Lean Principles, Behaviors and Implementation Strategies for the Automotive Product Design and Development

by

Lee Y. Koa

B.S., Mechanical Engineering
Luoyang Institute of Technology, 1983

Submitted to the Sloan School of Management and the
Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degrees of

Master of Science in Mechanical Engineering
and
Master of Business Administration

at the
Massachusetts Institute of Technology
June 2003

Signature of Author...
Department of Mechanical Engineering
May 9, 2003

Certified by...
Steven D. Eppinger
Professor of Management Science and Engineering Systems
Thesis Supervisor

Certified by...
Charles H. Fine
Chrysler Leaders for Manufacturing Professor
Thesis Supervisor

Accepted by...
Margaret C. Andrews
Executive Director of the MBA Program
Sloan School of Management

Accepted by...
Ain A. Sonin
Chairman, Committee on Graduate Students
Department of Mechanical Engineering

Lean Principles, Behaviors and Implementation Strategies for the Automotive Product Design and Development

By

Lee Y. Koa

Submitted to the Department of Mechanical Engineering

and Sloan School of Management

On May 9, 2003 in Partial Fulfillment of the Requirement for the Degree of Master of Business Administration and the degree of Master of Science in Mechanical Engineering

---

ABSTRACT

This thesis applies lean enterprise principles to the product development process at Ford Motor Company. Based on an internship, the author conducted a detailed study of three Ford product development sub-processes: head lamp appearance design, road load testing, and prototype build process. The value-added activities and wastes are analyzed using a value-stream mapping approach. Lean solutions are proposed in each case and for the overall organization. The last part of the thesis suggests the future research direction.

Management Thesis Supervisor: Charles H. Fine

Title: Chrysler Leaders for Manufacturing Professor

Engineering Thesis Supervisor: Steven D. Eppinger

Title: Professor of Management Science and Engineering Systems

Dedication:

I dedicate this thesis to my wife, Fenny and my son, Disi, for their unconditional support and encouragement for me during the last two years while I was in the Leaders for Manufacturing program at MIT.

My dedication also goes to my mother for her deeply caring for me during my early ages.

Thanks to my thesis advisors, Professor Charles H. Fine and Professor Steve D. Eppinger, for their precious advice and guidance.

Also I appreciate my colleagues in Ford Motor Company, for their helps on my project and thesis. My special thanks go to Mr. Nick Broggi, Mr. Joe Lee, Mr. Eric Schwartz, Mr. Mike Shashlo, Mr. Douglas Eberle, Mr. Tony Palumbo, and all other people in Ford, who have given me various degree of helps.

Biographical Note

Mr. Lee Y. Koa, was born in Chengdu, Sichuan, People's Republic of China on August 6, 1963. He went to Luoyang Institute of Technology and earned his Bachelor of Science degree in Mechanical Engineering. Mr. Koa entered MIT's dual-degree program, Leaders for Manufacturing in June, 2001. He will earn one MBA degree from Sloan School of Management, and one SM in Mechanical Engineering from Engineering School at MIT.

Mr. Koa has extensive experience in industrial instrumentation, automotive, and electronics distribution system. Prior to MIT, Mr. Koa was quality planning manager in Siemens Automotive Group, and quality manager in Lyon Manufacturing.

Mr. Koa is an expert of TQM (total quality management) and ISO/QS 9000. He was a key member of the American Society for Quality.

Mr. Koa and his family live in Canton, Michigan.

Table of Content

Chapter 1: Introduction

The purpose of this assignment is to facilitate implementation of lean principles and behaviors in the product development (PD) organizations of Ford Motor Company.

Project Scope and Context:

Ford Motor Company is currently evaluating their product development (PD) system for inefficient processes, tools and behaviors. Lean practitioners and academics have developed a set of lean product development principles. This assignment focuses on evaluating the effectiveness of those principles to specific Ford PD process challenges. Since the whole PD process is a complex system, for limiting resource and timing of the project, we can only examine a handful of sub-processes, which are major source of program delay and out of control. Three sub-processes are thus identified and chosen for our study. They are the headlamp appearance design process, road load testing process, and prototype build process. The primary resource is the current state of value stream maps of three sub-processes under study.

Approach

The approach used for this thesis is detailed on the following list:

- Conduct literature research on lean PD, and summarize lean PD principles.
- Study current value stream maps of three sub-processes in PD: appearance approval design, road load testing, and prototype process. Develop a set of systemic solutions that leads to the future state of the PD process, which is in line with the lean principles, and improves on-time delivery of program, value ratio, cost effectiveness and quality.
- Identify common and unique principles relevant to Ford PD system based on the study of three sub-processes of Ford PD.
- Identify a set of new behaviors necessary to support the future state and propose a method for Ford to implement a lean culture.
- Recommend strategies for implementing these solutions
- Tools and methods for the project may include case studies, value stream mapping, interviews, on-site visits, and literature research.

Chapter 2: Literature Research

This chapter includes following sections:

2.1. The Lean Principles Summarization

In this section, we will look into current literature on the lean principles, practices for product design and development. There is a lot of literature on this topic. However, due to scope and time limitation of the project, we can only choose five of them, which are prominent and/or relevant to automotive product development.

A list of recent literature about lean product development as follows:

- Book by MIT Aerospace Lean Initiative, *Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative*
- J. Morgan's Ph.D. thesis on Lean PD, *High Performance Product Development – Systems Approach to a Lean Product Development Process*
- Donald Reinertsen's book, *Managing the Design Factory*
- James Womack, *Machine That Changed the World-the Story of Lean Production*

2.1.1. Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative

Lean Enterprise Value boldly redefines lean production as a framework for enterprise transformation. Extending the prevailing view of "lean" to one of eliminating waste with the goal of creating value, the authors explore the core challenge for technology complex industries in the new century. The eight-year Lean Aerospace Initiatives study at MIT has provided a "living experiment" for the principles and the value creation framework developed and explored in the book."[Murman]. Although "The Insights from MIT's Lean Aerospace Initiative" does not address automotive industry, the lean enterprise principles and practices are generic to other industries as well. They can be transferred across industries. In the book, the major lean enterprise principles are categorized as follows [Murman]:

- Waste minimization
- Responsiveness to change
- Right thing at the right place, at the right time, and in the right quantity
- Effective relationships within the value stream
- Continuous improvement
- Quality from the beginning

Then the high-level principles are broken down into two dimensions: human-oriented practices, and process-oriented practices. The breakdown is illustrated below.

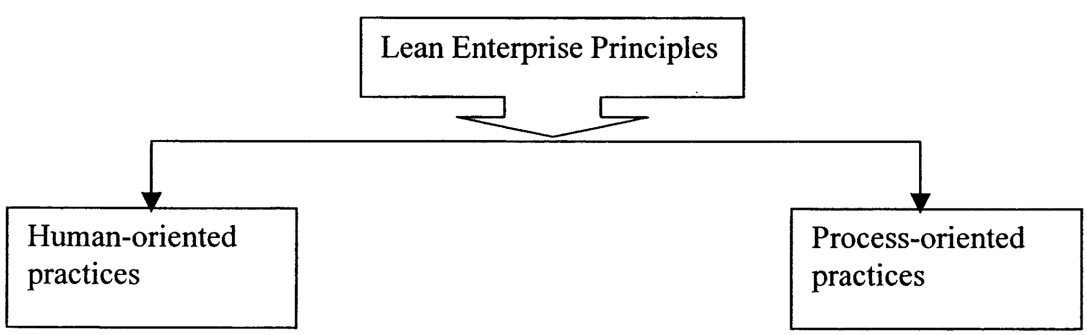


Figure 1: Lean Practice Breakdown

The detailed guidelines for each practice are followed:

The first is the human-oriented practices:

- Goals -Align and involve all levels of an organization to achieve the enterprise's lean vision
- Relationship-Relationships with customers and suppliers are based on long-term and stable mutual trust and commitment
- Decision making - Make decisions at lowest appropriate level
- Capacity - Optimize capability and utilization of people
- Customers' needs-Continuous focus on the internal and external customers' needs proactively
- Learning environment- Nurture a learning environment for attaining lean enterprise goals.

The second is the process-oriented practices, which are summarized in my words:

- Information flow - Provide processes to transfer of and access to pertinent information seamlessly
- Product and process development-Create an integrated product and process development process. Develop products through an integrated team effort of people/organization that are knowledgeable about and responsible for all phases of the product's lifecycle, from concept definition through development, production development, operations and support, and final disposal.
- Process capability-Establish and maintain processes capable of consistently designing and producing the key characteristics of the product or service
- Continuous improvement- Ensure a culture and systems that use quantitative measurement and analysis to improve processes continuously
- Enterprise flow - Optimize the flow of products and service, either affecting or within the process, from concept design through point of use

- Stability - Establish strategies to maintain program stability in a changing, customer-driven environment

Major elements of the two practices are listed together for comparison.

People-Oriented Practices	**Process-Oriented Practices**
Goal alignment	Information flow
Trust relationship	Product/Process development
Decision making	Process capability
Capacity optimization	Continuous improvement
Customers' needs	Enterprise flow
Learning environment	Stability

The principles and practices are aimed neither at automotive industry, nor at product development. The breakdown of the high level principles into two sets of practices is helpful in reality. For a complete structure, we need at least one more kind of practices beyond people and process aspects. It is the technology-oriented practices, since in the product development system, we believe there are three elements: people, process and technology. By doing so, we take all three aspects into consideration. For applying lean enterprise principles, all three practices are important. We need to integrate all three elements into lean practices. However this topic is beyond our scope.

2.1.2 The Machine that Changed the World: The Story of Lean Production

James P. Womack, Daniel T. Jones, and Daniel Roos authored this book in 1990. It is based on the Massachusetts Institute of Technology's five-million-dollar, five-year study on the future of the automotive. It is a groundbreaking analysis of the worldwide move from mass production to lean production. In this book, one section addresses the lean principles for automotive product development. There are four principles [Womack]:

- Leadership
- Team work
- Communication
- Simultaneous development

The detailed explanations of each of these five principles are summarized in my own words and followed:

Leadership: The large-project leader orchestrates all the skills needed to make a wonderfully complex manufactured product. It is the new super craftsman directing a process that now requires far too many skills for any one person to master. The program has the leader's name attached. The difference between Japan and western systems lies in the power and career path of the team leader. In Western teams, the leader is more properly called a coordinator, whose job is to convince team members to cooperate. It's a frustrating role, because the leader really has limited authority, so few team leaders report enjoying it. Senior management frequently overrides the team leader.

Teamwork: Team is organized across functionally and for the life of a program. The process is coherent, rather than moving from function to function. The key evaluation of a team member comes from the team leader rather his/her functional department. Team members are not representative of their departments. Team members remain stable employment.

Communication: Greater effort to resolve critical design trade-offs takes place in early stage. The conflicts about resources and priorities occur at the beginning rather than at the end of the process. The design process is kept at team headquarters rather than sequentially at functional departments. Major human resources are put upfront, and drop on later stages.

Simultaneous: Components/subsystem engineers and tooling engineers work together concurrently rather than waiting on sequential basis. They have basic knowledge of other side, which help them to do some early work rather than waiting.

These principles capture the essence of the lean product design and development. However, in the past ten years, the concept of lean PD has been constantly evolving. New meanings and contents have been added-up. The high level principles are enriched with new practices and methodologies.

2.1.3 Jim Morgan's Seven Lean PD Principles:

A recently completed, 30 months research study by the University of Michigan identified seven fundamental principles that account for Toyota's speed-to-market. These principles form the foundation for, and optimize, Toyota's product development and production systems. The seven principles are[Morgan]:

1. A holistic, systems approach to product development
2. An embedded customer first approach to product development
3. A front-loaded process
4. Built-in learning and continuous improvement
5. Synchronized processes for simultaneous execution
6. Rigorous standardization that creates strategic flexibility
7. Go-to-the-source engineering

The details of each principle are explained in my own words as follows:

A holistic, systems approach to product development:

The author consider that the product development system have three basic elements: people, processes, and technology, which should be fully integrated, aligned and designed to be mutually supportive. Highly skilled, intelligently organized people are the heart of the product development system. The knowledge workers instead of the labor workers are not key players in this arena. Processes should be designed to minimize waste and maximize the capability of the people who use them. Finally, technology must be right sized, solution focused and selected to enhance the performance of the people and the process. When these fundamental system elements are coherent by design, they combine to create a truly synergistic system effect. Clearly, in order to achieve this result, functional organizations must also be aligned.

An embedded, customer-first approach to product development

The author believes that truly internalizing this philosophy acts as the bond that creates a seamless integration between both functional specialties and fundamental system elements. The customer first philosophy results in a deep understanding of customer defined value. It is the first step in any product development process. All players involved in the product development must understand customer-defined value upfront. Product development must deliver a product design that both meets customer needs and is capable of efficient manufacture.

A front-loaded process

We saw numerous vehicle programs ended up as back-loaded processes. To avoid this from happening, the author believes that early engineering rigor, problem solving and designed-in countermeasures, along with true cross-functional participation, are key to maximizing the effectiveness of the product development process. Further, by effectively isolating distinguished phases from each as, such as isolating the plan phase from the execution phase, a company can minimize down stream process variation that is crucial to both speed and quality. A front-loaded process also enables simultaneously designed-in product and process characteristics that are the fundamental underpinnings of lean manufacturing. Lean design concepts such as modularity must be addressed early in the product development processes through standardization tools and timely manufacturing feedback.

Built-in learning and continuous improvement

It is important to build learning and continuous improvement into daily life of each person in an organization. A company can accomplishes this by setting increasingly rigorous performance goals for every project and by holding both real-time and post-mortem learning events that encourage functional specialists to validate and update their own knowledge databases. Learning and continuous improvement are also embodied in a problem solving process that creates multiple potential solutions and focuses on root cause countermeasures designed to stop future recurrence.

