaled down proportionally to the amount of work involved.

When the headcount in Figure 6.6 was estimated, the system was viewed as an extended enterprise and included headcount of supplier and support companies. Since team members participate in multiple tasks, multiple projects, and even non-fuel system projects, the total

number of people involved in the development of a fuel system is less than the sum of all the people listed for each step.

The costs estimated in Figure 6.6 do not include the salaries or standard business expenses, such as facilities and overhead, involved in each step. The total of all negligible expenses is less than 5% of the total expenses.

Identifying High Priority Resource Opportunities

An analysis of the resources used in each enterprise process listed in Figure 6.6 yields insight into which processes offer the greatest opportunities for improvement. Since timing was shown to be a key stakeholder value in section 6.1, timing is used as the key resource in the following resource analysis. Timing is also related to other key stakeholder values such as cost (when processing time and personnel are accounted for) and quality (when rework is accounted for). The operation times of each enterprise process from Figure 6.6 were combined to produce the pie chart in Figure 6.7.

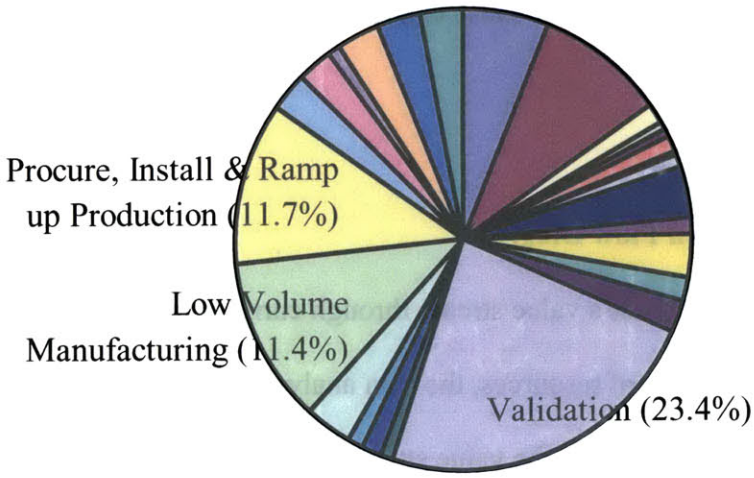


Figure 6.7
Process Times

This pie chart shows that the greatest percentage of timing resources are spent on Validation in the product development phase and the manufacturing processes (Procure, Install, Ramp-up Production System, and Low Volume Manufacturing) that support Validation with test parts. Together, these processes account for 46.5% of the entire development time! Validation can, therefore, be seen as the single greatest time resource drain in the enterprise.

The system effects associated with these resources should also be considered. Since the cycle of making prototypes and validating them represent such a significant proportion of the entire enterprise process time, efforts should be made to ensure that, at most, the process only has to pass through this cycle once. This means getting the prototype validation loop correct the first time through. Reducing the time required to make prototypes and validate them would improve the throughput time of the system. But, also ensuring that up-front processes are correct so that failures in prototype validation or changes that require this loop to be redone are reduced. This may mean that the biggest bang for the buck in improving the enterprise throughput timing could be gained by spending more resources on up-front processes to ensure that they do not contribute to prototype validation failures or cause changes that necessitate revalidation of prototypes.

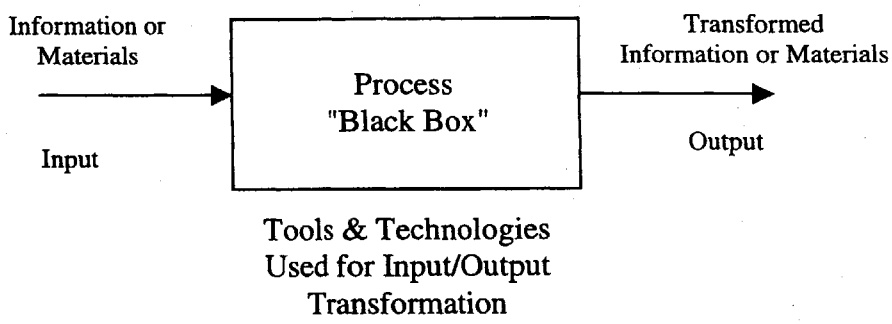
6.2.3 Input/Output Information Flow Diagrams

After identifying the enterprise's value stream through current state process mapping and establishing measurements in terms of resources, the lean analysis can be directed towards the flow of information and materials through the value stream. Analyzing the flow of information and materials through the system yields insight into the interrelations between process

components of the enterprise system. The goal of this analysis is to better understand how individual processes in the enterprise are interrelated and how value can be transferred through the system more efficiently. Input/Output Flow Diagrams are used to show how materials and information flow through the enterprise.

An Input/Output diagram is created by representing each process from the current state process map as a "black box." information or materials flow into the black boxes, are transformed by the "black box" process, and are then output to flow into the next "black box" process. An example of such a "black box" representation is given in Figure 6.8.

Figure 6.8
Input/Output Flow Diagram "Black Box" Model



This "black box" framework was applied to the fuel system enterprise to create the Input/Output diagram shown in Figure 6.9. This diagram shows the flow of information and material through the fuel system enterprise in the development of a typical fuel system. The "black boxes" used in the diagram were based off of the process flow diagram shown in Figure 6.5. The mechanisms for information and material flow, tools and technologies used to transform the information and materials, and flow times are also shown on the Input/Output diagram.