Synchronized processes for simultaneous execution

Truly effective concurrent engineering requires that each subsequent function maximize the utility of the stable information available from the previous function as it becomes available. That is to say, they must do the most that they can with only that portion of the design data that is not likely to change. Otherwise, working with early data will result in tremendous waste and actually require a longer duration than a linear process. Each function's processes are designed to move forward simultaneously, building around stable data as it becomes available. The practice is referred as simultaneous execution.

Rigorous standardization that creates strategic flexibility

This seeming paradox is at the heart of Toyota's quality and efficiency by creating far more predictable quality and timing outcomes than would otherwise be possible. This principle includes concepts and tools such as reusability, common architecture, and standard processes. It is crucial in driving waste out of the product development process. In fact, standardized skills, design standards and standard processes allow or specific program customization, broader scope of individual responsibility, a just-in-time human resource strategy, flexible product development capacities and many other system benefits. These standards are also crucial to downstream lean manufacturing capabilities.

Go-to-the-source engineering

In this day of high-tech engineering it is very tempting for engineers to divide their time equally between conference rooms and their cubicles. But as Kelly Johnson, the famous head of Lockheed's legendary Skunk Works said, " an engineer should never be more than a stone's throw away from the physical product." At Toyota this philosophy is referred to as gentchi genbutsu and is practiced in many ways. Examples of this philosophy in action include spending a significant amount of pre-program time at manufacturing plants and dealerships, by working on competitor teardowns, or by personally fitting parts on prototypes.

These principles are mainly derived from current Toyota's practice on the product development area. Although we cannot conclude that Toyota's product development is a lean system, Toyota's superior performance in the product development makes it a benchmark.

2.1.4 Managing the Design Factory: A Product Developer's Tool Kit, by Donald Reinertsen

Mr. Donald Reinertsen did not mention words like "lean product development" in his books. But I found some of guidelines for product development he suggested are very insightful.

He suggests 13 steps for the product development [Reinertsen]:

Step 1: Do your math-build an economic model to guide the day-to-day decisions:
Understanding the economics of your development projects and processes is the only way to select the "right" course of action. Economic analysis is the only reliable compass. The real objective of PD is profits, not products.

Step 2: Use decision rules:
Use the economic analysis to make day-to-day decisions. The intuition should be applied to model inputs, not in creating assumptions about the outputs. Important decisions should be framed as economic tradeoffs and made on the basis of facts. Don't send a signal to your organization that rational decision-making is ignored at the top of the organization

Step 3: Pay attention to capacity utilization:
The higher the capacity utilization is scheduled, the longer the queuing time is. To breakout with obsession to full capacity utilization, is to grasp the economics of queues. Use the cost of queue to identify the key areas of the process that require extra resources. Make a correct tradeoff between the cost of capacity and the cost of the queue. We cannot load a process with variability to 100% utilization without large queues.

Step 4: Pay attention to batch size

Need to break out the mindset of that large batch size is appropriate for product development. Measuring batch sizes or design-in-process inventory as a tool to drive down batch sizes. It is not at all uncommon to find phased development systems where 100% of work is transferred to the next phase on a single day.

Step 5: Respect variability

Variability is inherent to the PD process, and cannot be eliminated. The uncertainty actually creates the information, and the information creates the value of product development. Making the process tolerant of variability as a key design objective. It is foolish to try to drive out variability from the development process.

Step 6: Think clear about risk

A risk-taking action is viewed as appropriate, not based on its success, but based on whether it was sensible at the time the bet was placed. Don't punish failures, which contain very high information content. Failure increases the chance we will have to learn the same lessons over and over again. We should celebrate and publicize the failures that occurred as a result of prudent risk taking. These failures generate new learning and are a key source of valuable information.

Step 7: Think Systems

Managers below the level of senior management are encouraged to sub-optimize the overall system. Senior management is usually the only group in the organization that has a clear picture of the overall system-level effects. They should reevaluate the current incentives to ensure that they don't obstruct system-level thinking.

Step 8: Respect the people

Success is equally dependent on creating a workable system and populating this system with excellent people. This approach requires careful selection and development of people to ensure that the system will work as desired. Devote the scarcest resource, management time, to developing people. Shift our management attention to making people a key asset of the process.

We must welcome the chance to transform people into critical business assets rather than interchangeable cogs in a mind-numbing system.

Step 9: Design the process thoughtfully

Encourage deeper analysis and careful design. Ensure that development process design is approached with the same methodical rigor with which we would approach our product design. What may be labeled as "waste" may be serving a very different purpose in the PD environment.

Step 10: Pay attention to architecture

Architectural decisions have a huge impact on expenses, schedule, performance, and costs. It is unlikely that architecture will be treated as a business-level issues unless senior management decides that it is important. Once architecture is legitimized as a business issue instead of a technical one, we will be able to get other functions to play a role in these choices. We must ensure that all product architectures obtain cross-functional reviews before they are adopted.

Step 11: Deeply understand the customer

It is far more important to understand why the customer wants things, and to respect the fact that customers may have limited knowledge of their own requirements. The implication of this is that we have to spend much more time understanding the reasons why customers want certain things. We must constantly test whether our organization understands why customers require certain product characteristics and to remove any obstacles that stand in the way of obtaining such knowledge

Step 12: Eliminate useless controls

Too much of the control effort at most companies is directed at factors that have no economic significance. The senseless bureaucracy astonishes thoughtful workers. The solution is not to discard controls but to make them relevant by focusing on factors that truly impact economic outcomes. We suggest to review the time invested in supporting various control systems and ask whether this is aligned to the true economic importance of the controlled variable.

Step 13: Senior managers should get to the front lines

Behavioral congruency, or what is known as "walking the talk," is essential for good communications. For most people, how a leader spends his or her time will be the most important sign of what is truly important to the organization. Management demonstrates its interest in product development by the time it spends in the development organization. We suggest that senior managers get out to where the work is being done, to get a view from the ground level.

Mr. Donald Reinertsen's 13 steps are very practical. These steps can actually serve as principles for product development. Although we don't categorize them as "lean principles", they do address major issues and solutions in the PD area. Some insights are very interesting, which are different from our conventional wisdom.

For example, it says that the variability is inherent in the PD process, and cannot be eliminated. Only way is to design a system, which tolerates to variability. It also says what may be labeled as "waste" may be serving a very different purpose in the PD environment. These ideas seem contradictory to "lean" concept, which aims to reduce variability and eliminate wastes.

2.2 Process Enterprise Methodology

Dr. Michael Hammer is a pioneer of process enterprise. He is author of Agenda and Reengineering. The purpose of process enterprise is to redesign a business process, to drive out or minimize waste and non-value-added work, to achieve high performance of a business process. The set of techniques of process enterprise serve a bridge to cross current state (ineffective) to future state (high performance). Dr. Hammer does not use "lean" in his work. However, we find that the high performance future state described by Dr. Hammer is actually a lean state discussed by most lean literature. And the principles of process enterprise have similar traits as lean principles. According to Dr. Hammer, Principles of high performance process design are as follows [Hammer]:

- Work should be done by whoever is in the best position to do it, irrespective of history and/or organizational boundaries
- A process should be performed by as few people as possible to minimize handoffs
- Do work at the best time for it to be done avoiding artificial linearity or generic rules
- Location is a variable, not a given to be explicitly factored in.
- Strive for simplicity. Non-value-adding work breeds complexity
- Structure in terms of alternative rather than exception. Triage keeps the basic flow clean
- Consider the context when performing work. The virtues of uniformity have been greatly oversold
- Control must be subjected to cost-benefit analysis, just like everything else. Neither perfect nor free.

Key Dimensions of process design:

- Who
- When
- Where
- Whether
- What order
- What degree
- What frequency

Design the product development process:

1. Design a checklist for lean process, which reflects all lean PD principles and practices. The follow process design uses the checklist for achieving lean performance.
2. Design the PD process at high level. Assign process owner, and determine all process design parameters (who, what, when, where, whether, what order, what degree/how much, what frequency/how often).
3. Design medium level processes (sub-processes). Define scopes of each sub-process. Assign process owner to each sub-process, and determine their design parameters.
4. Design micro-level processes. This is a level, where a specific department and function or interface are involved.
5. When all high level, medium level, and micro-level processes are determined, we should define all supporting processes including people side and technology side: human resource (hiring, relocating, training, promotion, development, salary), rewards system, decision making mechanism, technology (web, internet, ERP, CAE, virtual build, etc.)
6. Adapt, continuous improvement, of the system

We believe that Dr. Hammer's process enterprise is one methodology to bridge the current state and future, lean state, which can be applied to Ford. We can directly design the future state of the process and/or VSM without bothering too much about the current state VSM.

Traditional ways to measure performance, determine compensation, provide training, and even organize facilities are tailored to vertical units, not processes, and to individuals, not teams. Companies making the shift to a process enterprise will need to take a fresh look at many of the basic elements of their organizational infrastructure.

The Infrastructure of Process Redesign [Hammer]:

The underlying purpose of a business	It is delivery of value to customers in a way that creates profits for shareholders.
Power distribution: Vertical power and cross-function	The power in most companies still resides in vertical unites sometimes focused on regions, sometimes on products, sometimes on functions-and those fiefdoms still jealously guard their turf, their people, and their resources. The combination of integrated processes and fragmented organizations has created a form of cognitive dissonance in many businesses: the horizontal processes pull people in one direction; the traditional vertical management systems pull them in another. Confusion and conflict ensure, undermining performance.
Goals: Focus on process management and goals	We need a leap from process redesign to process management. The process owners should be the best managers with real authority over work and budgets. The focus of the measurement systems should be shifted from unit goals to process goals. The compensation and advancement should base on process performance. The way to assign and train employees need s to be changed, and emphasizing whole processes rather than narrow tasks.
The infrastructure of the process enterprise -Measurement	Managers need to conduct a thorough analysis to determine what aspects of process performance are most directly linked to achieving the organization's overall objectives. Process owners not only use the metrics to track the status of a process and

	guide improvement efforts, they also disseminate them throughout the organization to reinforce people's awareness of the process and to focus them on its performance. Since the same process measures are used to gauge the performance of everyone involved in the process. the metrics also help to reinforce teamwork.
- Compensation	If frontline personnel and managers are to focus on processes, their compensation should be based at least in part on how well the processes perform.
-Facilities	In most companies, people are housed in vertical departments, according to their function, their region, or their business unit. But because processes cut across those vertical divisions, process workers need to be drawn from them into a new location where they can work as a team. By sharing the same facility, they get a better view of the entire process, and they are able to exchange ideas easily. When all work is process work, all space becomes process space.
Training and Development.	In traditional organizations, many people have relatively narrow jobs and need to know little outside the scope of their own department. For a process team to succeed, however, all the members must understand the whole process and how their individual efforts contribute to it. Usually, workers will need to be trained to take on their broadened roles.
Career Paths.	There is less need for middle managers in a process organization than in a traditional one. Process owners design and measure the process, and process teams carry it out, overseeing their own work and making all the day-to-day operating decisions required to keep things moving smoothly. As a result, most of the rungs on the traditional managerial career ladder disappear. A process enterprise therefore needs to develop new career models that are not based on traditional hierarchical advancement.

About Process Enterprise, refer to Dr. Michael Hammer's two publications:

Agenda: What Every Business Must Do to Dominate the Decade

The Reengineering Revolution

2.3 Value Stream Mapping Methodology:

Value stream mapping (VSM) methodology is widely used into manufacturing for implementing lean principles. It is useful because the main value flow is aligned with material flow. In product development area, the main flow is information, data and knowledge. The characteristics of PD VSM will be different.

Definition of value stream and value stream mapping (VSM):
"A value stream is all the actions, both value added and non-value added, curre.ıly required to bring a product from raw material to the arms of three customer or through the design flow from concept to launch" [Morgan]. Value stream mapping (VSM) is a technique for drawing these activities, as well as the flow of information and product between those activities. Mapping the value stream has proven to be a highly effective technique for visualizing the entire process and supporting fundamental process reinvention based on a collection of tools and techniques commonly referred to as lean manufacturing. VSM has proven to be a powerful tool for improving manufacturing processes and the missing ingredient in many-failed Lean manufacturing initiatives [Morgan]

According to Shook and Rother, VSM is so powerful because: 1) It helps you visualizing more than a single process. 2) It helps you see more than waste – it helps you see the sources of waste. 3) It serves as a common language for all participants. 4) If forms the basis of an implementation plan. It helps you design the whole system and becomes a blue print for lean implementation. 5) It makes decisions about flow apparent. 6) It shows the link between information and material flow. Clearly this is a very powerful tool. Although Shook and Rother include product development as a part of their definition, very little has actually been done to adapt and utilize this tool within the unique constraints of the product development environment.

VSM in Product Development
Quote from Dr. James Morgan is as follow[Morgan]:
Many of the issues endemic to complex processes are particularly problematic in the PD process. These issues include:

1) Task and arrival variability resulting in long queues and wasteful work and data-in-process inventories are pervasive in the PD process. Although some variability may be inevitable, even beneficial [Reinertsen], due to the nature of the work involved, the previously mentioned work by Adler and Loch demonstrate that it can be managed.
2) Non-value added activities or waste are rampant in the PD process just as they are in traditional manufacturing processes. The longer timeframes and highly complex nature of the PD process work tends to obscure a great deal of especially insidious non-value added activity.
3) Product evolution from one state to another over time. However fitful, the PD process does progress from concept to customer. In fact the PD process is made up of many progressive flows implying issues regarding batching versus single piece flow etc.
4) Capacity and scheduling related issues. System utilization is one of the best predictors of lead times in any system. Whether measured in man-hours or throughput, both types of processes must deal with capacity constraints.
5) Hand offs from one functional activity to another. The greatest challenges are often found at the intersections of activities whether in manufacturing or PD.
6) There is a work methodology, which must be analyzed and continually improved. Although the nature of the work may be different from traditional manufacturing, much of the work in PD is indeed the same across PD projects and may be enhanced through best practice standardization efforts.
7) Challenging time constraints. Although time frames may be considerably longer than a traditional manufacturing process, and many of the PD tasks concurrent, we are nonetheless concerned with improving cycle times and time in system, especially as compared to the actual value added time. Continually shorter time to market is a system level goal of HPPDS (high performance product development system).
8) Tasks must be synchronized. In product development concurrent tasks across functional organizations or work centers must be synchronized to minimize the waste of rework and maximize the benefits of concurrent or simultaneous engineering.
9) Constraints must be identified and managed. PD processes, like any process are only as good as the weakest link.
10) Creating flow. Once we have eliminated waste, synchronized cross-functional tasks and identified our constraints we must make the overall process flow. This is important in PD as it is in manufacturing.

These are all issues faced by both manufacturing and PD processes, and more importantly, issues that can be improved through the application of value stream mapping tool. In fact, it may be that the VSM tool is needed in the complex world of product development even more than it has been in manufacturing.

Chapter 3: Study Ford Product Development sub-Processes

This chapter includes following sections:

1. Ford product development system Introduction
2. Introduction to three processes under study
3. VSP Practice in Ford Motor Company

Ford is currently the second largest automotive company in the world, in terms of sales, assets and employment. It has 112 manufacturing facilities in over 25 countries as well as 3 main product development sites in Europe and USA.

3.1. Ford Product Development System (FPDS) Introduction:

There are four phases in the FPDS process [Ford]:

Define Phase	Design Phase	Verify and launch Phase
Manage Phase		

The details are as follow:

PD Phases:	Definitions	Contents
Define Phase:	This module looks at the definition of the product in terms of attributes, targets and the phased sourcing from suppliers.	Targets- target ranges are defined; Phased sourcing – suppliers are brought on board during this time as part of the team; Reusability – level of reusability is established by the team;
Design Phase:	It describes the techniques used to design the product including: reliability, analytical engineering, package and	Reliability- it will be designed into the product; Analytical engineering – it is used to ensure reliability using new tools (CAD, CAM, CAE, PIM); Appearance-appearance, function and package reduce the level of engineering time spent on fine feasibility of appearance concepts by

	appearance, manufacturing involvement and phased data notification.	the use of "coarse feasibility" processes. This allows adequate feasibility of multiple appearance and package concepts to support final appearance selection within defined resources; Total manufacturing involvement – design and manufacturing work together from start of the project; Phased data notification – the phased release of data through the CAD system & engineering release system (the non-geometric data).
Verify and Launch Phase:	It looks at the verification of objectives and subsequent launch of product.	Prototype Phases: • CAE • Lab and rig testing • Confirmation prototypes Bundled Changes – changes are grouped to ensure compatible changes;
Manage Phase:	It deals with management structure and tools, techniques and templates to implement FPDS. It spans the entire FPDS process.	Team structure – teams are formed early in the process; Quality Operating System – Project management and Quality Operating System(Integrator) to manage the project ensuring that changes are grouped to avoid expensive individual changes; FPDS Communications, including: work breakdown structure, integrator, lessons learned; Best Practices.

Note: Although these phases can be viewed as discrete, there is considerable overlap in their timings. The following structure is a different breakdown of the PD process, which has considered manufacturing, feedback and corrective action. The other view of the PD process is illustrated as follow:

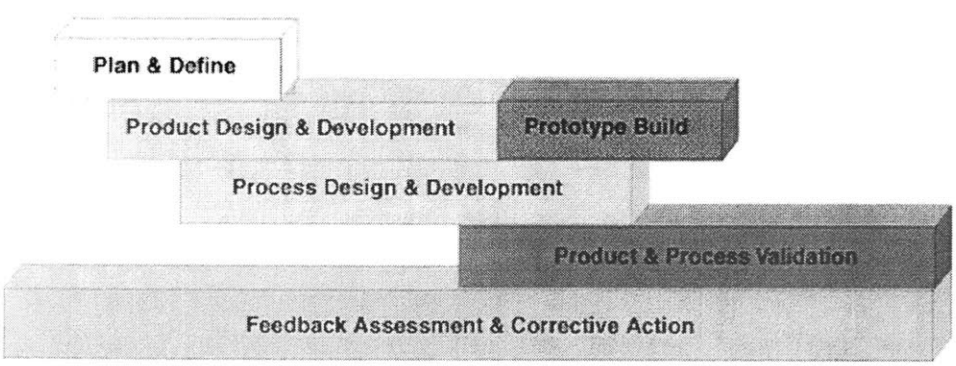


Figure 3-1: Product Development Model [Ford]

What is FPDS?

The vision of the Ford Product Development System is to document the process tasks and deliverables necessary to develop and launch a vehicle. Team events and milestones are defined to communicate progress at various points throughout the product development process. Each process task is related to at least one deliverable and a process description sheet. Currently, there are a total of 1099 tasks and 1255 deliverables in FPDS. The process tasks and deliverables are logically linked to create generic MS project work plan templates for large and small scale programs. FPDS is utilized by the following brands: Ford, Lincoln, Mercury, Jaguar, and Land Rover. [Ford]

How is FPDS Managed on a Product Program?

Some of the FPDS deliverables have been identified as critical in measuring a team's progress at each milestone and to determine their ability to proceed towards Job#1(start of production).

There are 14 major milestones in a common vehicle program:

- The beginning of program specific work
- Mission, vision & target customers defined
- Target ranges assessed
- Initial program direction established
- Strategic Confirmation: Team confirms strategy, viability
- Proportions/Packaging & Hardpoints: Vehicle proportions frozen
- Program Approval: All targets become objectives
- Surface Transfer: Interior, exterior surface provided
- Product Readiness: Designs ready for CP builds
- Confirmation Prototype: First CP vehicle available
- Change Cut-off
- Engineering sign-off complete
- Ready to launch
- Start production

Introduction to Vehicle System Model:

An automotive system can be divided top-down into three levels according level of details. The first is the highest level: vehicle level. The intermediate level is the system level, such as body, electrical, powertrain, etc. The lowest level is the component level, which does not contain other parts. We also call something between component and system as sub-system.[Ford]

Vehicle Level
System Level
Components Level

The concept of System Engineering underpins FPDS. The model used here is "top-down" from the vehicle level (whole vehicle) through the systems and sub-systems down to component level with bottom-up verification from components back to the vehicle level.

At the top level, inputs from the customer, regulatory organizations and FORD are translated into Vehicle Attributes such as Cost, Security, NVH(noise, vibration and harshness) etc. The vehicle attributes will be used to define the Vehicle Design Specifications (VDS).

> Examples of a system include: Body, Electrical, Power-train, and Chassis.
>
> Examples of Level 1 subsystem: Sheet metal, electrical distribution system, engine, and suspension;
>
> Examples of Level 2 subsystem: Front end, fuses, ignition, and wheels, etc.
>
> Examples of Component Level: fuel injectors, switches, etc.

The knowledge of FPDS, and vehicle system model are important for us to examine the some of the sub-processes, such as component design, verification, etc.

A detailed vehicle partitioning is as follows [Ford]:

Vehicle level	**Vehicle**				
System level	Body	Electrical	Power-train	Chassis	Climate Control
Sub-system or component level	*Sheet metal *Exterior trim *Interior trim *Customer convenience & entertainment IP & Console *Seating & restraints	*Electrical distribution system *Body control *Electronic security *Electrical power generation & storage *Intelligent vehicle highway systems *Communications network	*Engine *Transmission *Driveline axle *Power-train as installed *Power-train electronic control	*Suspension *Steering *Brakes *Frame/Sub-frame *Fuel delivery and storage *Interactive controls	*Refrigeration *Air conditioning *Heater *Controls

3.2 Introduction to Three Sub-Processes under Study.

Value stream mapping is one methodology for lean production used widely by Ford Motor Company. Ford Production System (FPS) has initiated a few value-stream mapping process in the PD areas. VSM teams, lead by FPS managers, have done value stream maps for the headlamp appearance design, road load testing, and prototype process. Build on their work, the author spent about 4 months in FPS, studied the value stream maps of the three sub-processes, conducted more than 30 interviews and on-site visits.

The following three sections are a brief description of the three sub-process of product development:

3.2.1 Road Load Process:

Introduction to the process:

The process starts from the overall testing plan by the attribute team of each vehicle program. An assigned test engineer prepares three things:

- channel selection based on standard list;
- request drawings, parts, part test data, and wheel, tire and weight information;
- job instruction sheet for technician; transducer design, selection, type availability.

Then the job instruction sheet and parts are sent to "Transducer Lab" at the Road Load Testing Department where a team of technicians instrument vehicles and conduct road load testing to collect data. Once received the TA(task agreement), JIS (job instruction sheet) and parts, the transducer technicians install transducers on to parts and calibrate them. The average program job is about 20 to 40 parts, and takes about 30 to 50 days.

The department receives a prototype vehicle for the program. The vehicle is inspected to determine if it's okay for testing. Some vehicle needs further CMM (coordinate measuring machine) inspection. Those instrumented parts are sent from "Transducer Lab", and vehicle build technicians started to build the vehicle. They put the vehicle on to one of a dozen workstations. Lift the vehicle, and remove components, and replaced with instrumented components which have transducers installed. Sometimes the vehicle needs to be modified for instrumentation. Once all instrumented components and all connecting cable channels are installed, a weight box is put on to the vehicle. Technicians do the static and dynamic test. Then the vehicle is run according to pre-determined "events" for the test condition in the Ford Proofing Ground. The actual test is highly weather dependent. Road testing is suspended if it is raining, snowing, or windy, which add noise to the testing signals. After road load testing, the data is reviewed and approved by test engineer.

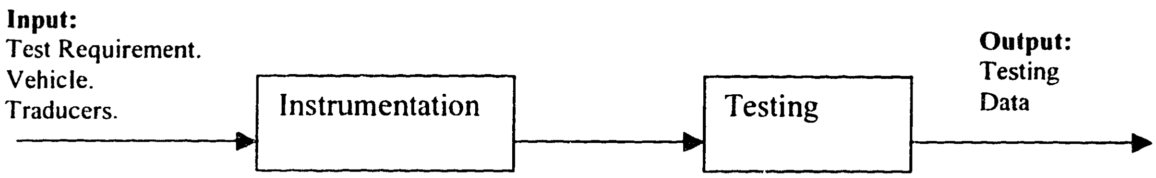
After the data acquisition, the data are sent to engineers, and further analysis follows.

The process flow:

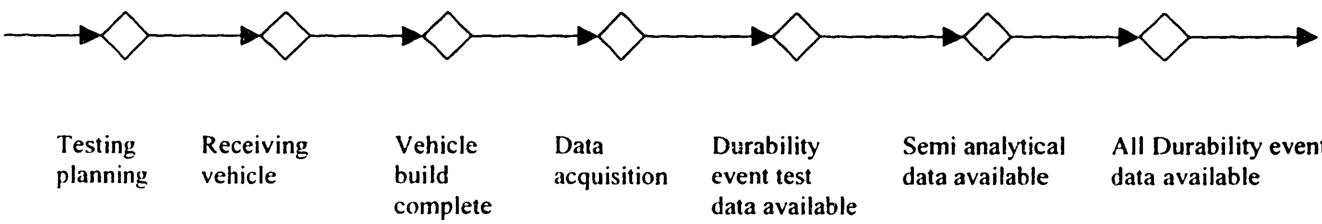
- Test Planning
- Instrumentation and calibration
- Vehicle build
- Road Load Testing and Data Acquisition
- Data Process

The detailed process flow is followed:

#	Steps	Who	Department	Input	Output
1	Test Planning	Testing Engineer	Engineering	Program testing plan	Road-load specific plan
2	Instrumentation and calibration	Transducer lab technician	Transducer Lab	Work instruction,	Parts Installed transducer
3	Vehicle build	Instrumentation technician	Vehicle build Work Shop	Testing vehicle and parts with transducers	Instrumented vehicle with all channels
4	Road Load Testing and Data Acquisition	Testing technician	Testing ground	Instrumented vehicle with all channels, and load	Testing data
5	Data Process	Testing engineer	Engineering	Testing data	Analysis of data



Major milestones:



Weather effects the road load testing: the road load testing is very weather sensitive. During inclement weather like snow, rain, wind, the road load testing cannot proceed. This limits the number of days per year; the facility can do the road load testing.

The Current State Performance of the Road-load Testing Process of 2005NA Program:

Note: Due to proprietary information, the actual model and program are referred to 2005NA.

(Based on 8 hours days and 4 weeks month and excluding holidays)

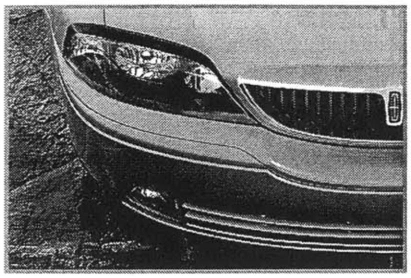
Lead Time	117-238 days
Total Task Time	100 days
Value Ratio	85% to 42%

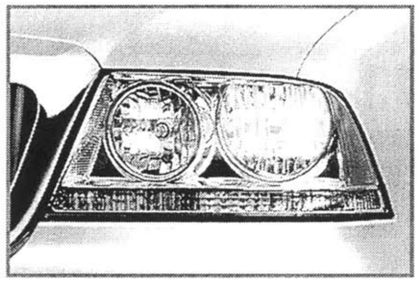
Note:

Value Ration = Value Added Time/Lead Time
Process Lead Time: The total calendar days of the entire process from beginning to finish.
Total Task Time: Total days the process team members actually work that create value

3.2.2 HeadLamp Appearance Design Process

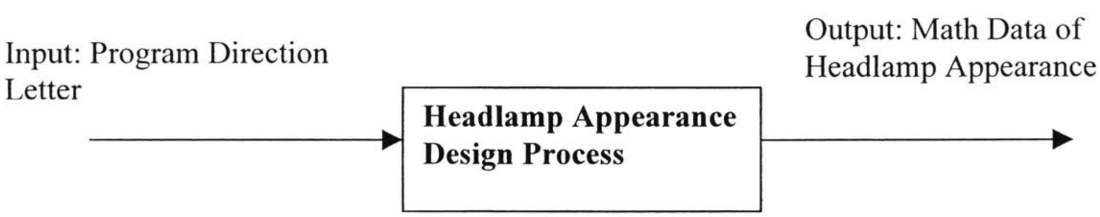
The picture below is a generic headlamp product, which is used as an illustration. The process we identified is only for the appearance design, not including detailed component design and manufacturing.