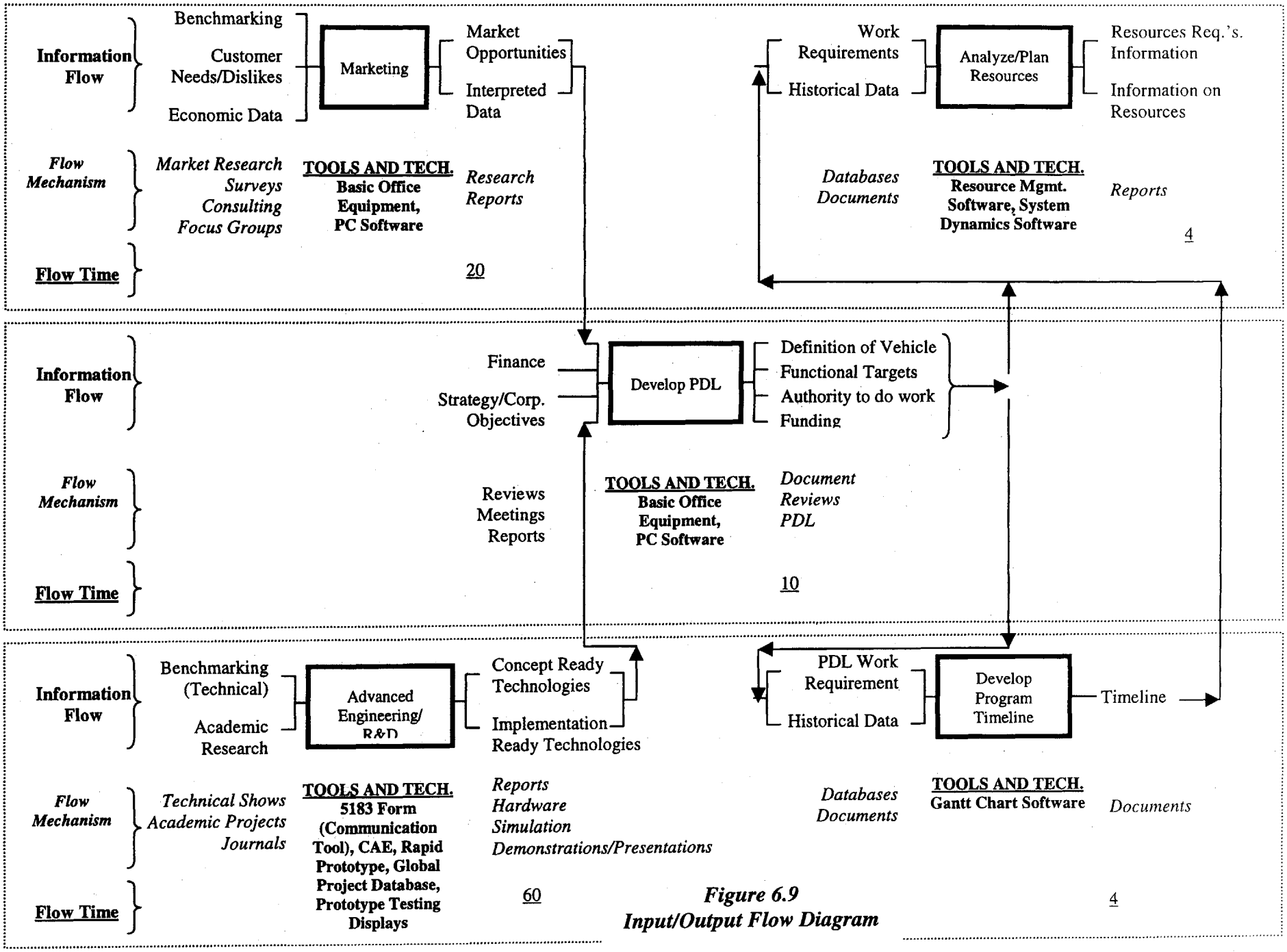


Figure 6.9
Input/Output Flow Diagram

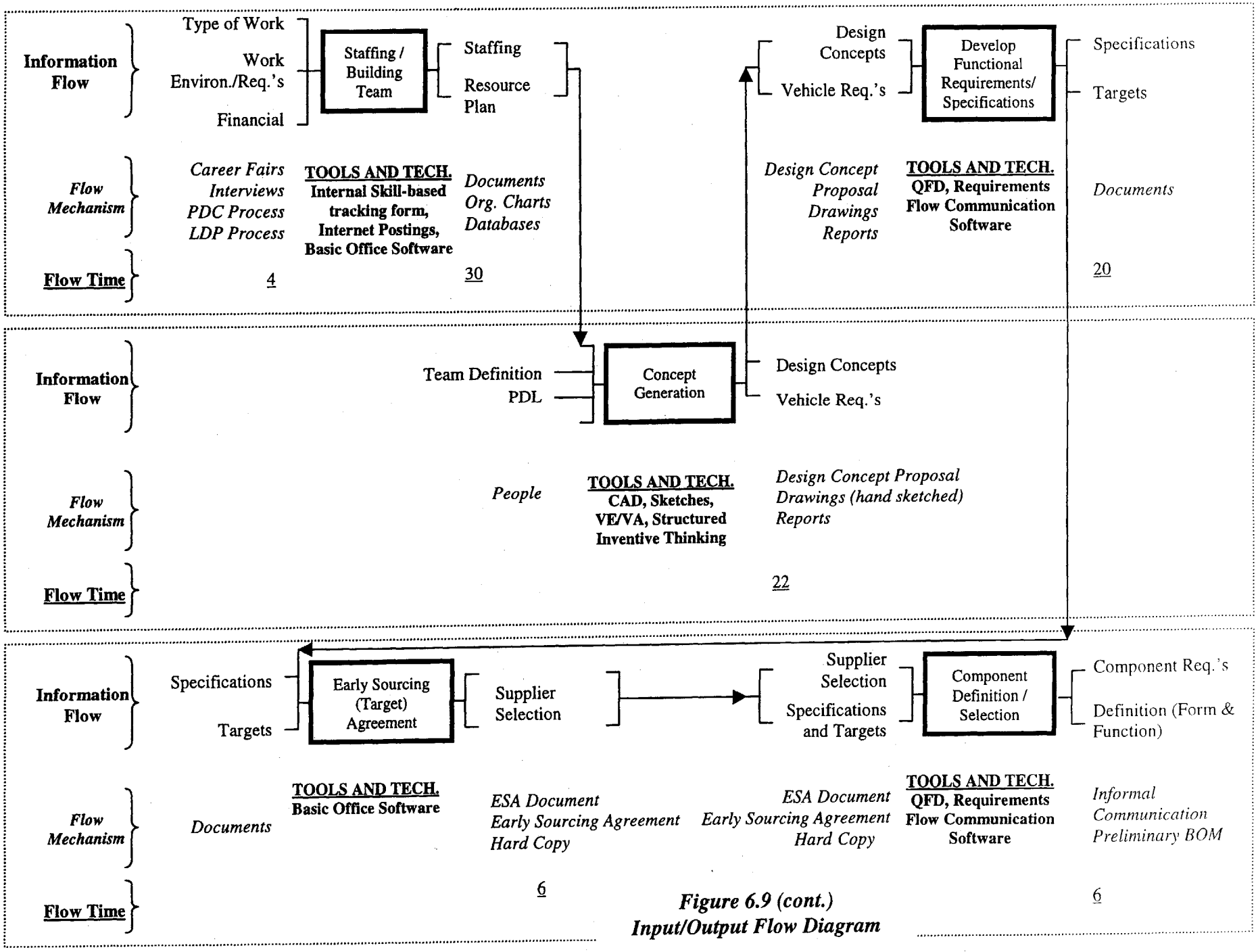


Figure 6.9 (cont.)
Input/Output Flow Diagram

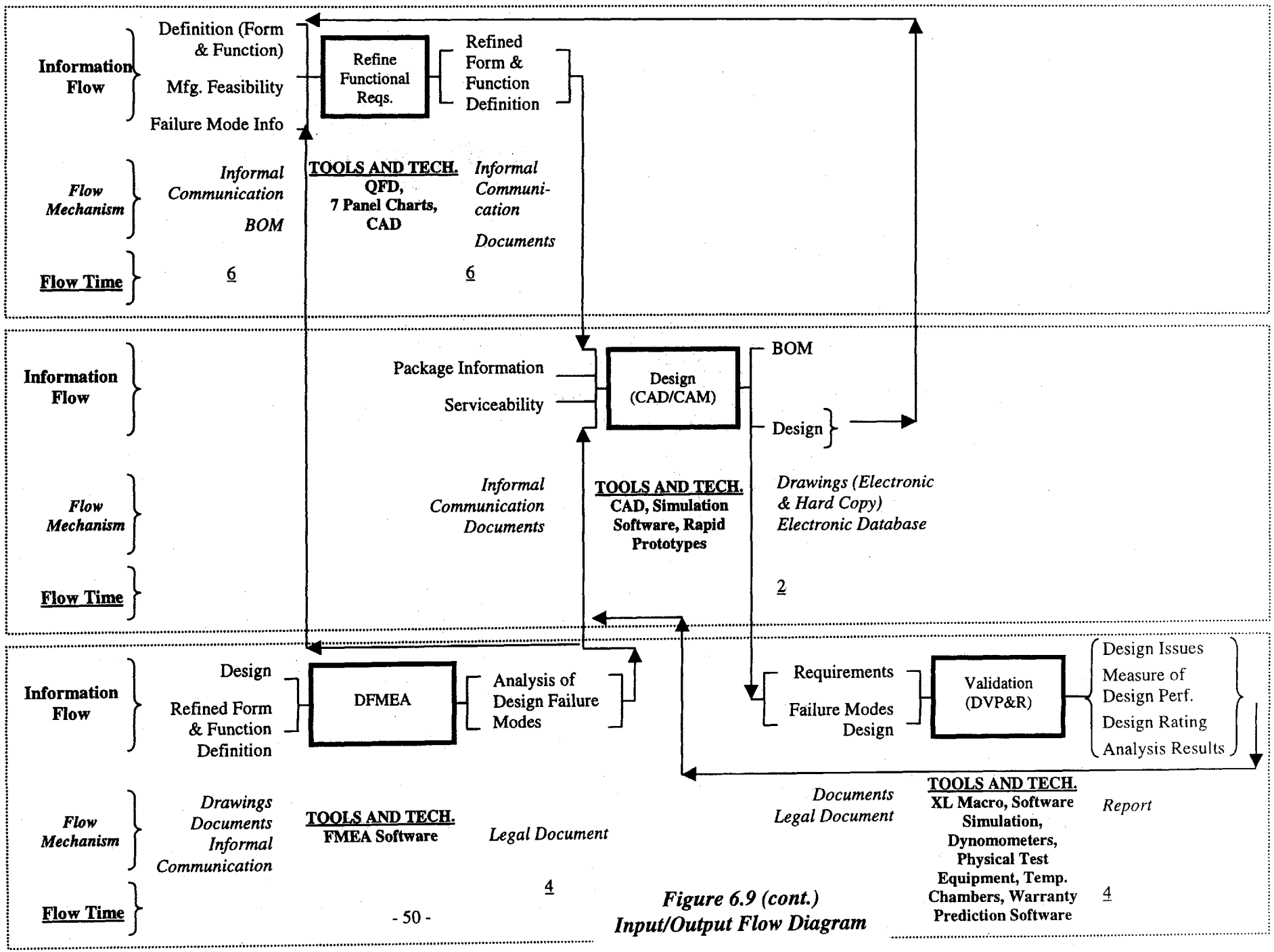


Figure 6.9 (cont.)
Input/Output Flow Diagram

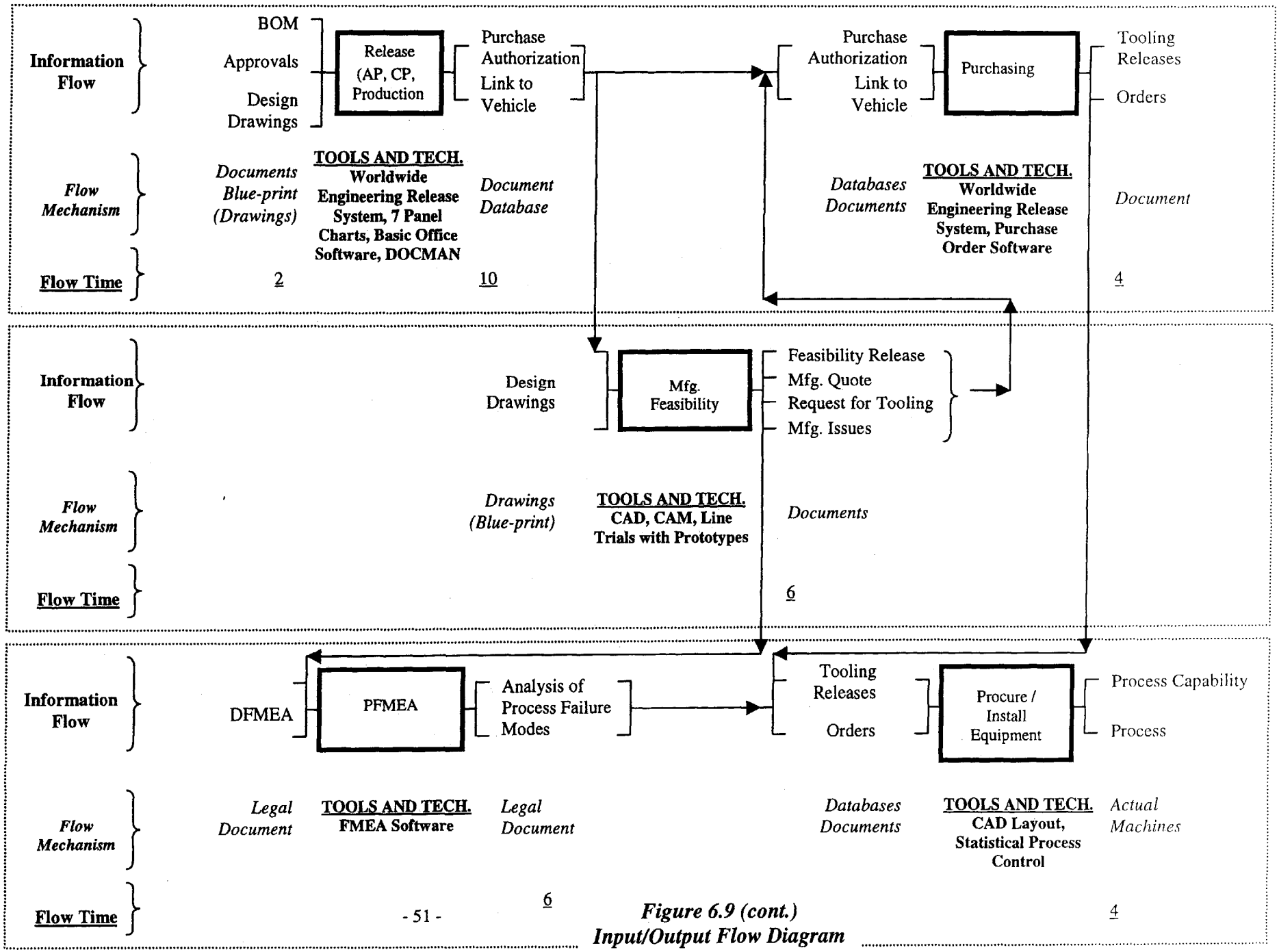


Figure 6.9 (cont.)
Input/Output Flow Diagram

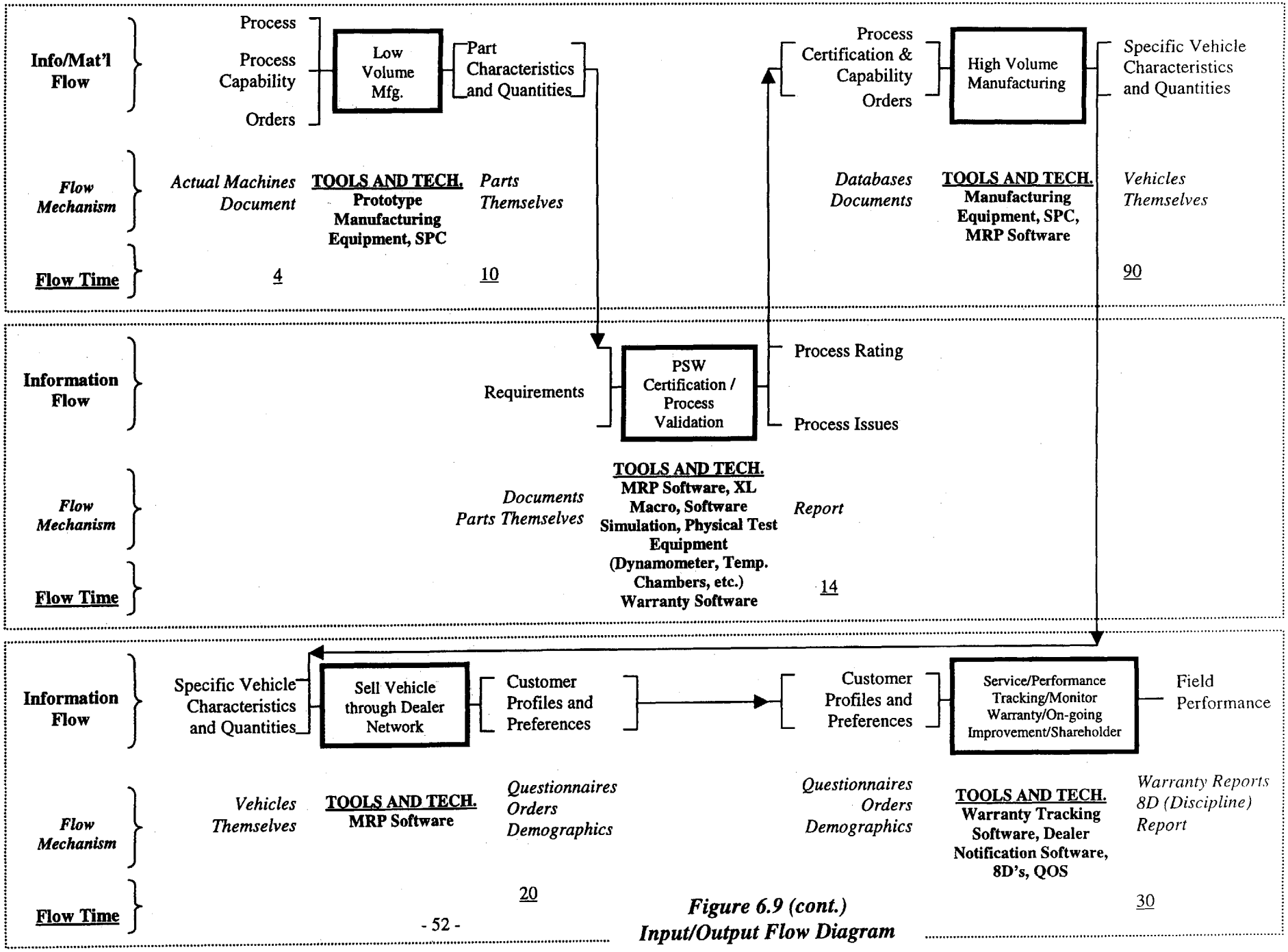


Figure 6.9 (cont.)
Input/Output Flow Diagram

Figure 6.10 defines the tools that are used to process information and materials in the fuel system enterprise and are labeled on the Input/Output diagram. In this analysis, tools are defined as the software, hardware, and processes that transform information or materials input to the process steps to the information or materials that are output. There are a few overarching tools that are not shown in the diagrams since they overarch several process steps. These tools include the enterprise's phase gate control process and the enterprise's and Advanced Product Quality Planning (APQP) process to control suppliers to enterprise expectations.

Resource Management Software – Software that outputs projected requirements for headcount and budget allocations based on receiving a project 'scale' classification input.
System Dynamics Software – Software for analyzing 'what-if' scenarios involving varying allocations of resources, can be used to determine potential effects on timing, etc.
5183 Form – A one-page document detailing critical information about an advanced project (cost, timing, development status, etc.).
Global Project Database – Ford's 'technology stream'. A widely accessible database which vehicle program managers (or other advanced eng. Groups) can browse/search in order to find out about what types of advanced work is occurring within the company.
Internal Skill-based tracking form – All Ford employees have this form on file with the company. It contains information about the employee's experience and future interests. Forms are circulated through HR committees to get matches when new openings arise.
Requirements Flow Communication Software – An automated system used to communicate requirements between the vehicle, engine, fuel subsystem, and component engineers and management.
VE/VA – Value Engineering/Value Analysis. A process used to identify subsystem requirements and opportunities to reduce costs and improve functionality. Within Ford, this has become a 'supplier cost reduction meeting'. Suppliers are tasked to reduce costs to Ford by some percentage each year. If a supplier is having difficulty committing to these tasks, VE/VA sessions are held between Ford and the supplier in order to 'help' the supplier identify area to cut costs.
Structure Inventive Thinking – A creative (brainstorming) exercise based on Altschuler's technique of decomposing items into a mutually exclusive, collectively exhaustive framework. Design alternatives are generated by considering alternatives by from other combinations within the framework.
7 Panel Charts – A one-page summary document which details critical information on CPMT business
FMEA Software – Software which aids in documenting the analysis of failure mode studies of a design in a standard format such that it is easily shared with other team members.
Dynamometers – Test equipment that can be used to simulate the vehicle loading on an engine under various driving conditions. This allows 'field like' simulation of engine components in a laboratory environment.
Temp. Chambers – Test equipment used to expose devices under test to a wide range of temperature and humidity conditions in a controlled manner.
Warranty Tracking Software – Ford gets warranty repair data from all major dealerships. Early in the launch of a new product, this data is monitored closely for adverse trends. 'Running (design) changes' are often rushed into production to mitigate any adverse trends detected.
Worldwide Engineering Release System – A widely (globally) accessible database in which critical design information (part numbers, costs, etc.) is captured in a standardized format. Users are able to electronically 'sign-off' on approval screens and route the electronic document to other team members.
DOCMAN – PC based software that allows CAD (Unix workstation) drawings to be accessed and viewed graphically, locally at PC station.
Statistical Process Control (SPC) – Techniques for measuring the accuracy and repeatability of a manufacturing processes ability to produce product. Critical (or significant) features which affect the functionality (or value) of a product are measured and trended. Negative trends are to be addressed prior to the product reaching an unacceptable level.
Dealer Notification Software – An electronic database and communication program maintained with all major dealerships. Through this system, the automobile manufacturer can provide participating dealerships with broadcast messages regarding enhancements to repair procedure documentation. These dealerships are also able to search a database for recommendations regarding identified field issues.
8D's – Eight (8) Disciplines. A standardized method for solving and documenting problems. Root causes of problems are identified, and both containment (short-term) and corrective (long-term) actions are identified.

Figure 6.10
TOOL GLOSSARY

The documented flow times were based on average flow durations reflecting typical waiting times and not based on the maximum speed in which information or materials could be transferred under ideal circumstances. The flow data includes only the typical transfer time from when information or material is output from one process to the time when it is input into the next processing step. It does not include any waiting time associated with individual sub-processes internal to each "black box."

Due to the proprietary nature of the flow times, the data was disguised using the same generic time units from the current state process map. When the flow time of the information or material output of one process is the input of another process, only the output flow of the first process was labeled on the diagram. Flow data used to generate the Input/Output flow diagram was based on several interviews with CPMT team members and the author's own first-hand work experience.

6.3 Make Value Flow without Interruptions

In the previous sections, value was defined in terms of the enterprise stakeholders. Then, the processes representing the enterprise's value stream, the flow of information and materials through the enterprise, and the tools and technologies used to transform information and materials were identified. Now, this section will apply the lean principle of making value (in the form of information and materials) flow without interruptions through the enterprise.

First, several major insights from the process map, resource map, and input/output flow diagrams are uncovered. These insights are analyzed and prioritized in terms of customer values to find key non-lean issues that create wasted and inhibit value from flowing through the enterprise without interruptions. These key issues are shown to be waiting, rework, and excessive validation.

Once the key issues that create waste and interrupt flow in the value stream are identified, countermeasures are proposed to enable the enterprise to reach a leaner state. This leaner state will reduce wasted and allow value to flow more efficiently through the enterprise. Finally, a future state process map is presented. The differences between the current state and future state process maps are detailed in a gap analysis.

6.3.1 Insights into Non-lean and Flow Issues

An analysis of the current state process map and the associated resource map uncovered the following insights:

- Process step times can vary significantly between different fuel system programs depending on the specific requirements of each program.

- Demanding scheduling pressures and a lack of cohesiveness between separate organizations within the enterprise can create situations in which one process step has not been fully completed before the next subsequent process begins. When this happens, the process times for these steps overlap.

- If a process passes-on incorrect information to subsequent processes, the failure is typically identified in later stages of the development process. For instance, marketing requirements frequently change during the development of a program. As the marketing requirements change, much of the work already completed on the program must be redone. This type of failure can cause significant rework and additional time and resources. However, this type of failure is not fully captured and depicted in a process flow model. This places increased emphasis on getting tasks done right the first time.

- Much of the actual time spent in a development program is associated with waiting for hand-overs of information or delays because one task can not start before an earlier one is complete. Sometimes a task may begin before a required proceeding task is completed and then have to be redone as information from the predecessor becomes available. When this occurs, a significant amount of wasteful rework can be generated. These types of time requirements are not fully captured and depicted in a process map.

- Steps 14 (Validation), step 19 (Procure, Install, Ramp-up Production System), and step 20 (Low Volume Manufacture) require the largest number of people to complete. This occurs because these steps involve labor intensive operations of physical equipment and product.

- Although vehicle level validation requires the most time to complete, it does not require a large number of people. This is due to the long lead times required to physically set up and test systems.

- For every cycle (AP, CP, and Production), the Procure, Install, Ramp-up Production System step requires the largest budget allocation. This is due to the high cost of manufacturing equipment. Also, the Production cycle itself requires more budget allocation than the AP or CP cycles for the same reason.

Analyzing the Input/Output Flow diagrams yields many insights into the flow of information and material through the enterprise. Several enterprise level issues such as informal flow rates, version control, and reliance on hardcopies are unique to the flow of information. Other flow issues at the enterprise level showed a close resemblance to issues typically focused on in the lean analysis of production systems. Typical areas in which wasteful flow is found in production facilities include over production, inventories, transport, unnecessary motion, waiting, over processing, and defects. These same areas also represent wasteful flow on the enterprise level.

Formal vs. Informal Flow Rates

Informal information typically flows faster than formal information. Informal e-mails and phone calls often provide a 'heads up' of critical events prior to related official reports being authored and/or distributed. This situation often results in the importance of the official event being reduced. This also results in waste in the system due to redundancies between formal and informal information. The important question then becomes which flow path, the formal or informal, is the wasteful one.

Information Version Control

The fuel system enterprise process is concurrently operating at multiple levels (system, sub-system, and component) with intermediate deliverables (AP, CP, Production). Documents that cut through multiple levels are often being updated by one group while simultaneously being used by other groups. Many changes are often "batched" into one large document update. In the mean time, some groups are working with what is known to be out of date documents, often generating waste and rework. This raises two questions:

1. What is the optimal batch size for change control for information? In manufacturing, reducing machine set up time enabled a reduction in the optimal batch size leading to "single piece flow". Can a similar enabler be identified for information flow?

2. Does it make sense to continue some work, even if it is known that the upstream information has changed?

Reliance on Hardcopy

The working distance between activities increases the reliance on hardcopy. Suppliers tell war-stories of being burned by kicking off work/expenses prior to receiving official purchase orders, only to get stuck with obsolete inventories when orders were cancelled. Similarly, different departments are unwilling to commit resources until the project is officially documented as approved. This occurs even when all team members involved recognize it as only a formality awaiting a high level signature. It seems that informal communication can provide improved response/reaction times. To improve the efficiency of the enterprise system, more efficient ways of formalizing communications that are currently informal are needed and the waiting periods associated with high level reviews need to be reduced.

Flow Issues Typical at the Production and Enterprise Level

In a lean analysis of a production facility, the flow of parts through the factory floor is often analyzed to find opportunities to eliminate waste and make the process more efficient. A similar analysis can be conducted on the enterprise level. For example, the flow of information and materials through the fuel system enterprise can be analyzed to find opportunities to eliminate waste and make the process more efficient.

Over Production

Data can be viewed as wasteful any time that it is created and not used by any subsequent task in the value stream. For example, this can occur in the fuel system validation task when tests are run, but the resulting data is never used.

Inventory

When changes occur in the process, but subsequent tasks are not informed of these changes, the subsequent tasks may be working with outdated and obsolete information that was placed in an information "inventory" for later use. This can lead to rework and a lot of wasted time and resources when the correct information is eventually passed down. For example, Marketing may discover halfway into a project that customer preferences have changed and the customer requirements it previously cascaded are now incorrect. By the time engineering finds out about this change, it may have already committed a lot of time and resources to meeting the original requirements. Additional time and resources will likely need to be committed to meet the new requirements.

Transport

Waste in transporting information can occur when different incompatible information systems are used within an enterprise. For example, CAD designers automatically generate a bill of material when they create CAD designs. But, because their CAD system is incompatible with the Release information system, the bill of materials must be recreated instead of efficiently transported. This redundant reprocessing of data represents a large waste.

Unnecessary Motion

Direct access to frequently used information was limited whenever it was transferred manually as documents as opposed to being placed in a database where the latest information could be accessed at any time. When frequently used information was

stored and transferred in the form of documents, it necessitated the movement of the information by circulating the documents to all affected team members. Waste often occurred as the documents needed to be forwarded through team members who had no use for the information, but were necessary to pass on the information to affected team members. Such unnecessary motion occurred throughout the fuel system enterprise. This type of waste could be eliminated through shared common databases. The Product Direction Letter (PDL) is an example of a document that would benefit from being placed on a common database because it is used in multiple processes and by many team members.

Waiting

The late or early release of information or materials by one process leads to the batching and queuing of information or materials at other processes. However, a continuous flow of information and materials through the enterprise could greatly reduce the overall development time of new fuel systems. The fact that the overall system time to develop a new fuel system far exceeds the summation of all process times indicates the occurrence of batch and queue waiting in the enterprise.