Introduction to the process:

The process starts at kick-off, and end surface transfer, which is the last milestone for the headlamp appearance design. It involves Ford's studio (appearance designer/artist), core engineering (lighting engineers) and full service supplier. Studio's artist, or headlamp appearance designer develops a few clay models of headlamp themes, and send scanned imagine to lighting engineers. Lighting engineers control the timing, weight, cost, and functionality of the headlamp sub-system and components. Once a theme is approved, the full service supplier conducts the detailed design, and manufacturing feasibility. The output is a complete math data ready for manufacturing.



The main process flow is followed:

The process flow:

- Input of program direction letter
- Define headlamp functional attributes/multiple themes

- Initial engineering feasibility/
- Initial headlamp fit & fitness assessment/refine single headlamp theme
- Math data generation

However, the process flow in this process is more complicated than the one in the road load testing process. There are a few simultaneous steps among three major players: designer in studio, core engineer of lighting department, engineer from supplier.

#	Steps	Who	Department	Input	Output
1	PDL as an input	Program Management	Program	Program level input	Headlamp specific input
2	Define headlamp functional attribute	Lighting engineer	Lighting department	PDL	Engineering statement of work(ESOW)
3	Refine multiple headlamp themes with boundaries	Designer	Studio	PDL, and theme model example	Clay model
4	Submit quotation	Engineer	Supplier	ESOW, including cost structure, renderings, lamp envelope	Quotation
5	Contract supplier	Program Management	Program Management	All suppliers' profiles	Selected preferred supplier
6	Initial engineering feasibility, and analysis of headlamp themes alternatives and trade-offs	Engineer /lighting engineer	Supplier /Lighting	ESOW	Engineering feasibility
7	Develop proportions and ranges for two headlamp themes within boundaries	Designer	Studio	Continuous work	Scanned clay model
8	Design refinement and Manufacturing feasibility	Engineer / lighting engineer	Supplier/ Lighting		
9	Single theme selection	Program Management	Program Management	Multiple themes profiles	Selected theme
10	Refine single headlamp theme	Designer	Studio		
11	Headlamp fit & finish assessment	Engineer	Supplier		
12	Final surface data, and math data generation	Engineer	Supplier	Final surface data	Math Data

The above process flow is only a proximate reflection of the true flow. There are a lot of iteration among players, which cannot be exhibited on this table.

The Current State Performance of the Headlamp Design Process of 2005NA Program:

(Based on 8 hours days and 4 weeks month and excluding holidays)

Total Task Time (TTT)	1984 hours
Total Time in System (TTS)	21,000 hours
Process Lead Time	804 days
Headlamp Design Value Ratio (total value-added time divided by total time in system)	9.4%

Note:

Value Ration = TTS/TSS
Process Lead Time: The total calendar days of the entire process from beginning to finish.
Total Task Time: Total hours the process team members actually work that create value
Total Time in System: Sum of total hours of all process team members work during entire process

The Current Process Flow for 2005 NA Program, which has not been finished as of the date of VSM:

Functions /Timing	**3 months**	**4 months**	**4 months**	**11 months**	**4 months**
Design Studio	2000 Auto show Quad beam & Evolution Clay them	Develop "Quad Beam" Clay Theme	Refine "Quad Beam" Clay Theme	Refine Single "Quad Theme" Clay Theme	Design Refinement of Single Quad Beam Theme
Supplier	Feasibility assessment to targets for evolution theme	Feasibility assessment to targets for quad beam theme	Limited studies and trade-offs for quad beam theme	Design refinement of single quad beam theme & resolution of commercial issues	Manufacturing feasibility of single quad beam theme
Core Engineer	Quad beam feasibility review	Quad beam theme feasibility review	Feasibility for multiple for quad beam themes	Refine single "quad beam" clay theme & develop APQP deliverables	Deliver level feasibility based on bulb & misc. design studio changes

Reporting Matrix:

The organization structure of the vehicle program is a matrix structure. Chief Program Engineer is the overall vehicle program leader. Under his leadership, a Program Manager or Project Manager integrates the whole process. A few integration supervisors, such Chassis, Power Train, Body, and Electrical report to Program Manager.

For the headlamp appearance design, the major tasks are done by studio designers, lighting engineers, and full service suppliers. Each of them has a vertical report of their home department or organization. It is a combination of cross-functional team, and vertical reporting structure.

Program manager and CPE are not involved in the daily tasks of the headlamp design. They give out the program direction letter at beginning of the program, and kick-off the design process. They conduct periodical reviews of the progress and deliverables.

For 2005 NA program, one to three studio designers, two lighting engineer and two to three supplier product engineers are assigned to work on the design job. The Ford lighting engineer(s) basically manages the design process by coordinating with studio designers, and product engineers of full service supplier.

The reporting structure is followed:

CPE	Design Manager/VP	Lighting Supervisor/Trim Manager	Visteon Headlamp Manager	Purchasing Supervisor
Program Manager, Integration Supervisor	**Studio Designer**	**Lighting Engineer**	**Visteon Product Engineer**	**Purchasing Agent**

The table above illustrates the vertical reporting structure for major players in the headlamp appearance design.

3.2.3 Prototype Build Process

The prototype build process takes place at vehicle verification stage and after design stage. In Ford, there is one facility designated to physically build prototype vehicles for almost entire North American models. However, the true prototype build process challenge lies on managing side rather than physical assembly side. There are a variety of prototypes and prototype builds. From vehicle structure level, there are vehicle prototypes, system or sub-system prototypes builds, and component prototypes. Our process is for vehicle level prototype builds.

There are 6 players for the process:

- Program Management & finance
- Prototype Planning, Build & Verification
- PPM (pre-production program management)
- Core Engineering
- VO: vehicle operation
- Purchasing

The process flow is as follow:

#	**Process Steps**	**Functions/Activities**	**Output**
1	Plan/issue build schedule	Planning activities	Build schedule
2	Solve BOM (bill of materials)	Planning activities	BOM
3	Vehicle BOMs established	Planning activities	BOM
4	BOM validation	Pre-production program management activities	BOM-validatation
5	Procure parts	Pre-production program management activities	Purchase order
6	Part follow-up	Pre-production program management activities	On-time delivery
7	Receive parts at warehouse	VO (vehicle operation)	Stock
8	Ship parts to build site	VO (vehicle operation)	On-site

9	Build prototype vehicles	VO (vehicle operation)	Vehicles
10	Manage Vehicle Build to BOM	Build Activities	Delivery
11	Deliver Vehicle to Customer	Build Activities	
12	Perform Vehicle Verification Tests	Vehicle engineering verification	
13	Update Vehicles as Required	Build Activities	

Sub-flow related to each party:

Core Engineer	PPM (Pre-Production Program Management)	Prototype Planning Build & Verification
Program definition & theme development	File setup	Develop initial build schedules
Engineering design feasibility, compatibility	Part procurement	Inputs to change control manage build schedule
Single appearance theme	Pre-production program management input file setup	Inputs to change control manage build schedule
Product design for released in BOM		Inputs to change control manage build schedule
builds, winter testing		build (30 units)
Resolution of remaining engineering issues		Incremental BOM reformalized

We can see the process flow is not oriented on the process, rather than functions. There are a lot of hands-off during the process. The prototype build planning is based on previous predictor model.

The Current State Performance of the Prototype Build Process of 2005NA Program:

(Based on 8 hours days and 4 weeks month and excluding holidays)

Total Task Time (TTT)	Not available
Total Time in System (TTS)	Not available
Process Lead Time	625 days
Headlamp Design Value Ratio (total value-added time divided by total time in system)	2% to 6% approximately

Note:

Value Ration = TTS/TSS
Process Lead Time: The total calendar days of the entire process from beginning to finish.
Total Task Time: Total hours the process team members actually work that create value
Total Time in System: Sum of total hours of all process team members work during entire process

3.3 VSM Practice in Ford

Ford FPS's current value stream mapping process:

1. Management decides to do a specific VSM for a functional department
2. FPS initiates the process, by appoint one VSM coordinator(coach) to the project
3. The coordinator and the functional department establish a VSM team, which comprises all parties of stakeholders, such as program management, core engineering, supplier, design department, purchasing, etc.
4. The coordinator is first trained with VSM methodology, or is required to have the knowledge as a prerequisite. The other team members must be trained prior to the task.
5. The coordinator starts intensive interview with people in the functional department, and all stakeholders to gain insights.
6. The coordinator is entitled to look into all records, documents, to gain first hand data on activities already going on.
7. Some picture is not obvious, the coordinator and the interviewees then come up with the after-facts.
8. This is basically what Ford does on the current state of VSM.

For the future state, it is almost the same approach. The same coordinator initiates the process after the current state VSM is done. The coordinator interviewed related personnel. The interviewees give their opinion on issues and solutions. The future state then is done based on these inputs. We need to find out how they do the interview. Is there structured interviewing process, such as the standardized questions? We need to find out what documents or records the coordinator is looking for. A list of them will be helpful;

In short, the common approach of doing PD VSM is that:

Do the current state value stream mapping first, then based on insights of people to figure out the future state.

There are problems with this approach. The task of doing the current state VSM is an endeavor. It requires a few months of hard work. It needs training for the team involved. It needs an expert on VSM to give guideline or coaching. The first hands data may not always available or accurate, since the data collecting jobs are not systematic, or daily routine. The data for VSM may become rough or inaccurate data. Even if the current state VSM is fine, the future state VSM is still something depending the smartness of the team. The quality of the future state VSM is highly unpredictable, and is determined by people. There are no mechanism to bridge the current state VSM and future state VSM.

One assumption we frequently heard is that without current state of VSM, you cannot do the future state VSM. People who support this assumption argue that only by doing the current state of VSM, you identify those areas of waste, non-value-added activities. Then you will have opportunity to eliminate the wastes.

However, future state is a kind of lean state of the process and organization. It follows certain patterns and principles. There are some systemic solutions, which can be implemented without look into the current state.

Also, the current state VSM may not be the true reflection of the real current state. The Current state VSM in most case is not done in real time. The one full cycle of the PD process for automotive PD usually take about 12 months to 46 months. The data collection depends on the accuracy of the records, documents and interviewees' thoughts. The authenticity of the data cannot be verified also. Therefore, we may not see the true picture of the current state.

Insights from studying three VSMs, three related PD organizations, interview, and shadowing.

1. The current state VSM may not be accurate: no original data, retrospect,
2. The VSM in PD has more than 3 or 4 parties involved. The tasks and process are very complicated. It is easy to lose track.
3. The VSM current state does not logically bridges to the future state. It needs whoever to interpret the future state.
4. There is no PDCA circle for continuous improvement. VSM now is done at one time basis.

5. No software for VSM, especially one for a type of product development process. Manually doing the VSM is very time consuming. This is a technical issue.
6. Doing VSM in Ford is not a standardize procedure. It is normally one time job. It takes extra effort for management to take the action. It should be in a continuous improvement effort. There is no PDCA Deming circle inherently.
7. The VSM is a very long process. The VSM process takes 9 to 12 months to complete. The total task time is also tremendous.
8. The VSM future state carries vision most management agrees with. But the execution of the future state becomes a major problem. It soon goes back to old process for example. The problems are: lean concepts are not well understood in PD; leadership from top is not supportive.
9. The three VSMs studied are higher level of VSM. To better understand the process, a lower level VSM is needed.
10. Most VSMs are done by retrospect. It highly depends on the documented records to trace back all information. The inaccuracy of the data may result in inaccurate VSMs.
11. For different phases, design, verification, prototype and launch, the VSM has different effectiveness. The upstream VSM is very complicated. We need to go down lower level to simplify the process. Also we may ignore some tasks to make it simple.

Conclusion from above insights:

VSM is not an effective way to bridge the current state to lean PD state.

Chapter 4: Issues, Causes and Solutions for three sub-Processes

This chapter covers following sections:

This chapter addresses the root causes and solutions for three sub-processes we discussed in chapter 3. Then based on the root causes analysis, we can compare and contrast them each other. A summary of what is in common and different is illustrated in section 4.4. The last section, 4.5 consists proposed solutions as whole, instead of aiming only individual problems.

4.1 Road Load Testing Process

The road load testing process has following features:

- Handcraft, precision work: it is mainly manual skill trades
- Labor intensive: all transducer installation is done by labor
- Customized work: each location of testing needs specific transducer tailored to part configuration
- Long lead time: everything from transducer installation to queue for assembly take time
- Capacity driven and queue: when fully utilize the capacity, queue is inevitable
- Skill and technology driven: the skill of worker and technology we use may have big impact on cost, and timing.

The major process flow of the road load testing:

Planning → Instrumentation/calibration → Vehicle build(installation)→Data acquisition → Data processing

The table below is a summary of issues, causes and solutions based on interview, on-site visit, brainstorming, and studying the value stream map of current state.

Item	Issues	Causes	Solutions
1	The instrumented parts at shop turn out being obsolete, and technicians start over again	The component engineer revises the design. The ordered parts by test engineer have long lead-time from order to receive.	Disciplined engineering freeze; no later change. On-line order tracking, like FedEx; real-time parts status. Reduce lead-time for fabrication.
2	The lead-time for road load testing ranges from 78.5 days to 162 days – too long.	The capacity of the road load testing is limited, with only 11 hoister, 8 full time, and 7 part time workers on all North America programs.	Eliminate the bottle neck by adding extra capacity. Apply theory of constrain, and queuing theory.
3	The vehicle is assembled at prototype shop, shipped to Road Load Testing, dissembled, and then instrumented.	Function mind-set	Do the components instrumentation (transducer installation) at prototype plant. Eliminate the disassembly work.
4	The database porting to TCS is not remote.	Old technique	Use remote data sensing technique to eliminate the channel cables.
5	Too many channels: too complicated, too slow. Not every channel is value added	For the sake of testing mind-set	Study the channel selection to avoid unnecessary or for the sake of testing.
6	CMM is used to inspect components disassembled from vehicle before instrumentation. But the CMM is a non-value-added work	No quality confidence on the incoming vehicle components	Eliminate the CMM process, and improve supply quality. Work with supplier to establish an incoming parts quality certification program, e.g.
7	The calibration fixture is specific design, and takes time to fabricate	Craftsmanship mind-set	Standardize the fixtures to save time and cost. It needs testing engineer and technician work together to find the commonality among parts, fixtures in order to design standardized fixtures.

Waste and Non-value-added tasks analysis:

Player	**Wastes and non-value-added work**	**Notes:**
Program Management	-	*The VSM does not give too much information about PM.
Test Engineer	-Waiting for requested parts and information- Waste -Do excessive channels for testing* - NVA(non-value-added activity)	* The channel selections should base on the needs, not for the sake of testing.
Technician	-Scrap or rework on parts due to design change (revision)-Waste -Queue due to long lead time of transducer installation-Waste -Queue due to lacking of capacity of jig-Waste -Wait vehicle before instrumentation -Waste -Use CMM to measure parts**-NVA	**CMM measuring is a kind of non-value-added work.

Categorize of wastes and non-value-added activities in the road load testing process:

- Lack of capacity
- Queue
- Waiting
- Do excessive tasks, which are not needed by customers
- Rework or scrape due to engineering changes

Waste: Pure wastes are activities, which are neither value-added, nor necessary.

Non-value-added activities: it is not value added activity but it is necessary.

The Future State Performance of the Road-load Testing Process of 2005NA Program:

(Based on 8 hours days and 4 weeks month and excluding holidays)

Lead Time	82 days
Total Task Time	35 days
Value Ratio	41%

Note:

Value Ration = Value Added Time/Lead Time
Process Lead Time: The total calendar days of the entire process from beginning to finish.
Total Task Time: Total days the process team members actually work that create value

4.2 Head Lamp:

The issues, causes and solutions for headlamp appearance approval process are summarized in the following table:

Item	Issues	Causes	Solutions
1	Future state is not followed in the new program U251. It fell back on the current state (VSM).	The new value stream map changes the process on paper, not in the organizational structure.	Re-design the process, organizational structure, and reward system. Refer to Dr. Hammer's process enterprise.
2	Full service supplier suspended their work for two weeks	The full service supplier was not committed up front, and resulted a stand off	Early commitment to supplier. Must have contract with suppliers done before <KO> or <SI> strategic intention
3	The lamp themes are revised more than 51 times. Supply involves in the styling, but no power. It is not design for execution, rather for further revision. I	Studio management overrides the FPDS system, and revise the design after freeze-date.	Highly disciplined on the engineering change. Studio artist/chief engineer freeze the theme. Program manager follows up the freeze
4	Core engineer for lighting in Ford has to fight artists on many issues, which not suppose to exist. It creates a lot of fighting, stress, etc. Core engineers felt powerless.	Conflict of interest between core engineer and studio: one for cosmetics, and one for cost, functionality and weight	Arbitrary, or leadership to end these issues A training program to ensure artists know the engineering spec, process.
5	Engineering looks for a cost of $50 a maximum and while studio's aesthetic design may cost $70	They have different objectives, which are not in line with each other. Designer is aesthetic focused, while lighting engineer is focused on cost, weight, functionality.	Cross-learning to gain insights of counterpart, and alight goals.
6	Supplier does not have benchmarking data to support	Supplier did not aware the needs of Ford.	Build benchmarking data
7	Upfront decision does not bring all parties together. No common goals for supplier, core, studio, and program management	Don't aware the "front-loaded process" principle.	Instill the "front-loaded process" principle. Bring all parties together for upfront decisions. Two parties: designer, lighting shall involved early to understand each others' goals.
8	No embedded organizational learning events	Not understanding the importance of the learning events	Embedded the organizational learning events into process design. At end of each major process step, a learning event shall take place, which helps step downstream and future programs.
9	Management review is not thorough.	No mechanism to ensure all aspects have been reviewed.	Use thorough checklists for review: Headlamp design checklist, fit & finish check list, mfg. Feasibility checklist, engineering feasibility checklist

10	Visteon has multiple contacts in Ford and cause hands-off	Multiple contacts increase the complexity of communication, and thus delays and errors.	Designate a single Ford contact for suppliers to reduce hand offs
11	No process design for headlamp. All program follows the FPDS	Still the function mind-set, not process oriented mind-set	Take process oriented approach to design the process: where, when, who, what, and how, plus designated process owner, timing, measures, inputs, and outputs. Refer to Dr. Hammer's process enterprise.
12	So many revisions are not a big problem. The big problem is the slow turn around of revision.	Management reviews in batch. Waiting on table is a major delay.	Measure the revision lead -time, and improve it. Make the change and its impact transparent– cost structure, interference, weight, and performance

Waste and Non-value-added tasks analysis:

Player	Wastes and non-value-added work	Notes:
Program manager	-Vague program direction letter, causing a vague engineering statement of work later on -Revise program direction letter issued -Program timing change-twice -Timing, cost and quality drift due to not embedded learning events to correct in-process -Missing control of progress due to lacking of explicit commodity specific deliverables at each milestone	Program direction letter serves as an input of the process. Engineering statement of work serves as an input for lighting design.
Core engineer	-Weekly meetings and coordination* -Engineering statement of work is vague, and take a few iterations and long lead-time	*Most meetings do not create values that customer would like to pay for. Coordination does not create value either.
Artist in design studio	-Design change/iteration (51 versions in 32 months)** -Weekly meetings and coordination*	**After certain milestone, any design change upstream will cause a series of rework down stream.
Supplier	-Weekly meetings and coordination -Work on a design that customer (Ford) does not want -Stop program support for 2 weeks, wait for contract from Ford -Supplier has multiple contacts with Ford: design studio, core engineering, program management, purchasing, causing hands-off, complexity and miscommunication.***	***The complexity level is in exponential proportion to the number of people involved. The more complex is, the higher the errors.

Purchasing	-Weekly meetings and coordination* -Rework on preliminary cost estimation due to 2 times of design changes/iterations -Rework on cost structure development due to 7 times of design changes/iterations**	

Categorize of 7 wastes and non-value-added activities in the headlamp appearance approval:

- Work on design that customer does not want
- Re-work due to revision, changes, iteration
- Waiting
- Meeting for the sake of meeting
- No in-process control: embedded learning event, specific deliverables at each milestones, specific measurements of process
- Hands-off and Multiple contacts

4.3 Prototype Development Process:

Item	Issues	Causes	Solutions
1	Testing is based on assumption, not on requirement. 100 vehicles are determined, but 120 are needed constant fight, or look for alternative.	Predict model for prototype planning has not been updated for three years. The new government requirements, new tech are not reflected.	*Re-visit the predictor model. Make correct decision. Abandon the model if necessary. Need shorten the update cycle. Update at regular. Establish frequency of updating
2	The program direction letter is not finalized. It is constantly revised and caused a lot of correction, rework	Management is not firm on the program direction letter issue date	Discipline on the program direction letter revision. It is better to do it explicitly upfront to prevent from changing later on.
3	Purchasing for prototype is lower priority comparing with production parts	Prototype purchasing is only buyers' part-time duty. There used to have designated buyers for this.	Specific buyers for prototype; Make the prototype parts higher priority; Prototype metric to be added to scorecard;
4	The lead time for prototype is too long, 5 to 6 months- Note: a few reasons for this	The suppliers prefer to ship parts all at material request data (MRD), which causes the warehouse panic	* Avoid same MRD for all suppliers, so that the arriving parts are balance for warehouse handling and capacity
8	No organizational learning event	Poor mind-set of senior management	Add organizational learning event
9	Accept parts, or having order change even very close to MRD(material request date).	Not disciplined	No acceptance or order changes 4 weeks to MRD. 100% PD illustration, 100% process sheets
10	The program direction letter has many revisions which causes revisions and confusion	Not disciplined. Not evaluating the consequence of late commitment.	Simplify the program direction letter. Take explicit program direction letter
11	Prototype vehicles are not shared among programs	The benefit of sharing is not understood by management.	Study the optimization the use of the prototype vehicles. Promote vehicle sharing: loaner prototype fleet availability for testing
12	Poor quality of design specification for test requirements Also poor quality of testing	The engineer who wrote the procedure does not have in depth knowledge about testing. The writers	Improve the quality of the design specifications. Only assign an expert to write the testing procedure.

	procedure	are not well trained Also the standards are not clearly communicated.	
13	No rigid 8D process for corrective action internally, or with suppliers	Mind-set: we don't think it is important enough to have an 8D.	Change the mindset. Establish internal 8D for PD.
14	When a design is changed, the DVP is not updated.	Lack a mechanism for an automated update or prompt.	Have-to change: testing failure, then redo Other system changes lead the design change. Management's decision: market driven,
15	Too many meetings, and reiteration wasted a lot of time, and no decisions. Too much communication, too little decision making or problem solving.	Poor design of the workflow and communication channel.	Reduce meeting numbers, Well-designed meeting for solving problems.
16	Issues are not tracked by vehicle integration, even it is tracked by system/subsystem engineering	It takes effort for attribute team to update vehicle integration on any changes of issue status. There is not a convenient, disciplined issue tracking system, like an issue tracking system for launch.	Program wide tracking system for issues. Establish an issue tracking system on all levels.

Waste and Non-value-added tasks analysis:

Player	Wastes and non-value-added work	Notes:
Program manager	-Vague PDL. It is not thorough, accurate and timely. -PDL (program directional letter) change iteration 3 times -Re-run predictor model 5 times due to PDL changes -Program timing change -Timing, cost and quality drift due to not embedded learning events to correct in-process -Missing control of progress due to lacking of explicit commodity specific deliverables at each milestone -Targets (attributes) and assumptions are changed by a senior marketing manager.	
Prototype	-Weekly meetings and coordination	

Planning, Build & Verification	-Prototype vehicles are not shared. The usage of them is not optimized -There are conflict, duplication among prototype planner, test planner, and test facility planner. The three planners are not integrated. -The prototype planning uses assumption (predictor model) instead of DVP requirements -There are too many prototype colors that are unnecessary. 2 colors are enough.	
PPM	-Design change impacts inputs to the BOM* -Weekly meetings -CAD work files saved in personal computer does not have standardized naming conventions in metaphase, which causes troubles.	*After certain milestone, any design change upstream will cause a series of rework down stream.
VE	-Design changes cause a series of troubles	
VO (vehicle operation)	-Obsolete parts are shipped to warehouse** -All parts arrive at warehouse at the same date: MRD(material require date) causing chaos.*** -Rework, and Scrape -Send vehicle to assembly plant to pain/E-coat take about 2 wks to 1 month. -The parts in warehouse are mis-picked.	**They are useless, and cost us on inventory management. ***All suppliers wait to ship parts at due date: MRD.
Purchasing	-Purchasing of prototype build material is set aside (waiting) due to low priority to RPS materials in eyes of purchasing.	

Categories of seven wastes and non-value-added activities in the prototype process:

- Non-synchronized planning
- Resource is not shared: fleet of vehicle for prototype life cycle
- Re-work due to revision, changes, iteration
- Confusion due to non-conventional information/data
- Waiting/Batching
- Meeting for the sake of meeting; Coordination
- No in-process control: embedded learning event, specific deliverables at each milestones, specific measurements of process

The Future State Performance of the Prototype Build Process of 2005NA Program:

(Based on 8 hours days and 4 weeks month and excluding holidays)

Total Task Time (TTT)	Not available
Total Time in System (TTS)	Not available
Process Lead Time	625 days
Headlamp Design Value Ratio (Total value-added time divided by total time in system)	26.3%

Note:

Value Ration = TTS/TSS
Process Lead Time: The total calendar days of the entire process from beginning to finish.
Total Task Time: Total hours the process team members actually work that create value
Total Time in System: Sum of total hours of all process teammembers work during entire process

4.4 Common themes, Difference and Proposed Solutions

Upon studying of the three sub-processes in Ford's product development, we found some common themes across two or three of those sub-processes. It is very useful to put common themes of three sub-processes together based on dimensions of PD process.

Common Themes:

Processes	**Road Load**	**Headlamp**	**Prototype**
Goals	Different among players	Different among players: artist, engineer, supplier	Different among players
Capacity	Capacity limitation: # of technicians, # of rigs		Capacity limitation: # of vehicles (100 –120), build capability/painting
Input		Vague PDL. Many revisions of PDL	Vague PDL. Many revisions of PDL
Lead Time	Lead time too long: >12 month	Lead time too long: >12 mo	Lead time too long
Design Change	Design change/revision	Design change/revision	Design change/revision
Procedure	Test requirement, procedure are not high quality	No procedure to describe intermittent steps. Only one milestone <ST> is far from enough..	Test requirement, procedure are not in high quality. No procedure to determine program specific deliverables for each milestones
Learning	No embedded learning events	No embedded learning events	No embedded learning events
Coordination	Too many coordination, meetings	Too many coordination, meetings	Too many coordination, meetings
Standardization	Non standard calibration fixture	Improvising the working process	No standard process. No shared vehicle.
FPDS Discipline	Missing milestone	Missing milestone	Missing milestone
Rewarding & compensation	Vertical department	Vertical department	Functional department
Perform. review	Vertical department	Vertical department	Functional department
Decision		Decision is not at lowest level. Management frequently intervenes.	Decision is not at lowest level

Lean PD System Model:

The purpose of a lean PD process is to simultaneously achieve an optimized product performance with highest quality, fastest speed, and lowest cost. The model below shows the lean PD process model we proposed. One the left side of the model, we have three aspects of a PD system, process, people, and tools and technology, which serve as given to the system. They can be re-design, or controlled as inputs in some degree. The right side of the graph illustrate our three simultaneous goals for our system output.