Over Processing

Many iterative processing loops were identified in the product development phase of the enterprise. Since processing exhausts the enterprise's resources, it will typically benefit the enterprise to process information or materials correctly the first time and avoid expensive rework. The enterprise would, therefore, benefit from opportunities to

reduce the iterative processing loops and bring down the over all product development times.

Defects

If a process in the enterprise does not complete the processing of all information or passes incorrect information to subsequent tasks, a lot of rework may be generated. Rework typically wastes valuable time and resources. For example, if the FMEA process fails to discover an important failure mode, this "defect" in information may not be discovered until significant resources have already been committed to subsequent tasks such as design and validation. On the discovery of the "defect", these tasks may have to be redone which makes the previous work a waste.

Further insights uncovered by analyzing the flow of information and materials on the enterprise level include:

- No weighting of importance was given to the different flows of information. All information flows were represented in the analysis as being equal in importance. In reality, however, some information is much more critical than other information. In fact, some information can be considered a distraction and wasteful in the process. Prioritizing information could be helpful in efforts to lean out processes.

- In the lean analysis, there were no indications of where critical decisions in the process are made. When leaning out a process, it would be beneficial to know what are the critical decisions and where they are made.

- Information from some tasks may flow through several other tasks sequentially, but is not shown in this manner on the process flow map. For example, information from the Product Direction Letter affects information that flows through nearly every task in the fuel system process although it is only shown on the map to connect with the first few downstream processes.

- The times documented in this report assume tasks were completed correctly the first time. In actuality, tasks may require several iterations before they are completed correctly. When a task is completed incorrectly, it may pass false information to subsequent tasks which later result in rework. Such rework may result in longer process times. A quantification of the risk of completing a task incorrectly would be very helpful (although extremely difficult to determine in reality) when analyzing a process for lean opportunities.

Tools and Technologies

In the Input/Output Flow diagrams, the tools and technologies used to transform information and materials input into a process to the information and materials that are output were listed under each "black box." Insights in terms of how well the tools and technologies support the flow of value through the enterprise are now presented. Three key issues in terms of integration, redundancies, and deficiencies are identified.

Integration

Most of the software tools used to complete individual process steps seem to have been created with little regard to their compatibility with downstream process tools. Software tools were optimized only for their specific tasks (i.e. CAD software just for the design process, StarFMEA software just for the FMEA process, and so on). This leads to a high dependence on printed documents to transmit information from one step to the next within the fuel system development process. Often, information must then be translated from documents and wastefully reformatted for downstream process software (see redundancies).

Figure 6.11 illustrates the direct compatibility of information software and documentation tools used in the fuel system development process. Tools are considered directly compatible if the inputs and outputs of the tools are interchangeable without any wasteful reformatting (copying from text, changing code, etc.) of the information flowing between them. Since hardware, software/document, and process tools will always require the information flowing between them to be reformatted, they are not considered compatible. Therefore, only software/document tools were considered for integration in Figure 6.11.

In the figure, each major process tool is assigned a number and listed along the horizontal and vertical axes. To find the compatibility of one tool with another, find the first tool's number designation along the horizontal axis. Then, follow the matrix horizontally until the vertical intersection of the second tool listed on the horizontal axis. The box located at this intersection point will have a notation representing the compatibility between the tools.

Figure 6.11
Tool and Technology Compatability

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	*			-		-	-	-	-				-			-		-						-			
2		*	+																								
3		+	*																								
4	-			*																							
5					*						-														-		
6	-					*																					
7	-						*																				
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24	-																							*			
25					-					-															*		
26																										*	
27																											*

Integration:

(+) = Direct & Full
(blank) = Info can not be transferred without reformatting
(-) = Sometimes Integratable
(*) = Not Applicable

Tool Key:

1. Standard Office Equipment/PC Software
2. Resource Management Software
3. System Dynamics Software
4. 5183 Form
5. CAE & Simulation Software
6. Global Project Database
7. Gannt Chart Software
8. Internal Skill-Based Tracking Form
9. Internet Postings
10. Requirements Flow Communication Software
11. CAD/PIM
12. Sketches
13. 7 Panel Charts
14. Rapid Prototype Software
15. FMEA Software
16. XL Macros (DVP&R)
17. Worldwide Engineering Release System
18. DOCMAN
19. Purchase Order Software
20. SPC Software
21. MRP Software
22. Warranty Tracking Software
23. Dealer Notification Software
24. 8D (Issue Tracking/Resolution) Software
25. CAM
26. FPDS
27. APQP

Figure 6.11 shows that there is very little direct compatibility between systems and therefore very little integration. This can be observed by noticing the high proportion of blank boxes in Figure 6.11. Blank boxes represent the lack of integration between two tools since information must be reformatted to transfer from one to another.

When process tools are not well integrated from one process to the next, they tend to act as an impediment to the flow of information or materials through the enterprise. Great opportunities to reduce waste, improve efficiency, and increase the accuracy of information being transferred exist through better integration of the enterprise's tools and technologies. Such integration may be possible by utilizing shared databases on a distributed company Intranet with automated entry and report systems. Further studies should be conducted to better understand the cost/benefit relationship of achieving greater computer system integration.

Deficiencies

The tools and technologies that have been identified in this analysis are far from being perfect. In fact, many of these tools and technologies are deficient in various aspects. For example, the Basic Office Equipment/Software is currently being utilized in almost every process step; however, most of the software still contains many errors/bugs and have to be shut down periodically, sometimes with loss of information. Another similar example is the computer simulation software which does not accurately predict/simulate real events. Although we can practically find at least one deficiency per tool/technology, the majority of the times, it is not the tool/technology itself that contains the deficiency, but it is the way it's been utilized. Most tools and technologies are deficient because they are not being fully utilized. An example of this situation is the

CAD system. The CAD system contains countless number of functions; however, most users at Ford (or any other company for that matter) hardly use them. Most users will stick to using the basic functions of the CAD system.

Redundancies

Redundancies occur when information is wastefully duplicated. Redundancies also occur when information must be reformatted without adding any value to it just so that a different process can use it. Redundancies represent wastes of enterprise resources and should, therefore, be targeted for elimination. Examples of redundancies include:

- **Duplication**: All information contained in 7 Panel Charts is also contained in other process documents such as DVP&R XL macros and the Worldwide Engineering Release System. The information contained in the 7 Panel Chart is only a duplication since it just repeats information from other sources without adding any additional value to it.

- **Reformatted Information:** Information generated by CAD systems is typically recopied into Build Order Matrices (BOM) and 7 Panel Charts using standard office PC software. Without adding any more value to the information, it is again recopied into the Worldwide Engineering Release System to kick off manufacturing and design processes. Sometimes, CAD information must also be translated into different software code so that it can be used in CAE and software

simulations. This reformatting of data without adding value to it is a redundant waste.

Metrics and Incentives

The automotive company has established metrics to measure the progress of the uppermost enterprise model (including the entire company, suppliers, the dealer network, and customers) towards achieving its key strategies. Incentives have also been created to motivate employees (especially top management) to achieve the strategic initiatives to given expectations.

The company's key strategic initiatives are cascaded through the organization from the top down to the lowest level functional or product group. Each level within the organization is charged with interpreting the strategic initiatives of the next higher level and creating its own strategic initiatives to support the higher level strategic initiatives. Associated with the strategic initiatives at each level are metrics and incentives.

No current metrics and incentives exist, however, for the fuel system enterprise. This is due to the fact that no current metrics span the company's functional organization. The separate functional organizations like marketing, research, product development, and manufacturing all have their own specific metrics and incentives, but no responsibility within the organization is given across the entire fuel system enterprise.

6.3.2 Prioritizing Major Flow Issues

The preceding analysis uncovered many insights into opportunities to eliminate waste and create smoother flow of value in the system. These insights were generated by identifying the value stream and flow of information and materials through the enterprise.

All of the insights that uncovered opportunities to make the enterprise leaner warrant further study. But, in reality, it would be difficult to address all issues in a reasonable time frame. Therefore, a way of prioritizing the issues is needed. Following the lean framework introduced in Chapter 3, customer values should be used to prioritize the major non-lean issues for further study and action.

A re-examination of Figure 6.4 shows that timing, cost, and quality are customer values for fuel systems that are important for most of the enterprise's customers. Since these customer values have such a wide span over most of the customer base, it is reasonable to assume that they are particularly important customer values. Insights gained from the analysis in the preceding sections showed many non-lean issues did, in fact, affect program timing, cost, and quality.

Timing issues uncovered in the preceding sections included inefficient information hand-offs, loss of time due to rework, and loss of time due to the need for long validation tests that occur late in the value stream. Most of timing issues could be summarized as problems related to waiting, rework, and validation.

Several cost issues such as redundant processing of information, rework, and the need for expensive and time consuming validation were identified in the previous sections. Many of these cost issues could also be linked to timing issues. Creating redundant information, program delays due to waiting, reworking information or materials, and repetitively validating products affect not only cost, but timing as well. When analyzing insights from the preceding chapter in terms of their affect on the customer value of cost, the main issues were again related to waiting, rework, and validation.

Quality issues uncovered in the lean analysis included information version control, "defective" information, and improper information hand-offs. These quality issues also created waste and flow problems in the enterprise in the form of rework, waiting, and validation.

Most issues occurred on the enterprise level and specifically in the pre-program and product development phases of the system. As stated in Chapter 5, the company has already completed extensive work in applying lean principles to its manufacturing operations. For this reason, most of the remaining high impact opportunities to apply lean principles exist on the enterprise level across the company's various organizations and specifically within the pre-program and product development phases.

Considering the impact that waiting, rework, and validation issues had on the key customer values of timing, cost, and quality, these issues will be given high priority for further analysis and countermeasure activities. These issues will be studied on the enterprise level and also specifically within the pre-program and product development phases.

Waiting Time

Summing the time resource data from Figure 6.6 shows that a total of 788 time units are actively used to process information and materials in the development of a new fuel system. As the current state process map indicated, this active time begins when the enterprise identifies new fuel system customer needs and extends to the time when the first production system is manufactured to meet those customer needs. However, actual

enterprise timing plans show that the development of fuel systems is scheduled for 1200 time units to complete in reality.

This means that 412 time units (1200 - 788 = 412) are not accounted for in the development of new fuel systems in the enterprise. If information or material is not being actively processed, it can be considered waiting to be processed. The 412 time units represent a huge chunk of time accounting for over a third of the entire development time! This large waiting time is a significant waste that offers a tremendous opportunity to improve enterprise efficiency through lean activities.

Waiting time is also reflected in the Input/Output Flow diagrams in Figure 6.9 by the transfer times between processes. The individual transfer times, however, can not be summed to yield the total 412 time units in waiting due to the fact that several processes overlap and run in series instead of sequentially. Also confounding a straight summation of the Input/Output transfer time to yield the total enterprise waiting time is the fact that many processes are reworked and transfer times may be duplicated in the development of a new fuel system.

Rework Time

An analysis of the resource data from Figure 6.6 also shows that a considerable amount of time is spent on processes that are repeated several times. For instance, "Design (CAD/CAM)", "Manufacturing Feasibility", and "Release" processes are repeated during AP, CP, and Production loops. Summing the times required to reprocess information and materials in iterative loops totals 264 time units. This represents nearly a quarter of the entire fuel system development time.

In the current enterprise, these multiple loops are needed to ensure that systems meet all requirements in a planned time frame. However, it is not a customer value to repeatedly process information and materials over and over again. Customers only value having the systems meet their requirements regardless of how many times they were processed. On the other hand, customers do value systems with the lowest cost and development times. Since the multiple iterative loops are very expensive and time consuming, the enterprise should be highly motivated to reduce its need for them. This type of rework generated by reprocessing in iterative loops will be called "iterative rework" in this paper. Improving the enterprise's processes such that the information and materials they generate are more consistently correct the first time they are processed is another area that promises significant opportunity for lean efficiency improvements.

On top of iterative rework time, additional rework time is also generated when a process in the enterprise system does not correctly process the information or material that a sequential process needs. Incorrect information or materials are then forwarded to sequential processes. The sequential processes spend resources to work on this incorrect information or materials. Eventually, the information or materials are recognized as incorrect and must be reworked. For example, marketing may identify a false customer need early in the enterprise process. Based on this false information, a PDL could be generated, concepts generated, early sourcing agreements made, and so on until the error is recognized. Once the error is recognized, information and materials must be reworked through these processes again. This type of rework generated through process failures will be referred to as "error rework". A very conservative estimate by the author on the

amount of error rework in the system is one-fifth of the total development time or 250 time units.

Rework is also generated when sequential processes begin before required predecessor processes have had the chance to fully complete their operations. For example, manufacturing may be under heavy time pressures to set up its operations and employ its workers before a design has been fully completed. In this situation, the manufacturing facility may go ahead and set-up its equipment based on partial information and estimates before it has received all required information on the design. When the final complete information on the design finally flows down to the manufacturing personnel, it may be different than what they had estimated. This causes rework since the manufacturing personnel will have to reprocess this information and adjust the work they have already completed. This type of rework will be referred to as "Sequential Rework" in following sections. A very conservative estimate by the author on the amount of sequential rework time that exists on average in the fuel system enterprise is one-tenth of the total development time or 120 time units.

Validation Time

The AP and CP iterative loops are used to develop and validate fuel systems at various stages of design maturity. Validation also occurs in (DVP&R) testing of designs and process validation of manufacturing operations. Similar to rework iterations, however, customers do not value how much validation a system has undergone. They do value the fact that systems operate to their requirements, though. Moreover, the lower the cost and faster the development time, the higher the customer value. Some regulatory

tests are required, but even these have the potential to be reduced if the enterprise can develop consistent methodologies of processing information and materials correctly the first time. Therefore, the enterprise should be highly motivated to avoid excessive iterations, complete processes correctly the first time, and reduce its dependency on expensive and time consuming validation.

In addition, Figure 6.5 shows that the validation process occurs relatively late in the enterprise's product development phase. This is analogous to quality control checks at the end of manufacturing process lines. In both cases, productivity gains can typically be achieved by implementing in-process checks and "poke-yoke" systems. Productivity gains typically stem from catching errors and addressing them at the point they happen instead of catching them with a quality check at the "end of the line." This saves resources in the case of a defect do to its quicker feedback. A quicker feedback loop prevents further resources being spent on defective information or materials in subsequent processes before the quality check and also prevents more products from being processed in a defective manner before the defect is found at the quality check.

An analysis of Figure 6.7 shows that a significant percentage of the total development time is spent on validation. If multiple iterative loops, design testing, and process validation could be eliminated, then an additional 474 time units could be spared. This figure does not even include the lengthy times required to build the prototypes that are validated, but still represents nearly 40% of the entire fuel system development process!

Process Time Summary

Figure 6.12 summarizes where time is spent in the fuel system development process. Significant improvements are possible if the enterprise can be "leaned-out" in terms of reducing waiting, rework, and validation testing time. Only 27% of the current enterprise process time is actively used to process information and materials without iteration! In a fully "leaned" and continuous process in which no waiting, rework or validation occurred, this would be the only time used in the enterprise to develop new fuel systems. The actual lean process would take even less time than 27% of the current process time since this represents sequential processing, but in reality the time is even less since many of the processes overlap and occur in series.

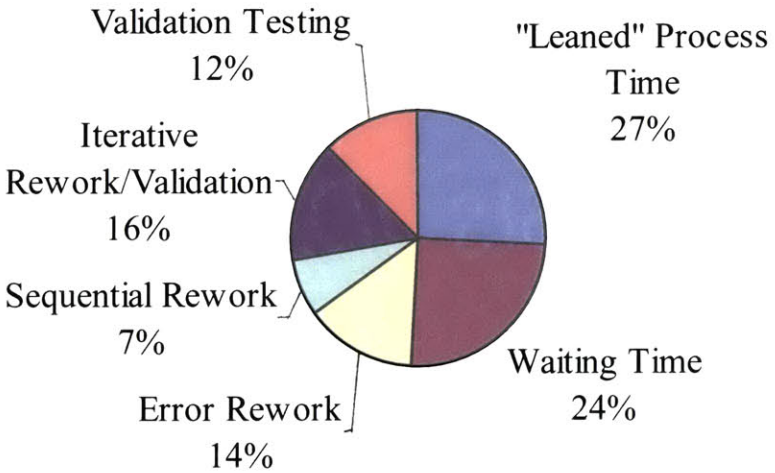


Figure 6.12
Process Time Summary

The current process has nearly as much waiting time as active first-pass processing. If the process could be "leaned" such that information and materials flowed continuously through the enterprise, this large amount of waste could be eliminated.

Time spent on rework and validation testing combine for a whopping 49% of the enterprise's total development time. Reductions in the enterprise's use of rework and dependency on excessive validation would therefore represent major process improvements. Steps to address issues with waiting time, rework time, and excessive validation will be reviewed in the following section.

6.3.3 Countermeasures to Reach a Leaner Enterprise State

To reduce the non-value adding activities in the enterprise and allow information and materials to flow more efficiently, the major issues of waiting time, rework time, and excessive need for validation must be addressed. Proposed countermeasures to address these issues include implementing continuous flow (avoid multi-tasking), gradually eliminating safety nets, aligning clear decision points, adding an "Andon Cord" system to product development, implementing more tightly integrated product/process design (IPPD), using enterprise metrics and incentives, utilizing common computer systems throughout the enterprise, and implementing standard work techniques in product development. These countermeasures link to the key non-lean issues in the following manner:

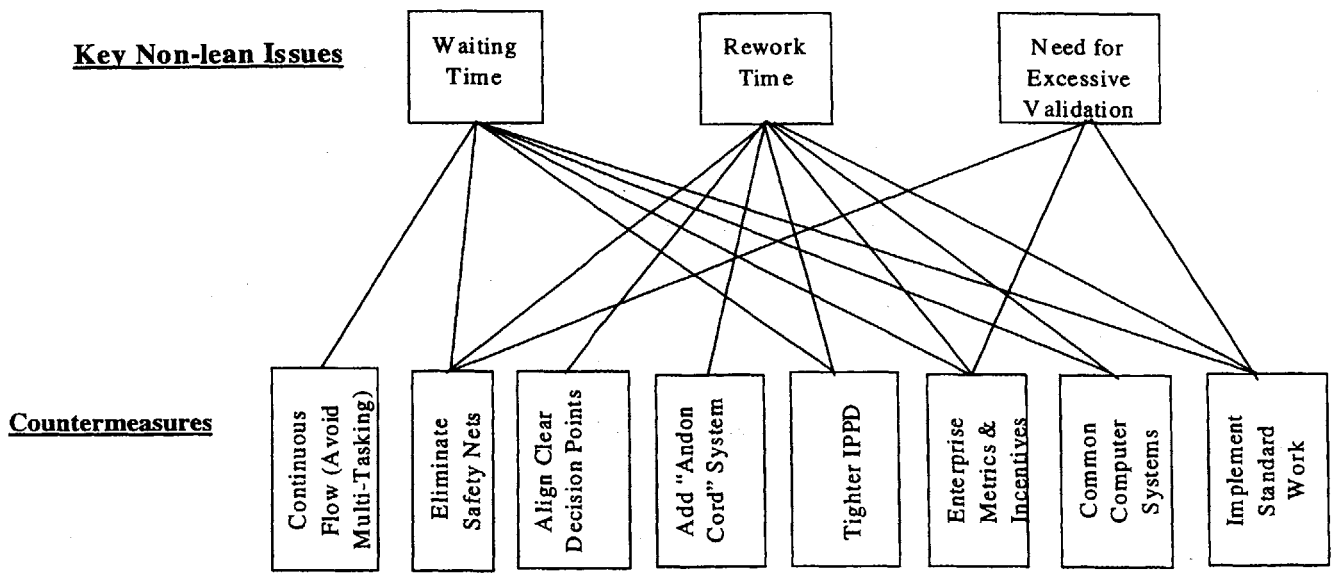


Figure 6.13
Countermeasures to Address Major Non-lean Issues

Implementing Continuous Flow - Avoid Multi-tasking Project Leaders

When project engineers work on multiple vehicle programs, waiting time is typically introduced into the product development process as engineers work on only one project (vehicle) at a time while the other projects (vehicles) wait. This problem is compounded when several engineers responsible for individual subsystems of a product all multitask and introduce waiting times into the overall process.

A project leader should be assigned the responsibility of managing a single value stream to ensure its smooth flow through the process. The size of the system that the project leader is responsible for should be large enough so that it encompasses enough work to represent the project leaders complete job. Rather than having a project leader responsible for the current fuel system chunk on multiple vehicles, the size of the system chunk should be increased. For example, the new system may be three times larger (i.e. extended to include the fuel nozzle or the intake manifold), but limited to one vehicle. This should effectively make a single vehicle program product development team easier to manage since there will be less individuals involved. Also, by extending the scope of the system, more optimal tradeoffs within higher level systems can be more effectively evaluated.

Gradually Eliminate Safety Nets

In the current fuel system enterprise, completing process work right the first time is not always emphasized. This is partially due to the fact that team members know that they have multiple iterations (AP, CP, Production, etc.) to get the process correct. It is also partially due to the lack of enterprise tools and processes that allow work to be

completed right the first time. Gradually eliminating the multiple iterations that represent safety nets for enterprise process work will create a tension in the system that will drive an emphasis on completing process work correctly the first time and creating better enterprise tools and processes to support this.

Align Clear Decision Points (Instead of Tasks) with Process Milestones

Much rework is generated when key decisions in the development process are not made at the appropriate time. The development process often has enough momentum due to its tight deadlines to proceed despite the fact that key decisions have not been made at the appropriate time. Assumptions about the decision are typically made and the development process caries on under these assumptions. Later, when the key decision is finally made and cascaded, much rework is generated when assumptions about the decision outcome proves wrong and tasks must be completed again with the new information. For example, hard points defining the geometry of neighboring subsystems may not be decided before the design of the fuel system proceeds. This design proceeds under assumptions of what the decision on the outcome of the hard points will be. When the actual decisions are made, they may be different from the assumptions made in proceeding with the fuel system design. If subsystems were designed under false assumptions and now do not fit together, this will cause much rework as the fuel system with have to be redesigned.

The current fuel system development process uses a phase gate system that establishes and defines milestones in the project based on the tasks completed. Basing phase gate milestones on tasks assumes that key decisions were made, but this is not

always the case. Establishing and defining key decision points in the future state process insures that adequate information has flowed to the right place in order for the development to proceed. This will help avoid working under false assumptions that later drive rework in the system.

Add an "Andon Cord" System to Pre-Program and Product Development Phases

To create continuous flow in the enterprise, a pre-program and product development Andon cord should be implemented. This Andon cord will be "pulled" when an enterprise team member notices a problem with the quality of incoming work. At this point the development process stops, and well-defined enterprise resources are brought in to correct the problem.

While on the surface this appears to cause more interruptions to the flow, in the long term the opposite is true. Indeed, it has been learned from the Toyota Production System (TPS) that the Andon cord is necessary to achieve continuous flow.

Utilize More Tightly Integrated Product/Process Design (IPPD)

The current state process map showed several iterative loops between product development and manufacturing phases. Several processes such as refining requirements, design, release, and manufacturing feasibility require iterative hand-offs between product development and manufacturing team members. More tightly integrated product/process design teams with well-defined roles would help the enterprise move more quickly and efficiently through these development phases.

Implement Common Computing & Data Storage Systems (ERP)

Much waiting and rework are introduced into the development of the fuel system when information for one task is processed in a unique computer system that can not be further utilized by downstream computer systems. To process this information in downstream tasks, the information has to be translated and reloaded into a new computer system. This can lead to waiting as the information is translated and reloaded. This can also lead to errors that drive rework if information is translated and reloaded incorrectly.