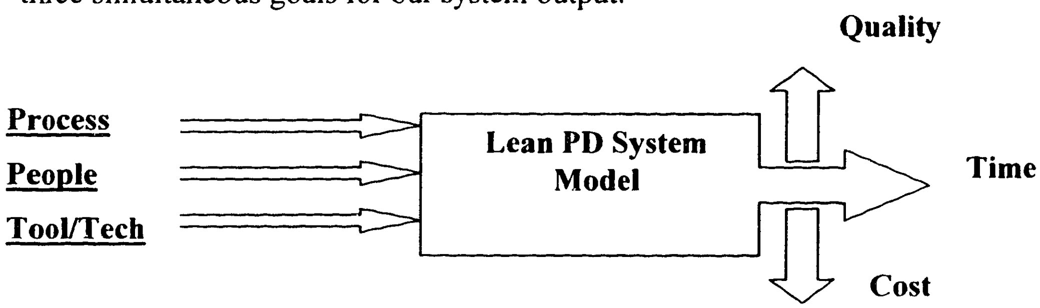


Figure 4-1: Lean PD System Model

With this model, we will summarize some common guiding principles on each side of inputs: process, people or organization, tools and technology. We try to avoid high-level generality of principles. We also avoid labeling these guiding principles as "lean PD principles". The true lean principles must undergo rigorous tests and be proven.

Guiding Principles on Process Side:

Elements of Process	Principles
Goals	Use process goals, instead of functional goals
System	Senior management to have a clear picture of the overall system-level and to ensure the current incentives not to obstruct it.
Architecture	Senior management to legitimize the architectural decision as a business-level issues instead of technical one.
Process Input	Have specific, accurate, and timely inputs (e.g. PDL)
Process Control	Eliminate unnecessary controls. Keep and/or add in-process controls that have truly impact on economic outcomes.
Capacity/Queue	Pay attention to capacity. Don't fully utilize capacity. Make trade-off between cost of queue and cost of capacity.
Batch	Avoid single day transfer of work to next phase. (note: in PD world, the batch size is defined as design-in-process inventory.)
Design Change	Make change transparent, fast. Avoid any change after design-freeze.
Milestones	Discipline on sticking to milestones
Measurement	Measure process performance in line with overall objectives
Decision	Make it at lowest level. Use economic decision model instead of intuition.
Corrective Action	Do internal PDCA loop
Lessons	Adapt embedded learning events. Do internal 8D (Eight disciplined problem solving methodology)

Guiding Principles on Organization/People Side:

Elements of Lean PD	**Principles**
Leadership	Senior managers should get to the front line, to get a view from the ground level, but not override lower level decisions.
People	Shift management attention to making people a key asset of the process. Workers at front line are the most important people. The role of management is to support them.
Organization:	Reduce or eliminate the vertical power for any process. Empower cross-functional team. Place a heavy-weighted process owner. Abandon conventional organizational chart.
Location of Work	Break function wall. Put process team together
Training and development	Train on whole process and how their individual efforts contribute to it
Compensation	Compensation should be based at least in part on how well the processes perform
Career path	Design new career model for process team

Techniques/Tools for Lean PD:

On tools and technology side, we don't intend to provide any guiding principles since they are beyond the scope of our research. The following is a brief list of lean PD tools and technology based on our research and understanding. A couple of them are coinage of the author, which is believed necessary for the lean PD system.

- **CAE/Virtual Design-** It saves time, cost and improves quality of design.
- **Fast prototype** – It saves time, cost and improves quality of design
- **House of quality (QFD)-** Deeply understand customer needs, and transfer to attributes inward.

- **DFM** – It means design for manufacturing, which push the manufacturing decisions upstream at design stage.
- **Pert**-A kind of resource management tool
- **Gantt chart**- A kind of project management tool
- **Critical path**- It has the biggest impact on the overall timing.
- **Theory of constraint**- It is for the capacity of the process. Need to identify bottleneck.
- **Queuing theory**- It is for the process control. The cost of queue and cost of capacity are highly related.
- **Design for meeting**- It is a new concept, in order to save the time, resource, and salary usage. We can do VSM on meetings, so why not try "DFM"?
- **Internal Process 8D** – We have 8D for product quality concerns, but no one for process quality issues. It is on the management and process side. We need to surface any issues, which constitute the internal wastes.
- **Standard report/Rigid written format** – It is for a rigid information exchange. Which facilitate the quality, speed of the information exchange. It is a proofing method used by TOYATA.
- **Process design/enterprise** – It is a revolutionary methodology developed by prior MIT professor, Dr. Michael Hammer.
- **DSM**- Design structure matrix. Refer to MIT professor Steve Eppinger's work.
- **Design for Replacement** – It is my coinage. All replacement does not have a concept of "design" in mind. Process needs the right skills, experience, and knowledge at right time and right amount. It cannot be ad hoc.
- **Design for Training** – It is my coinage. It is for any process, task, and program. Not just in time training, but just in time replacement.

Differences among the Three Sub-processes:

Other than common themes of the three sub-processes, we are also interested in the difference among them. A product development process goes through a few distinguished phases, and an automotive product design and development process is extremely complex. It makes sense to understand the differences of sub-processes in order to find out and apply for lean practices to each of them. Those differences may determine the nature of lean practice. Then we may figure out a common set of lean principle for the whole PD process, as well as a few sub-set of lean practices for each stage, sub-process of PD.

For the three sub-processes under study, we found out some differences in terms of some criteria. The Road Load testing does not require sophisticated engineering work, but it requires skilled technicians to instrument parts. It is physically limited in one location where instrumentation takes place in lab and rig hoisters. It is an information process at end, but the most work is done on parts manually. The inputs are testing requirements and vehicle (components). The output is the testing results ready for analysis.

The headlamp design process is a pure design process. It processes data, and output with a new design, which is materialized into math data and ready for manufacturing. It involves a few parties: Ford studio, Ford core engineers, and Visteon lighting. There is not queue at key process equipment.

The prototype process is similar to roadload testing process in some degree. It is in a central location. The process is basically a manufacturing process, which assembles parts into a drivable vehicle, its output. The capacity of key process equipment determines the queue.

The table below is a good list of those differences we observed from three sub-processes we studied.

Processes	Road Load	Headlamp	Prototype
Labor	Technicians	Artist, Designer	Skill trades
Team	Ford technicians	Studio artist, core engineer, Visteon engineer	Ford workers
Organization/location	Proofing ground	Ford Studio, Ford Lighting, and Visteon lighting	Prototype Plant
Process type/object	Information/Parts	Information/data	Manufacturing/Parts
Key process enablers	Adept manual work + instrumentation	Sophisticated mental work + software tool	Adept manual work + tools
Technology	Gage/instrumentation /test data acquisition	Clay model/CAD, CAM, CAE tools	Hard tools
Queue	Long queue	Not clear	Long queue
Inputs	Test requirements, parts/gages	Concept: requirements	Parts/prints
Outputs	Test data	Design data	Vehicles

Chapter 5: Supporting Lean Behaviors

Content of this Chapter:

1. Definition of Lean Behavior
2. Ford Lean Behavior Model
3. Observation and Assessment of the Three sub-processes
4. Lean Culture Implementation

5.1 Definition of Lean behavior.

Lean Behavior Definition:

Based on M.L. Emiliani, Lean Behaviors is defined as follow:

The concept of "lean" behaviors is analogous to lean production Lean behaviors are defined simply as behaviors that add or create value. It is the minimization of waste associated with arbitrary or contradictory thoughts and actions that leads to defensive behavior, ineffective relationships, poor co-operation, and negative attitudes. A person exhibiting lean behaviors is most easily recognizable by their ability to resist the temptation to contribute wasteful verbal or gesture content to conversations. In contrast behaviors that inhibit workflow are analogous to wasteful batch and queue mass production methods. These behaviors are termed "fat" behaviors, and are defined as behaviors that add no value and can be eliminated. They include the display of irrational and confusing information that results in delays or work stoppages, or the articulation of un-sustainable subjective thoughts and opinions. Fat behaviors are recognizable as lots of talk where nothing has actually been said, or indirect words whose meanings are subject to variable interpretations. [Emiliani]

The Category of Behaviors:

When I study the three sub-processes, headlamp, prototype, and road load, I found people behave differently from one process to another. It inspires me to think about sub-set of lean behaviors tailored for certain group of people. I start to think categories of organization, and people.

All behavior is based on people and their actions. Since we are talking about the organizational behavior, we can categorize people in an organization into some groups, who have some different behaviors one group from another. Also for a complex organization like Ford, it consists of sub-organizations. A example of the categories are listed in the table below:

Therefore, I propose to study sub-set of lean behaviors for each category of people, and or organization. For example, we can study the lean behaviors of design organizations in common.

Scale	Expertise	Position	Function	Status	Effectiveness
Individual behavior	Operator behavior	Employee behaviors	Manufacturing organizational behavior	Supplier/ Contractor's Behavior	Fat behavior
Group/team/ Department behavior	Engineer behavior	Middle management behaviors	Design & development organizational behaviors	Permanent employee's behaviors	Lean behavior
Organizational behavior	Accountant behavior, Etc.	Senior management behaviors	Research organizational behaviors		

The above table illustrates a few categories of behaviors. The first column "scale" means that the group behavior is established on individual behaviors. And the organizational behavior is built on group behaviors. The second column "expertise" gives example of behaviors according the different job titles. This column does not list all possible job titles. The third column "position" shows what behavior relates to the ladder of positions. The fourth column "function" tells the difference among manufacturing, design, development and research functions. The 5^{th} column is the status of employment: contractors or permanents. The last column has two levels of behavior: fat, and lean. "Fat" means non-value-added behavior. The last column is a generic category. We must exercise care when we use them. The reason is explained as follow.

We give detailed categories of behaviors above. By doing so, we will have better understanding the behaviors. Behavior to most people is a "soft" concept. When we talk about behavior, and lean behavior, 10 people have 10 different denotation and connotation. The meaning, scope and application of lean behavior are not understood on the same page.

Now, with clear objects of behaviors, we can easily and deterministically investigate behaviors of each category in reality. Then with these "true behavior", we can identify the gap between "lean behavior" and "true behavior".

5.2 Ford Lean Behavior Model:

Ford Product System developed its own version of Lean Behavior model for Ford Motor Company. Top management of Ford has approved this lean behavior model. A lean behavior assessment tool has also been developed to evaluate organizational degree of "lean". At end of year 2002, a few assembly plants have actually used the lean behavior assessment tool. The Ford lean behavior model is a 3 by 6 matrix. It consists three major elements: people, process, and continuous improvement. Each element has 6 key points to address the issue. Due to the Ford intellectual property, the model is not included here. Instead, some comments of the author are provided here.

The Ford Lean Behavior Model has a list of key verbs and observable actions. Those key verbs are: respect, provide/feedback, engage, listen, seek, focus, honor, share. By examining these verbs, we can find some clues on the intention of these principles. These verbs and corresponding objects represent a set of behaviors, which suppose to be one aspect of lean system. Further more, we can look into the opposite of the action. For example, we say respecting of others is lean, the opposite of this action is not respecting of others. Apparently, an assumption is behind the actions, which means that if you do these, you exhibit lean behavior, and on the opposite, if you don't do these, you exhibit non-lean behavior. If the lean behavior assumption above is correct, then we will have a set of Dos and Don'ts to guide our daily working behavior.

Dos and Don'ts of behaviors:

Lean Behavior	Non-lean Behavior (fat behavior)
Respect others	Not respect others
Provide frequent feedback	Not provide frequent feedback
Engage people in related decisions	Not engage people in related decisions
Listen and seek first to understand	Not listen and seek first to understand
Focus on issues but blaming people	Not focus on blaming people but issues
Honor other's priority and time	Not honor other's priority and time
Share ideas/knowledge/information	Not share ideas/knowledge/information

The Ford Lean Behavior Model is an excellent tool for assessing and implementing a lean culture. It is intended to use for the whole Ford Motor Company. It captures the similarity of all sub-organizations: people, process and continuous improvement. However, the model does not capture the difference among those sub-organizations and environment. For example, people behave differently in manufacturing than in design and development. The current lean behavior model is more generic than specific. Above behavior model should have a list for management, a list for GSR (general salaried roll), and a list for suppliers. Management acts different from employees, such as engineers, technicians, staff etc.

Comment 1:

The Ford Lean Behaviors model does not address the individual level behaviors. Also it does not address the PDCA/CI loop. It does not address technical driven behaviors.

Comment 2:

About Behavior Model:

When we refer to behaviors, we mean the observable actions, reactions people exhibited. The Individual is at the center of the model. By nature, each individual behavior certain way, which is shaped or driven by his/her sex, race, maturity, vocation, position and education for example. When an individual joins in a team, interacts with other people/organization, involves in a process, and works in an environment, he/she behaves differently. In our study, we are interested in the behaviors of people, who interact with other people, process and environment. From

generic to specific, we will study behaviors in an automotive PD context. From studying these behaviors, we will identify lean PD behaviors that support lean product development.
The current state has a big variation on behaviors. For example, an individual may exhibit aggressive, or defensive behaviors at different situation. He or she may be talkative at one time and silent at another time. However, the future state specifies a tuned-in state, where all kind of behaviors is in line with the lean principles.