Common databases and computer systems like those used in Enterprise Resource Planning (ERP) systems can eliminate the wasteful activities of translating and reloading data. This further reduces the amount of rework and waiting time in the development process. A study should be conducted to estimate the benefit the enterprise could derive from better integrated systems in comparison to the cost to implement them.

Implement Standard Work Processes

Mistakes are repeated and rework generated when process tasks that should be standard procedures are reinvented over and over again. The tasks also take longer to perform when they are reinvented as compared to completing standard procedures. In addition, established and proven-out methodologies lead to less mistakes and rework than procedures that are reinvented. To avoid this type of wasteful activity, "standard work" methodologies should be introduced into the development process. "Standard work" methodologies are published for all repeated tasks typically performed in the development process. Workers are trained to be able to perform tasks according to "standard work" procedures. When a new way of completing a task is invented, it is

reviewed by a "standard work" committee that can approve this method and update the definition of standard work.

Standard work can also provides templates to allow for in-process checks of pre-program and product development work. Errors in process work can be seen by comparing the work to standard work expectations. This type of in-process quality checks can give much quicker feedback than waiting for the final validation step. In-process checks before the validation step can save enterprise resources by detecting errors sooner.

Implement Enterprise-wide Metrics and Incentives

Workers typically perform according to the metrics used to measure their work. The current state process uses metrics that are contained within organizational chimneys and functional departments instead of across the enterprise. This drives performance according to local optimization instead of systemic optimization across the enterprise. A list of enterprise metrics is given below. These metrics would drive continuous improvement in leaning out waste across the entire enterprise process. These metrics would help drive on-going reductions in rework time, waiting time, and excessive validation. Metrics that drive leaner behavior could be implemented across the entire fuel system enterprise and specifically for the product development phase.

Lean Enterprise Metrics

The company uses seven core strategies to guide its actions. These core strategies are defined as:

a) *Empowered People*
b) *Nimble Through Process Leadership*
c) *Achieve Worldwide Product Excellence*
d) *Low Cost Producer*
e) *Lead in Corporate Citizenship*
f) *Lead in Customer Satisfaction*
g) *Achieve Worldwide Growth*

The company has also defined several metrics associated with each of these strategies to track its status and guide efforts for improvement. These strategies and their associated metrics were created for the entire company, which includes, but is not limited to the fuel system enterprise. These strategies and metrics must be interpreted and cascaded through lower levels in the organization. Ideally, in our future state "lean" enterprise, a manager would be assigned to each product subsystem, such as the fuel subsystem, as a mini enterprise. This manager would then be responsible for translating the strategies and metrics from the higher level enterprise to his/her lower level subsystem enterprise taking into consideration his/her customer values. The value stream manager would also be responsible for cascading and reaching a consensus on the interpretation of strategies and metrics to the component level.

For the fuel subsystem enterprise, the value stream manager must interpret what the company-wide enterprise metrics mean for his/her business chunk considering the values of his/her customers. The company-wide enterprise level metrics that support the seven key strategies can be generally organized under the areas of:

1. *Flow Time*
2. *Stakeholder Satisfaction*
3. *Resource Utilization*
4. *Quality Yield*

Value Stream Metrics Defined

Considering the company-wide metrics and the values that customers place on fuel systems, the following metrics can be used as lean guidelines for the fuel system enterprise:

1. Flow Time

- **Product Cycle Time** (PCT) – An enterprise measurable to gage the time that elapses from initiation of the Product Direction Letter (concept kick-off stage) to the production of the first saleable product.

  PCT = Total number of control concepts / rate of product introductions

  Where control concepts = Product Direction Letters released

  To achieve a finer resolution of where the time is spent within the process, more focused timing metrics can be applied to the product development and manufacturing loops within the enterprise:

- **Dock-to-Dock** (DTD). A production measurable to gage the time that elapses from when raw materials are unloaded to when finished products are shipped.

  DTD = Total units of control product / End of line rate

- **Concept-to-Final Release** (CTFR). A product development measurable to gage the time that elapses from concept kick-off (PDL initiation) to release of the final design. Analytically, this corresponds to:

  CTFR = Total number of control designs / rate of design releases

  Where control designs = Newly Tooled End Items (NTEI)

- **Continuous Flow of Information and Material** (CFIM)

  CFIM = Sum of cycle times for each process/Total cycle time from concept to production

2. **Stakeholder Satisfaction**

   - **Performance Satisfaction** (PS)

     PS = Percent functional requirements met

   - **Cost Satisfaction** (CS)

     CS = Cost of lowest price competitor / Cost of fuel system product

     TLC = Total Life Cycle Cost / Fuel System Product

3. **Resource Utilization**

   - **Headcount Utilization** (HU) and **Resource Utilization** (RU)

     HU = Workers / Fuel System Product

     RU = Program Expense / Fuel System Product

   - **Process to Schedule** (PTS) - An enterprise metric to assess whether or not information or materials are being processed to customer demands in the right amount, kind, order, and time.

     PTS = % Volume * % Mix * % Sequence

   - **Overall Process Effectiveness** (OPE) - An enterprise metric to assess if processes are being utilized when they are supposed to, if they are being utilized at the correct speed, and how effective they are in processing quality information or parts.

OPE = % Availability * % Performance Efficiency * % Quality Rate

- Metric for integrating product and process development.
- Metric to measure strength of supplier and other stakeholder relationship.
- Metric to assure the enterprise is a learning organization.

4. Quality Yield

- **First Time Through** (FTT)

  FTT % = (Designs Produced – (scrap + fixes + retests)) / Designs Produced

- **Rework**

  Rework = Redesigns / Total number of control designs

- **Rejects per Thousand** (RPT)

  Rejects/1000 Fuel System Products Produced

- **Control Process Variation**

  Add Statistical Process Control to Process

- **Growth**: The amount that the number of NTEI's exceeds the number of planned NTEI's at the start of the program (measured as % of planned NTEI's).

Lean Product Development Metrics

The automotive company already uses several metrics to drive lean behavior in its manufacturing process. These metrics allow manufacturing groups to assess their current performance, drive for improvements, and support lean principles. Likewise, the company could extend the use of similar metrics into its product development area to

allow groups to assess their current performance, drive for improvements, and support lean principles. These metrics directly relate back to customer-defined values of cost, quality, and time.

Manufacturing groups use the measurable First Time Through (FTT) to reflect a process's ability to produce goods correctly the first time. Similarly product development groups could use FTT to reflect a process's ability to produce designs or process information correctly the first time. In product development, the formula for FTT would become:

FTT % = (Designs Produced - (scrap + fixes + retests)) / Designs Produced

Dock-to-Dock is a key measurable used in the company's manufacturing sites to gain insight into the time that elapses from when raw material enters a process until the time it is shipped as a finished good. Product development groups could use a similar measurable to gain insight into the time that elapses from when a concept (product assumption based on a marketing need) enters the product development process until the time a final design is released. This measurable could be called Concept-to-Final Release (CTFR). To calculate CTFR, product development analysts could use the formula:

CTFR = Total number of control designs / rate of design releases

where control designs = Newly Tooled End Items (NTEI)

To assess whether or not the manufacturing group is producing goods to customer demands in the right amount, kind, order, and time, the company's manufacturing sites use the measurable Build-to-Schedule. Similarly, product development groups could use a measurable to assess whether or not the product development group is processing information to customer demands in the right amount, kind, order, and time. The measurable in this case could be called Design-to-Schedule (DTS). To calculate DTS, the following formula could be used:

DTS % = % Volume * % Mix * % Sequence

Overall Equipment Effectiveness is used by manufacturing sites to measure whether or not production equipment is running when it is supposed to, if its running at the correct speed, and how effective it is in producing quality parts. Product development groups could utilize this type of measurable to assess if its product development processes are being utilized when they are supposed to, if they are being utilized at the correct speed, and how effective they are in processing quality information. This measurable could be called Overall Process Effectiveness (OPE). To calculate OPE, use:

OPE % = % Availability * % Performance Efficiency * % Quality Rate

6.4 Letting Customers Pull Value

The lean concept of letting the customer pull value is difficult to extend to the enterprise level since many enterprise activities such as marketing, research, and product development are done in areas in which customers have not yet realized a demand. To some extent, pull in an enterprise occurs when manufacturing fills purchasing orders, this can send a pull message to product development to develop new products. This in turn pulls pre-program areas such as marketing and research to engage in their processes.

In the current enterprise state, however, pre-program activities such as research and development and marketing engage in their processes as directed by top management teams. Through the use of the Product Direction Letter (PDL), pre-program activities deliver requirements and push the product development teams to engage in their processes. As figure 6.14 shows, requirements are first pushed to vehicle level teams and then further cascaded (pushed) through the system level teams down to the component level. In product development phase, component designs are combined into higher and higher levels of systems. At each level, validation testing is completed to ensure there are no adverse system interactions. As Figure 6.14 shows, this validation in effect creates a pull system from the vehicle level down to the component level. Product designs are then typically pushed to manufacturing organizations to produce.

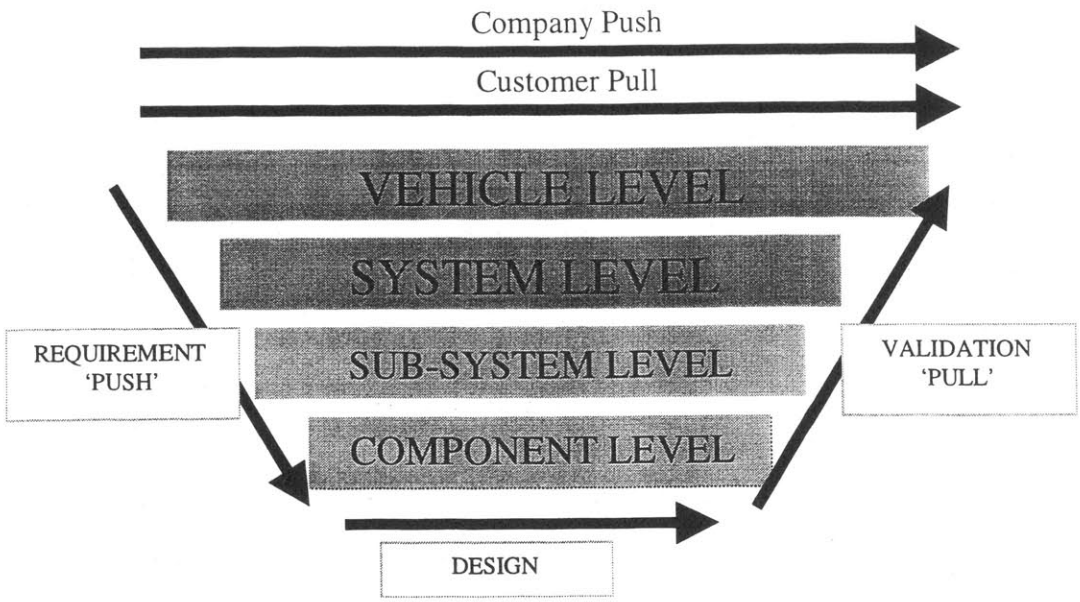


Figure 6.14
Push & Pull Within the Enterprise

Within the manufacturing organizations, many repetitive tasks occur on the production line as multiple products are manufactured and assembled. Pacing production speed to takt time (how often a product should be made in order to meet customer sales rate requirements) becomes important to avoid over- or under- production. In such a setting pull can be effectively utilized to drive lean behaviors of linking all processes and producing only what the next process requires when it requires it.

Today, however, there is a noticeable difference between the automotive company and the dealer sales network. Most automobiles are sold off of dealers' lots from dealers' inventory. This means that the automotive company is pushing (selling) its vehicles to the dealers and then the dealer pushes (sells) vehicles to end customers. The primary underlying issue is that it takes too long to truly build-to-order. A 45-60 day wait is

typically required today if a vehicle is "special" ordered. A pull system would require the process to deliver to specific orders in a much shorter time frame.

Manufacturing organizations currently have more concern for producing their pre-scheduled number of vehicles than they do for selling the vehicles that they have already produced. As a result, the upstream operations act more as the customer to the assembly plant than the down stream operations. That is, the assembly plant has more concern for satisfying the marketing department, for example, than it has for satisfying the end customer. This misalignment of values shows that the automotive company still runs its manufacturing process more by a push system than by a pull system.