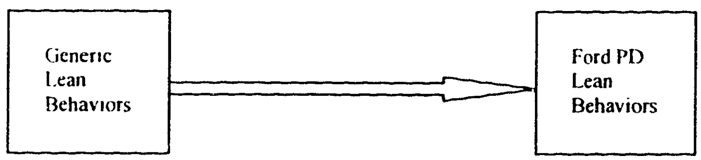


Figure 6-2: Lean Bridge

We may invent some PD lean behaviors just by comparing with manufacturing lean behaviors:

Typical manufacturing lean behaviors	**PD lean behaviors**
PDCA cycle	Treat PDCA cycle equal important for PD as for manufacturing
Preventive action	Do preventive action in PD.
8D for problem solving	Treat internal problem seriously, apply 8 Disciplines for internal customers/suppliers
Invert triangle of support	Engineers, designers, technicians are in front line. Management is supporting
Rigid communication in writing	Convert "Talking culture" into rigid communication in writing.
Simple A3 communication tool is used	Don't tolerate lengthy reports. Use simple, short, standardize written tool.
Training to qualify a job	Beware incompetent PD personnel cost us more

	chronologically and seriously. Constantly evaluate employees for competency, and give them training with measurable results.
Process flow determines the work force layout	Process oriented. Eliminate vertical compensation, performance review, and career path for process-oriented jobs.

However, without looking into the mindset of people, the behaviors are hard to explain. Therefore, we need to find out the lean mindset for manufacturing, lean mindset for PD.

Now it is obvious that the following is a list of behavior drivers:

1. Position related: title, level, responsibility, type of work, report, performance review, salary, rewards, all organizational, HR issues
2. Team related: cross-function versus function role
3. Interaction related: meeting, position/reputation power, all communication issues
4. Work environment: office setting, building arrangement, meeting room, commune, filing,
5. Process: product(material or information), milestone, deliverable, checklist,
6. Techniques: network, database, email, machine, phone/fax, etc.

5.3 Observation and Assessment of the Three PD Sub-Processes

Our approach is as follows. From specific symptom, we identify the common behaviors it represents. Then we analyze the structure that supports such behavior. Finally we suggest structural way to change the behavior to lean behavior.

We believe that there are a few key behavior drivers. And they are:

- Rewards/punishment system to encourage or discourage some certain behaviors
- Decision making mechanism

- Metrics to track performance
- Physical environment design

The table below exhibits the lean behavior solutions based on the study. The first column "examples" gives all symptoms we saw. The second column "fat behavior" identifies bad behaviors associated with the symptoms. The third column explains why such behaviors exist, and what supports it. The last column gives the systemic solutions to correct the bad behavior for lean behaviors.

	Examples	**Fat Behavior**	**Why is it fat?**	**How to correct?**
1	Vice President(VP) override headlamp design, at later stage, causing revision/rework	Top management intent to interfere FPDS system	Encourage cowboy mentality; no punishment for wrong decision	Change rewards system; punish wrong decision
2.	Headlamp appearance design ST to next function is delayed. The internal customer has not power to control upstream	Ignore internal customers, only focus on customers externally	Milestone is ignored, because no discipline for the delay. Missing the milestone is not a serious issue at eyes of management. The performance is not evaluated by internal customer	Give internal customers the right to join the performance review of internal suppliers. Encourage those follow the FPDS, and punish those who don't
3	Visteon as full service supplier for Headlamp, has no veto power even they are brought on board	Suppliers' voices are ignored by Ford management	Ford is the "master", and suppliers are "little guys".	Suppliers to join Ford internal functions' performance
4	Visteon did not get XXX program contract for headlamp until it suspended the work for 2 weeks.	Supplier is not committed, and has not veto power. (headlamp)	No discipline on early suppliers commitment. Not seeing the benefit of early commitment	Set up early milestone for supplier commitment. Understand the economic impact of it
5	Prototype Suppliers wait until 1 month before MRD, and all parts arrive on the day of MRD, causing warehouse crisis	All parts arrive at Material Request Date (MRD)	The Ford specified MRD becomes single milestone for all suppliers.	Ford should plan with suppliers to spread out the MRDs, and reasonable lead times

6	Road load testing parts are obsolete when revision is made by engineers	Engineering changes causes obsolete parts, waste and longer process	Engineers have no discipline to freeze designs. The information for revision is not communicate in real time	Discipline engineering change, and adapt real time revision track.
7	Typical XXX program meeting	Ask all to attend; come late and leave early; no key decision maker presence; too long and lost tracking; or hasty decision making	Believe "meeting" is a panacea. No metric on meeting effectiveness	Set up meeting metric and drive for efficiency.

5.4 Lean Culture Implementation

Today, many companies and other organizations are striving to achieve a lean culture. How to implement a lean culture is a new topic and few literature and examples are available. Because lean culture and culture implementation are relatively on soft and intangible side of an organizational system, we have hard time to define it, measure it, change it and maintain it. Because of these features, initiatives, like lean behaviors and lean culture implementation usually fad away quickly and seldom structurally materialized. To overcome these shortcomings, we need to develop a structure for implementing and maintaining a lean culture initiative. We need to consider all drive forces behind culture. We need to look into organizational mechanisms, such as human resource, reward system to find ways to fundamentally change and maintain cultures.

Some of the changes essential to develop a more lean culture may be presented in the following areas [Rose]:

- Mission
- Vision
- Motivation
- Risk taking
- Human resources
- Management process
- Reward system
- Organizational change

- Investment

Here we only give a skeleton of the lean culture implementation structure, which is the first step for further research on this subject.

Mission-

- Examine the organization's mission statement to ensure that high performance culture areas not being overlooked and that the previously developed mission statement is still valid.

Vision –

- Revisit the vision statement to be sure that it states very clearly the kind of company that senior management wants to have.
- Establish that growth is needed to provide the opportunities, resources, and rewards essential in a lean organization.
- Strongly endorse lean culture and lean efforts at all levels in the organization
- Stress the need for the creation of new culture
- Establish that managers and leaders must communicate the lean vision in everything they do.

Motivation-

- Employees set their own standards
- Breakdown barriers between units, create affinity with the larger organization, the company
- Senior managers must live and preach the new culture
- Rewards reinforce the primary focus upon the company-not on individual business units

Human resources-

- Need self-renewing people
- Focus on people- employees are important
- Team of people working together is powerful
- Move managers across units
- Recruit lean conscious people
- Redesign the work, job description to eliminate non value added work
- Entry level people need attention from above
- Need for mentoring and sponsoring – provide incentives for good senior managers and technologists to perform these responsibilities
- Must accommodate classical, more traditional career path
- Performance appraisal –constructive honesty
- Organization is built around people in the company at any given time
- Longer time assigned to key jobs -show performance before moving to new assignment
- Train must be "just-in-time" - Don't over train or under train

Management process –

- Management style and philosophy follow lean principles
- Communicate mission and vision, plus lean principles
- Set the long-term strategy
- Senior manager active participants in the problem solving process
- Foster a "can do" attitude
- Senior management creates an environment for lean culture
- Must have discipline toward goals as well as lean culture
- Small cross-organizational group
- Process and customer oriented
- Senior management must live, preach and market the culture
- Can criticize problem solving without criticizing people –candid, critical, frank, open thinking
- Senior management review/evaluate top high potential people in company for performance and potential
- Eliminate resistance to change and old rigid thinking

Reward system-

- Parallel ladder for technology professionals and perhaps others as the situation dictates
- Ideas are important. Generation of good ideas is rewarded
- Focus on performance
- Rewards are based upon employee performance
- Incentives are provided to increase motivation and commitment
- Promotions go to "culture" believers
- Rewards, incentives, and promotions are based on true value to internal and external customers, not based on activities
- Put trust and value in the performance appraisal system

Organizational change-

- How can we change the organization to take advantage of the strengths of people
- Some jobs are truly unique and are designed only for the incumbent
- Eliminate bureaucracy
- Organizational changes get people focused externally and reduce the tendency to create empires
- Large organizations must tolerate non-standard creative behavior
- Move managers across units

Investment-

- Investments are made to foster productivity, growth, and success, and all three of these factors enable lean culture
- Investment are made in core competencies as well as business units

We believe that the above changes will move a company much closer to a lean culture.

Chapter 6: Future Research Direction and Conclusion

This chapter will discuss suggestions on the future research direction for academia and automotive product development organizations. Since our research is limited in scope and scale, the conclusions are subject the constraint as well.

6.1 Proposed Lean Solutions

Due to time-constraint and the complexity of Ford PD system, the research and proposed solutions are only valid to a point when only partial information is available.

The purpose of doing value stream mapping is through studying the current being of the process (current state) to design a lean state of the process (future state). For the three sub-processes under study, we propose to take following actions to bridge the current state to the future state:

- Early supplier commitment
- Early issue of program direction letter, and very explicit
- Build a wall to fend off any override of FPDS after certain time (like design freeze point)
- Fast turn around of the revision
- No shipment / receiving of the obsolete parts.
- Add organizational learning events
- Meeting management: eliminate unnecessary meeting, improve efficiency and decision making, etc.
- Reduce handoffs by single contact
- Appoint a process owner for each sub-process in a program and refer to "process enterprise" for a systemic solution.
- Use mature technology, software, and skilled people. Don't use something new, which brings variation, instability.
- Synchronize the data release. Use checklist for feasibility, and other engineering activities, to prevent from missing, or low quality of job.

These specific solutions should combine with common guiding principles for process and organization we discussed above. Also we need to consider technology and tools for lean PD system. All three aspects, process, people/organization and tools/technology must be integrated for implementation.

6.2 Generic Implementation Strategies

Based on causes and solutions from our limited study on the three sub-processes of the Ford PD system, an implementation strategy is proposed from my point of view.

I believe that there are two major problems with current implementation practices. First, there are too many initiatives, which may conflict with each others, and waste the enterprise resource. Second, the FPDS on documentation may be perfect, but the perfect system may not be followed.

Based on studying successful implementation cases, the following list is a representative content for an implementation [Rose]:

1. Scope of Implementation
2. Objectives
3. Strategies to Achieve Objectives
4. Framework for Action
5. Management Buy-in and Organization Awareness
6. Barriers, Constraints to achieving Objectives
7. Tactics and Action Steps
8. Technology Enabler
9. Risk Analysis
10. Resources, Support and training requirement
11. Measurement and Evaluation
12. Implementation timing and Plan

Following are tips for doing a comprehensive and competent implementation plan:

Scope of implementation Plan:

This section of the plan should describe what will and will not be included in the plan. It is very important to establish the bounds of the implementation plan. If this is not done the reader may wrongly assume that the action plan includes contents that it does not. This leads to misunderstandings what should be avoided.

Objectives:

This section of the plan should specifically address what the plan is attempting to accomplish. Why is this plan being undertaken? What are the anticipated results?

Strategy to achieve objectives:

This section of the plan should tell the reader how you intend to execute this plan to achieve the objectives. In general what steps or process will be followed and in what sequence.

Framework for action:

This section of the plan tells the reader what major areas will be presented in the contents of the plan.

Management buy-in and organization awareness:

This section of the plan should include the way to get the management to buy-in the plan. It tells what level of management should be committed. It should address how to raise the organization awareness in order to successfully implement the plan.

Barriers, constraints to achieving objectives:

This section of the plan presents the obstacles that you expect to confront in the execution of the plan. How you will overcome or deal with these barriers and constraints should be included in the next section of the plan. Every plan has barriers, constraints, and the completeness of this section of the plan will convince management the thoroughness of the plan.

Tactics and action steps:

This section of the plan includes the specific detailed action steps that are essential to achieve the objectives. For each action step, you should provide the following:

- Who will be responsible?
- What will be done? What action is to be taken?
- When will the action be taken? In what sequence will the action steps be taken?

As mentioned above, when an action step deals with one or more barriers and constraints, this should be highlighted.

Risk Analysis:

This section of the plan should present the risk(s) involved. A sensitivity approach or a high/low approach may be appropriate. When possible, ranges of variables should be used in the writing of the plan, and the magnitude of the range is a measure of the risk involved. Three types of risk should be discussed:

- Risks associated with the tactics/action steps of the plan included in the prior section.
- Risks of not being able to achieve the plan objectives.
- Risks of not undertaking your action plan. This is the risk of maintaining the status quo also referred to as the risk of "doing nothing".

Resources, support and training requirement needed:

This section of the plan should present very clearly

- what resources, support and training are needed.
- From whom do you plan to obtain each resource/support/training
- When will each resource/support/training be needed.

Review dates:

This section of the plan should identify the points in time at which progress in the execution of the plan will be reviewed, what will be reviewed, and the levels within the organization at which the reviews will occur.

Measurement and evaluation:

This section of the plan should address the way the implementation is measured and evaluated. A set of metrics would be helpful for such purpose.

Implementation timing and plan:

This section of the plan should provide an overall schedule of the detailed activities included in the plan. A bar chart with a time line with each major action step noted on the bar chart is appropriate. A review of this schedule may tell the reader if you have included all of the essential steps in the plan.

6.3 Future Research Direction

We have provided following five suggestions here.

A. Expand the research to the whole product development organization, phases, and functions.

Our research is limited by time, scope and depth. During my internship in Ford, I can only investigate three processes (functions) in the complex Ford Product Development process. Due to the limitation, observations, analyses and conclusions are far from accurate. We have only studied one commodity design, headlamp appearance, which can neither represent other components, nor systems.

Further research should exam the concept design process, system design process, verification process, and launch process. For system design process, the body, chassis, electrical & electronics, and power train are four major systems. They are so complicated, that focused, detailed studies are needed.

B. Horizontally study one vehicle program.

Study the lean product development can come from multiple directions. However, one important direction is the vehicle development process, or a program. This is a process, which focuses on one product, but from concept design, engineering design, prototype, design verification, and launch. The customer is the manufacturing, where the new model vehicle is produced at mass production level.

The next lean PD project may be defined in a new vehicle program from KO (kickoff) all the way through Job 1(mass production). A whole process study is necessary to provide sufficient information to derive at solutions for the process. Study only portion of the process cannot give a true picture, and therefore the conclusion from partial study cannot be applied to new program development. However, such project takes much longer, or at least a program's cycle time, which is 48 months in average for a S5 program (note: S5 is level of complexity of a vehicle model).

C. Study the lean enterprise

We have studied a few sub-processes of a vehicle design and development. Also we suggest to study a whole program process. Then, from enterprise level's point of view, all horizontal programs/PD processes are put in a big, enterprise-wide system. Each program must not only satisfy customer needs and requirements, but only subject to enterprise goals, resources constraints and shareholder value. A program/process may be considered as lean if only from process or customer's point of view. It might be non-effective in terms of enterprise interest. We need to go one level up to study the enterprise process. All programs in a company are considered. Infrastructures, and enabling processes, like human resource, and information technology are considered also. All stakeholders' voices must be listened. In this direction, we have many, many research subjects.

D. Study the information technology infrastructure that support and enhance the product development.

MIT has cooperated with Ford, Polaroid and other US manufacturers to develop a collaborative design tool, which is called Dome. The software connects independent design engineers, product engineers, financial personnel, program management, and suppliers together. It is a client/server model. Such kind of software is going to change a lot about product development: procedure, communication, decision-making, organizational structure and culture. It will go beyond product design or system design. It changes the process, and supply chain as well. Its role as to PD is the worldwide web as to the world. When design the process, we need to take the IT into consideration seriously.

E. Further study the lean PD culture.

Corporate culture can shape people's behavior. To sustain our lean PD implementation, a lean culture must be in place. Current Ford Lean Behavior model is a good starting point for lean culture initiatives. These lean behaviors are derived from manufacturing environment, and become supportive to current Ford Production System, a lean production system. In product design and development organization, do people exhibit different lean or non-lean behaviors? Are there special lean culture traits for product design and development organization? What are elements of lean culture in PD organization? How to change a culture and implement a lean culture? These are major questions we need to answer, which bring up further research endeavors.

6.4 Conclusion

After studying the three sub-processes of Ford Motor Company's product development organization, a set of solutions have come up and detailed in Chapter 4. The three processes are only sub-processes of a vehicle program process and a small portion of the Ford product development organization. The solutions and recommendations we addressed here are subject to further evaluation to the entire vehicle process and other programs.

So far we have summarized the lean product development principles from a few important literature. Dr. James Morgan's lean PD principles are particularly relevant to the automotive industry. Mr. Donald Reinertsen's work is insightful and eye-opening. Dr. Michael Hammer's process enterprise theories do have essence of lean principles within, which are worth to do future study on its application to the automotive product development.

The three sub-processes, headlamp appearance design, road load testing, and prototype build process are major hurdles to the delivery of the entire vehicle program. The value stream mapping studies of the three sub-processes help us understand the nature of wastes, non-value-added activities and ways to reduce and/or eliminate them in a non-manufacturing area. After the study, we are equipped with common solutions to bridge the current state to high performance state.

The lean behaviors and lean culture are very interesting. We just touched the basics of the two topics. It is worth to do further research and study.

In conclusion, this project is just a start of a journey toward the lean PD world. We hope the Leaders for Manufacturing Program will do more contribution to this subject in future internship projects. We greatly appreciate colleagues in Ford, and faculty of MIT for their tremendous support and encouragement.

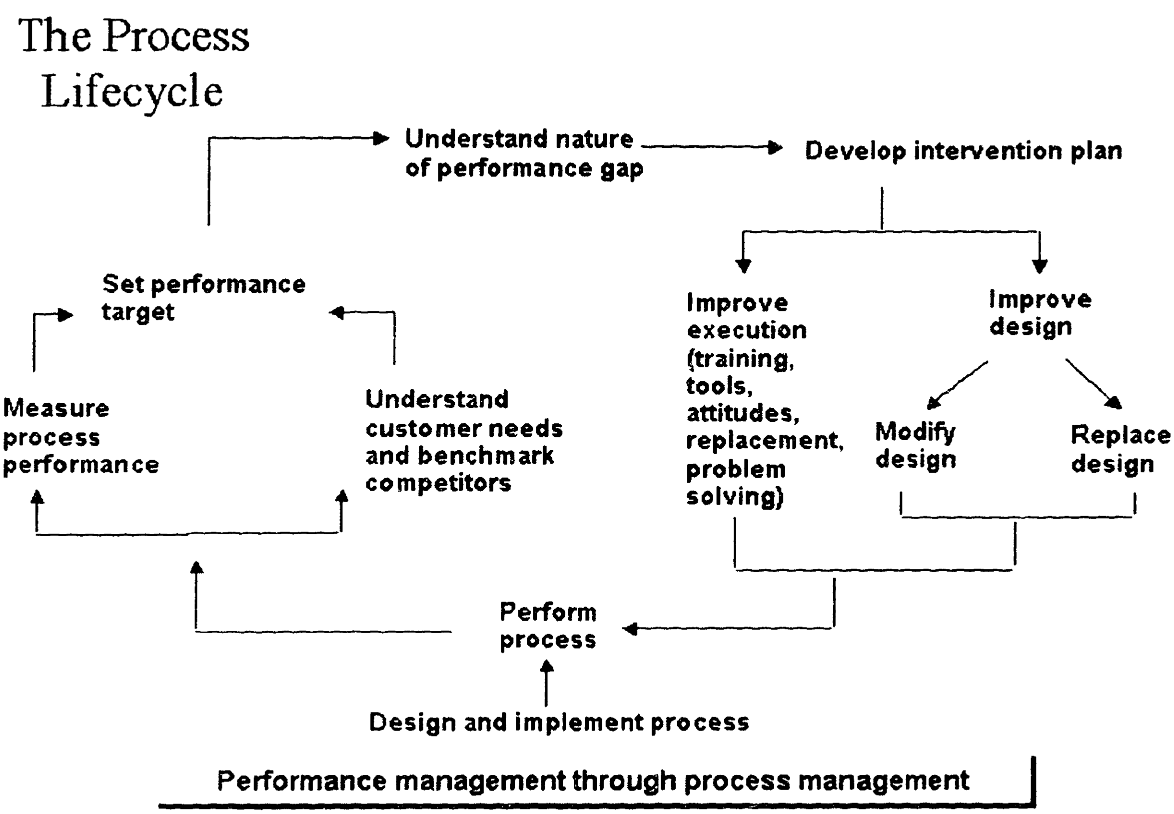
Appendix 1: List of Interviewees

1. Broggi, Nick, New Programs/Strategy Manager, Ford Production System.
2. Dr. Chen DeShiou, Product Design Engineer, Analytical Method Development.
3. Duplessis, Ronald (R.M.), Final Area Superintendent, Dearborn Assembly Plant.
4. Mr. Douglas Eberle, FPS, Lean mfg manager, New Program/Strategy, Ford Production System.
5. Greene, Richard (R.K.), Supervisor, Product Development Center.
6. Goocher, Lawrence (L.E.), Technologist, Road Load & Data Acquisition.
7. Mr. Han Bo, Product design engineer, CAE/Analytical verification.
8. Dr. Jia, Howard (Z.H.), Supervisor, Project Management & Forward M, Product Development Center.
9. Dr. Kang Hongling, Vehicle Integration, Product Development Center.
10. Kao, Elizabeth (E.E.), Cycle Plan Supervisor, Product Development Center.
11. Dr. Li Fengzhu, Product Design Engineer, Product Development Center.
12. Dr. Tim Ling, CAE/Body Specialist, Product Development Center.
13. Mr. Joseph Lee, Director of Ford Production System.
14. Ms. Pan Ming, Lincoln program launch supervisor.
15. Dr. Qiao Hong, Development Engineer, Vehicle NVH Department.
16. Mr. Eric Schwartz, Project manager, PD leadership program, Product Development Center.
17. Dr. Edward Sketch, Ford Human Resource Director, North American CBG Training and Development.
18. Dr. Linda Stott, lean leadership/culture, FPS Labor Relations.
19. Dr. Kannan Subramanian, Product Design Engineer, VEV/Structural Durability and Road Loads Department.
20. Dr. Lee Tsai, Headlamp design engineering supervisor, Product Development Center.
21. Mosakowski, Martin (M.M.), Supervisor, Core Process and Systems, Proto Build, Design & Exterior Group, Advance Vehicle Technology.
22. Nowka, Brian (B.W.), Road Load, Supervisor, Certification Test Laboratory.
23. Nowery, Mark (M.B.), Design Manager, Interior Design Manager,, Design Studio.
24. Jonik, Peter (P.J.), Administration Supervisor., Product Development Leadership Group, Advance Methods, Facility & Quality, Advanced Vehicle Technology.
25. Moeller, Robert (R.D.), Product Development Finance Supervisor, D219/258 Finance.
26. Dr. Dennis Reger, Visteon Exterior Design Manager,
27. Trenczer, Robert (R.), Material Handling Supervisor, Vehicle Operations, Pre-Production/NMPDC Mat., New Model Program Development Center.
28. Shashlo, Mike, Manager New Program. Process, Process Dev & PD Systems.
29. Williams, Yvette (Y.V.), Enterprise Integration, Process Dev & PD Systems,
30. Biberstein, Willy (W.F.), FPDS Process Engineering Specialist, PDC - DESIGN CENTER.
31. Dr. Yi JianWen, Technical Specialist, R&A - Research & Advanced Engineering, Combustion Systems Simulation, Ford Science and Research Lab.

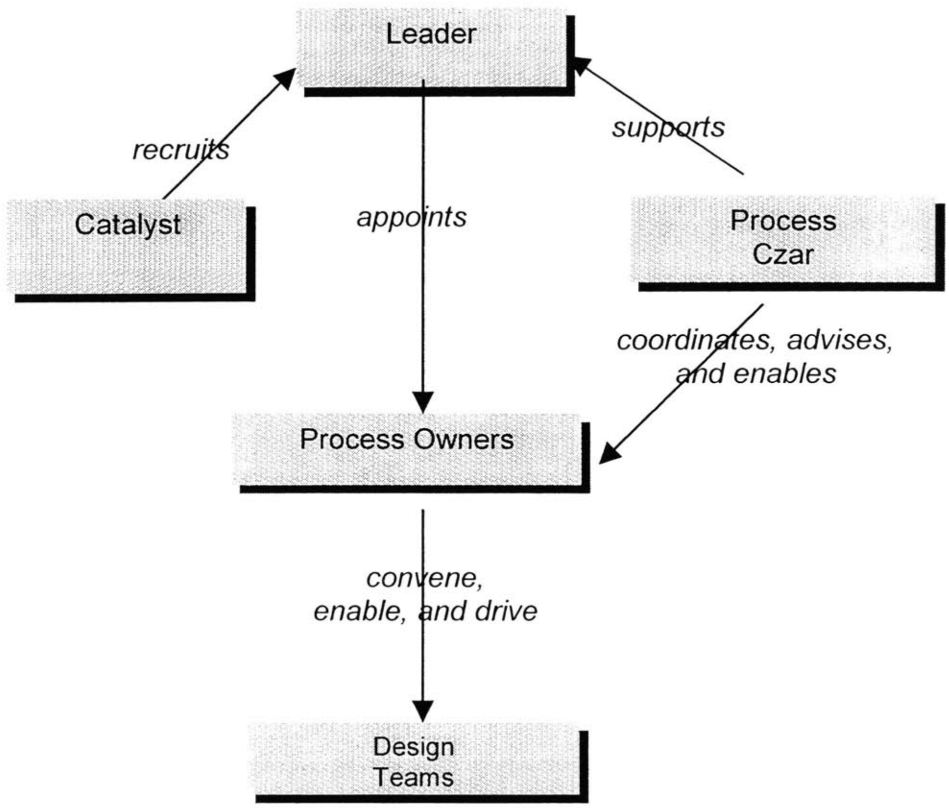
Appendix 2: Literatures

1. Cusumano, M., and K. Nobeoka, (1998). *Think Beyond Lean: How Multi-Project Management is Transforming Product Development at Toyota and Other Companies.* Cambridge, MIT International Motor Vehicle Program.
2. Fine, C. (1998). *Clock Speed: Winning Industry Control in the Age of Temporary Advantage*, New York, Perseus Books.
3. Ford Motor Company. (1999). *FPDS Process Overview,* Dearborn.
4. Ford Motor Company. (2001). *Organizational Principles and Operating Model,* North American Truck, Dearborn.
5. Hammer, Michael.(2001). *Agenda: What Every Business Must Do to Dominate the Decade,*New York, Random House.
6. Morgan, James. (2002). *High Performance Product Development: A Systems Approach to a Lean Product Development Process,* University of Michigan.
7. Murman, E., and A. Thomas, and K. Bozdogan, and J. C. Gershnfeld, and H. McManus, and D. Nightingale, and E. Rebentisch, and T. Shields, and F. Stahl, and M. Walton, and J. Warmkessel, and S. Weiss, and S. Widnall. (2002). *Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative*, New Yor, Palgrave.
8. Reinertsen, Donald. (1997). *Managing the Design Factory: a Product Developer's Toolkit,* New York, Free Press.
9. *Rose.Ross, Professor of Sloan Management School, 15.902 course materials*
10. Wethersfield, (2002). *Lean Behaviors, M.L. Emiliani,* Managing Director of Lean Behaviors LL, MCB University Press [ISSN 0025-1747].
11. Wheelwright, S., and Kim Clark.(1992). *Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency, and Quality,* New York, Free Press.
12. Womack, J., and D. Jones, and D. Roos, (1990). *The Machine that Changed the World: the Story of Lean Production,* New York, HarperPerennial.

Appendix 3: The Process Lifecycle [Hammer]



Appendix 4: Governance for Process Redesign [Hammer]



Appendix 5: A Process for Process Redesign[Hammer]