Although the company currently operates with many push characteristics, implementing pull systems in the manufacturing organizations is still theoretically possible. As the company's build-to-order time continues to drop, the full benefits of implementing a pull system will become more and more attainable.

Pull, however, is difficult to extend from manufacturing to the enterprise level. Many of the processes in the pre-program and product development phases are done only once for a product instead of repetitively like on a manufacturing production line. Takt time is also difficult to determine in the pre-program and product development phases. Most automotive companies rely on forecasting based on previous historical data of customer sales trends to schedule the activities of pre-program groups. Long time delays in early processes such as research, marketing, and product development further complicate the implementation of pull on the enterprise level.

At best, pull techniques could be implemented across the enterprise if pre-program and product development phases were viewed as one single (albeit large)

process. When viewed in this way, the customer pull (as represented in figure 6.15) could be used to determine when the enterprise should begin the development of new programs based on customer demand. Linking underlying manufacturing, product development, and pre-program activities, however, is problematic. Since this thesis is concerned with linking the underlying manufacturing, product development, and pre-program activities instead of treating them as a single large chunk, pull is not further addressed.

6.5 Pursuing Perfection

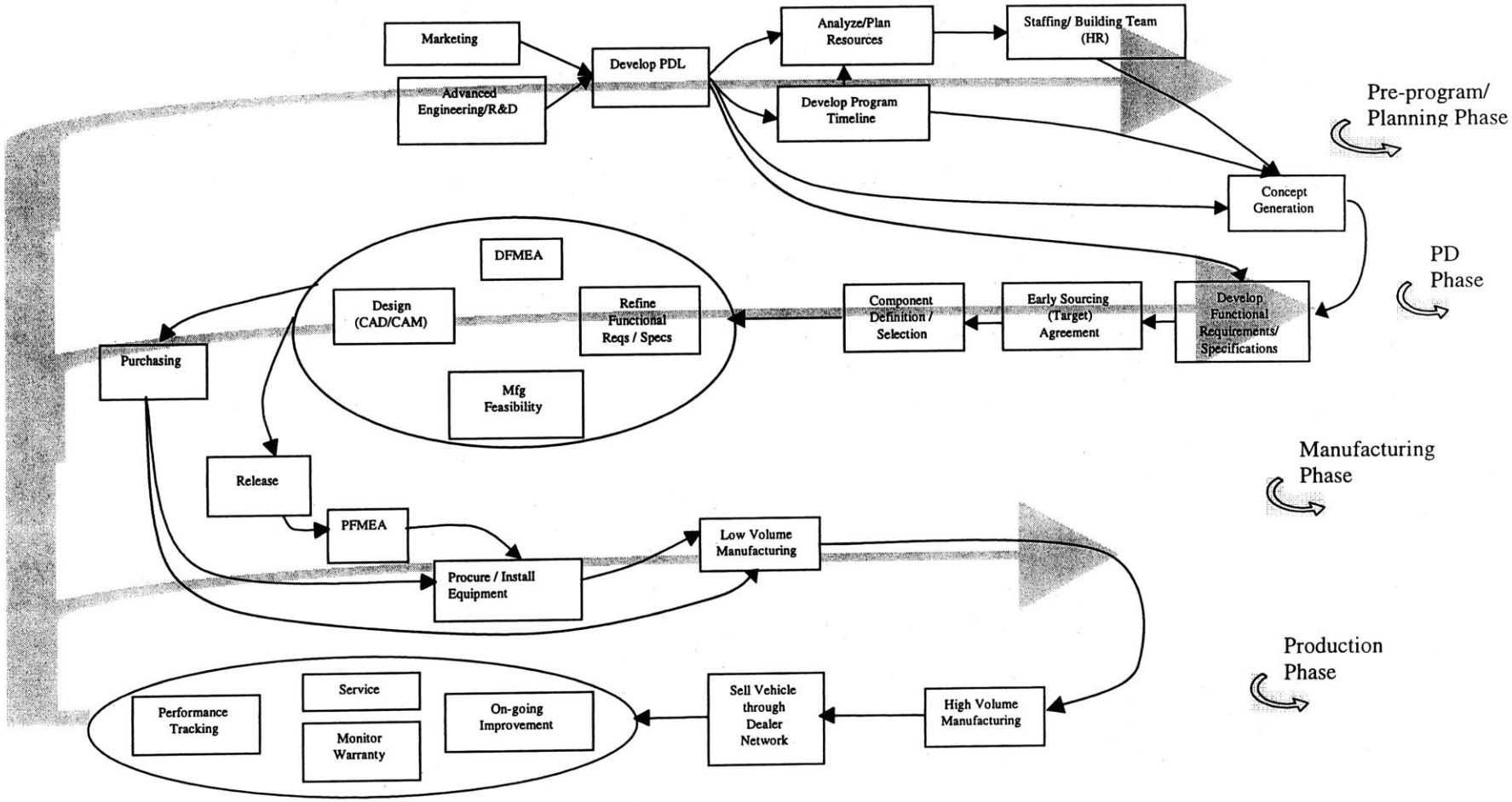
As team members of the fuel system enterprise complete the cycle of identifying their value stream and making value flow continuously, they will further see where additional waste could be removed and how products could be changed to more accurately provide what customers value. This pursuit of perfection is endless as the enterprise strives to reach a lean ideal.

A future state process map representing a goal for a future leaner enterprise is presented in this chapter. A gap analysis presents the differences between the current and future state process maps. In the spirit of continuous improvement and pursuing perfection, other opportunities for further lean analysis are also presented.

6.5.1 The Future State Process Map

The current state process map and its associated resource matrix showed that only 27% of the time spent to develop new fuel systems in the enterprise was actively used in first-pass, non-validating processing of information and materials. The rest of the time can be attributed to waiting, rework, and validation. The future state process map shown in Figure 6.15 sets a goal of eliminating waiting, rework, and the need for excessive validation. While such bold moves could not realistically be achieved in the short-term, they can serve as excellent goals for directing lean activities over the long-term.

Figure 6.15
Future State Process Map



The future state process map shown in Figure 6.15 shows all iterative loops removed. This places an emphasis on processing information and materials correctly the first time. The lengthy validation loops have also been removed from the current state process map in creating the future state process map. In place of the time consuming and expensive validation loop will be in-process and "poke-yoke" type quality checks.

Other than validation and the multiple iterative loops, no other process steps could be viewed as waste opportunities to be removed from the current state process to create the future state goal. A more in depth view of the processes using tier 2 process maps as recommended in section 6.2.1 would likely reveal further opportunities to eliminate wasteful activities from the sub-processes within the enterprise process steps.

The only other waste apparent from the analysis was in the form of redundancies. As described in section 6.3.1, redundancies took the form multiple ways in which information was transmitted (ie formal vs. informal) and tools that require information to be duplicated or reformatted. In these cases, studies should be conducted on the most efficient methods and made into "standard work." The redundancies should then be eliminated in a lean effort to reduce waste.

Large semi-transparent arrows are also seen passing through all phases of the fuel system enterprise process in Figure 6.15. These arrows represent seamless real-time information being disseminated throughout the enterprise. This information would be efficiently available on-demand to all enterprise team members that need it. Providing enterprise team members with data-on-demand would help link all processes systemically and ensure that the right information is available at the right time at the place where it is

needed. A smooth continuous flow of information and materials from process to process is envisioned in the future state enterprise.

The countermeasures introduced in section 6.3.2 are also fully implemented in the future state enterprise. This includes metrics and incentives that motivate lean behavior and career paths that coincide with the lean initiatives. Tighter IPPD is also represented in the future state process map as Design, DFMEA, Refine Functional Requirements/ Specifications, and Manufacturing Feasibility process steps are bundled into a larger process chunk. The individual process steps required several iterative loops and hand-offs in the current state process. To complete the processes in the quickest and most efficient manner, product development, supplier, and manufacturing team members are more closely integrated in this phase of the process.

Most of the high impact benefits in applying lean principles to the current state fuel system enterprise resulted from addressing systemic issues that caused waiting, rework, and excessive need for validation. Appendix A offers a guideline and a framework for implementing the lean initiatives in the automotive company.

6.5.2 Opportunities for Further Lean Analysis

Further opportunities to improve the lean efficiency of the enterprise include increasing the scope of the lean analysis, specifying processes and their interconnections so that they are self-diagnostic, controlling variation, and creating a learning organization. These areas are recommended for further study.

Increasing the Scope of the Lean Analysis

As chapter 4 described, the lean analysis was limited in scope to the fuel system enterprise due to logistical and practical issues. However, the biggest bang-for-the-buck in applying lean principles is achieved when they are applied to a complete extended enterprise representing the entire company, its suppliers, and stakeholders. Therefore, once a systemic understanding of the subsets of the entire enterprise has been achieved and lean principles applied, it may then be possible to combine subsets and reapply the analysis. A higher level understanding of an enterprises value stream will enable the application of lean principles with increasingly more leverage on the efficiency of the enterprise, productivity of its subsystems, and value fulfillment for customers.

Specifying Processes and their Interconnections so that they are Self-Diagnostic

In their *Harvard Business Review* article, "Decoding the DNA of the Toyota Production System," Steven Spear and H. Kent Bowen assert that Toyota has created a corporate culture in which all employees in its production system approach problems as a community of scientists. "Whenever Toyota defines a specification, it is establishing sets of hypotheses that can then be tested. In other words, it is following the scientific method."[14]

All processes and interconnections are highly specified. For example, the way in which a component is bolted to a vehicle in the assembly process, the moving of production equipment in a factory, or the testing of a prototype all follow highly specified procedures. These specifications are treated scientifically as hypothesis with expected

[14] Spear, Steven and H. Kent Bowen, "Decoding the DNA of the Toyota Production System," *Harvard Business Review,* September-October, 1999, p. 98.

outcomes. Every action can then be regarding as an experiment against a hypothesis. Processes are then compared to their specifications and actual outcomes are compared to expected outcomes. Deviations are immediately signaled creating self-diagnostic systems. By constantly testing hypotheses in this manner, the production system allows its workers to experiment and continually and constructively improve the process. In this way, the highly specified system becomes paradoxically flexible and adaptable.[15]

The relationship between this type of operating method and its relation to systemic improvement in a lean context could be further studied. Specifying processes and interconnections so that they are self-diagnostic opens up many cultural issues within organizations, but could further improve system performance in a lean context.

Controlling Variation

When the lean ideal of single-piece continuous flow is introduced into a system, the control of variation becomes critical. Without any buffers or back-ups, large variations in a system can bring a continuous flow system to a grinding halt. Therefore, more study in the area of managing variation in the enterprise context is a practical enabler to lean implementation.

Better methods are needed to control the impact of variation in a lean context. In her 1999 MIT presentation "Variation Management and the Lean Enterprise," Anna Thornton points out the importance of identifying system requirements that are sensitive to variation as well as features and processes that contribute to system variation. Making assessments of variation once it is identified is also critical. The probability and cost of

[15] Spear and Bowen, pp. 97-106.

variation should be quantified. Once variation has been identified and assessed, a means of mitigating it should be addressed. Identifying, assessing, and mitigating variation can lead to a systematic and proactive decision framework for optimally managing variation.[15] Such frameworks would improve the practicality of implementing lean principles across enterprises and drive greater lean efficiencies.

Further Systemic Insights through the Utilization of Design Structure Matrices

A Design Structure Matrix (DSM) is a tool for mapping information flows through a process. Unlike the Input/Output Flow diagrams explained in section 6.2.3, Design Structure Matrices map feedback and feedforward loops between processes. When a problem occurs, a DSM could be used to trace what other processes or information in the system will be affected.

This type of information could give lean practitioners further insight into which types of failures cause the greatest problems in a system. This, in turn, could present a way of prioritizing efforts and focusing on the most important processes and information within an enterprise. Because of its promise of uncovering further wastes and barriers to continuous flow in an enterprise, DSM's are recommended for more in-depth analysis of systemic processes.

A guideline about creating DSM's can be found in the Eppinger article; *A Model-Based Method for Organizing Tasks in Product Development* referenced in the attached bibliography.

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[15] *Variation Management and the Lean Enterprise* presentation by Anna Thornton to the MIT class; Integrating the Lean Enterprise (1999)

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Appendix A:

Implementation Plan for a Leaner Fuel System Enterprise

A.1 Transition to Lean

To transition the current fuel system enterprise into a leaner enterprise state, a well thought-out implementation plan is required. Transitioning to a leaner enterprise state will require more than just implementing a handful of new countermeasures. To successfully transition to the leaner state envisioned in Chapter 6 and inspire continuous improvement towards a lean ideal will require changes to the corporate culture and mental models of all involved employees.

The transition to lean will challenge all levels of the enterprise. Figure A.1 shows the critical levels within the organization that will be affected by the transition to lean. The enterprise is represented by a pyramid with culture and mental models at the base and leadership in the uppermost section.[16] This representation shows how the enterprise is based on its members' mental models. It also shows that the mental models are the biggest section which represents the fact that it is the most challenging and time consuming to change. This time constant decreases at higher levels in the organization. However, all sections are critical in implementing change.

[16] *Organizing for Effective Innovation* presentation by Rebecca Henderson to MIT Technology Strategy class (1999).

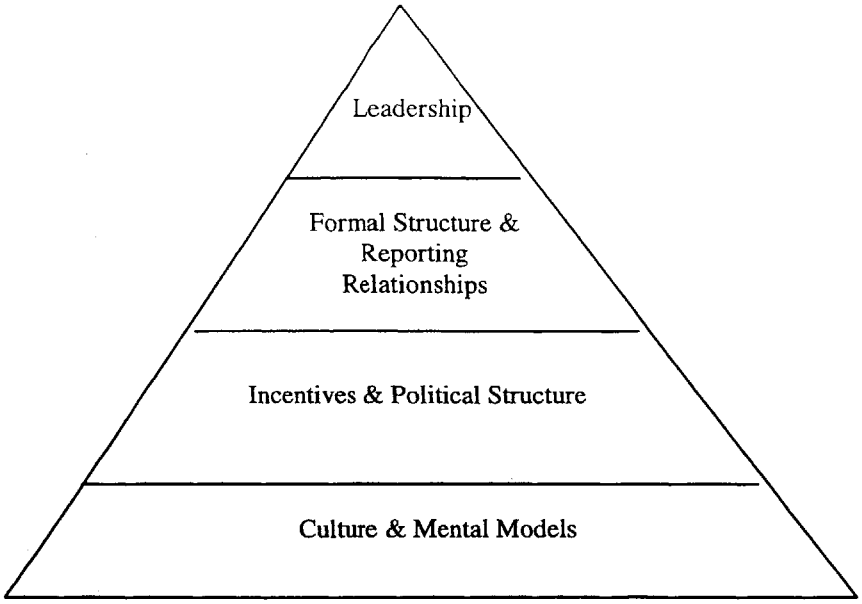


Figure A.1
Transitional Enterprise Model

Leadership is key to the transition for it's role in communicating the vision and allocating resources to support the transition. Changes in the enterprise's structure are important as new forms, processes, and reporting relationships are explored. Addressing incentives is necessary to ensure that actions follow the lean vision. Finally, mental models must also evolve to support a new "lean" culture and expectations.[17]

Implementing a successful lean transition in an enterprise is no small task. But, the rewards of a successful implementation as envisioned in Chapter 6 make it well worth the effort. Enormous savings in enterprise process cycle times, headcount, and budgets are possible. A lean orientation can also be leveraged to drive growth and competitive advantage over non-lean rivals in the marketplace.

[17] Henderson (1999)

A.2 Implementation Roadmap

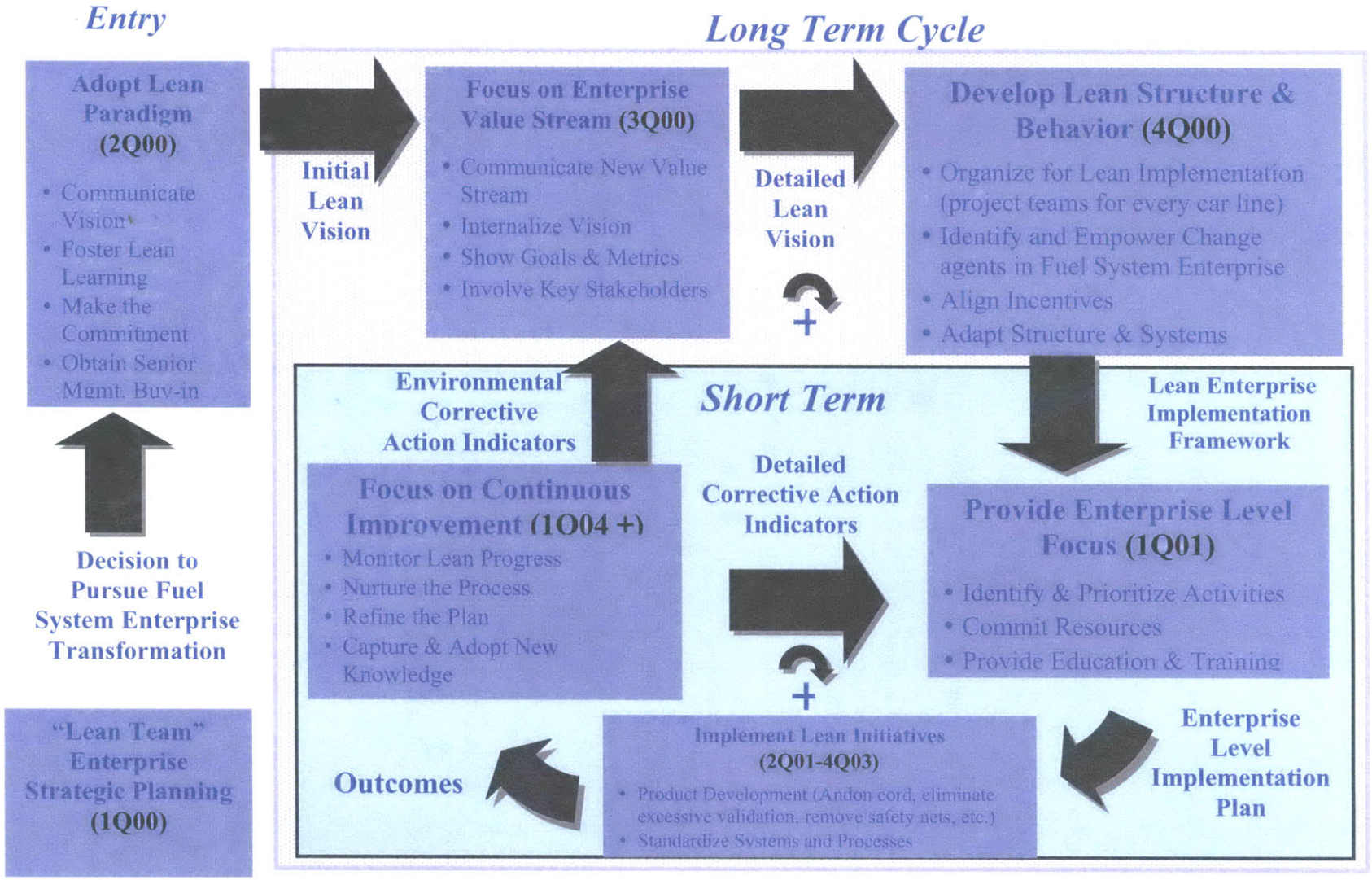
Figure A.2 lays out a framework for implementing a lean transition plan.[18] The first step in the transition to lean (TTL) plan is to adopt the lean paradigm which includes the communication of the new vision, fostering lean learning, making the commitment, and obtaining upper management commitment. The emphasis of this step is to make the stakeholders aware of the future changes and how they will affect and benefit the enterprise. The opportunities of greatest improvement should be addressed first when communicating the new vision. Incentives and career paths conducive to lean behavior should also be considered at this stage.

The second step in the TTL plan is to focus on the new future state fuel system process map. This step is critical to the transition because it involves the communication and explanation of the new value stream to the whole enterprise. All key stakeholders need to be heavily involved and prepared to help in the changes. During this step, the new goals and metrics are introduced to the enterprise.

The next step in the TTL plan is to develop an enterprise organization structure conducive to lean behavior. This step involves the major organizational re-structuring. The enterprise will be organized to include various Integrated Product Team's (IPT's). The goal of IPT's will be to develop a specific vehicle line and not multiple subsystems of various vehicle lines (reduction in multi-tasking). Change Agents will be identified and empowered to develop the lean structure.

[18] Nightingale, Deborah, *Transitioning to a Lean Enterprise: A Guide for Leaders, Alpha Version.* Cambridge, MA: Lean Aerospace Initiative, Massachusetts Institiute of Technology (Dec. 1999).

Figure A.2
Fuel System Enterprise Lean Implementation Roadmap



The fourth step is to start prioritizing activities that address the validation, waiting, and rework issues. Resources are now committed and the necessary training and education is provided to the key stakeholders.

After the fourth step, the prioritized Lean initiatives will be ready for implementation. The following is a list of these initiatives:

1. Implement changes embodied in the future state process map
    - Gradually eliminate excessive validation an replace it with in-process checks.
    - Gradually eliminate the iterative "safety nets" from the development process
    - Utilize more tightly integrated product/process design
2. Avoid multi-tasking project leaders
3. Align clear decision points (instead of tasks) with process milestones
4. Add an "Andon Cord" system to Pre-program and Product Development phases
5. Implement enterprise wide metrics and incentives to drive lean behaviors
6. Implement common computing and data storage systems (ERP) throughout the enterprise
7. Implement "standard work" processes

Finally, the last step in the Transition to Lean (TTL) plan will be to focus on continuous improvement. The enterprise will need to monitor lean progress, nurture the

process, refine the plan, capture and adopt new knowledge, and address any other re-organization needs.

A.3 Barriers to Implementation

In implementing a major change initiative within an enterprise such as a transition to a leaner state, several barriers will have to be overcome. The following is a list of several barriers anticipated as the TTL plan is implemented.

A.3.1 Overcoming Mental Models

The automotive company's early success due to mass production and subsequent growth into a large established company has resulted in a deep entrenchment of mass production processing ideas. The new leaner vision for the enterprise is quite different from the current state. It will require the work force to not only learn the new lean techniques, but to *unlearn* the existing methods. This will require significant emphasis on training the enterprise workforce and communicating the lean vision.

A.3.2 Breaking Down Functional Chimneys

The fuel system enterprise has a heavy-weight functional reporting structure. While there are product managers that work as system engineers in resolving sub-system interface conflicts, the actual engineers responsible for different sub-systems report in to different managerial chains. This results in a focus on cross vehicle sub-system commonality, but a weaker focus on individual vehicle development.

In order to focus the organization on delivering entire vehicles, a realignment of the organization reporting structure is recommended to a product focus. This re-alignment will encourage engineers to optimize vehicle systems rather than sub-systems.

A.3.3 Managing (eventual) Reduction in Workforce

Assuming the transition to lean plan is successful, a significant amount of the workforce will be no longer required in order to support current product development needs. These excess resources must be removed from the system in a timely manner in order to keep the remaining workforce focused on continuous improvement and avoid complacency. Given that the automotive market is already over-capacitated (even in its inefficient state), it is unlikely the solution will be to grow sales in the current automotive market. Growth into new automotive markets, such as China, or into non-automotive markets should be investigated to keep employees productively working.

A.3.4 Leadership Commitment

As with any other change initiative, this transition to lean will require significant commitment (and understanding) of high-level management. The current vision does not provide the detail required for "blind implementation". Those involved are required to actively participate in order for success to be achieved. Leadership will be required to keep focus on the direction of the vision when the inevitable conflicts occur during implementation.

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