Integrating Lean Principles in Automotive Product Development:
Breaking Down Barriers in Culture and Process

by

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Bachelor of Science, Mechanical Engineering
Clemson University, 1992

Submitted to the System Design and Management Program
in partial fulfillment of the requirements for the degree of

Master of Science in Engineering and Management

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Abstract

Lean principles have been applied throughout the manufacturing industry with noted success although the process of integrating them into the entire enterprise has been complex and slow. Certain areas of the automotive industry, specifically product development, require a deeper study of its readiness to transition to lean. This thesis analyzes the product development enterprise at a large North American based auto manufacturer with respect to cultural and procedural inhibitors to becoming lean. The traditional lean principles and historical advancements in lean techniques are presented along with a description of the area studied. The scope of analysis focuses on three major phases in product development; the early concept phase, the middle core design phase and the launch phase. Recently, there has been difficulty in translating the lean principles into the product development environment. In this study, unique product development definitions of the lean principles are required and used to develop a framework for analysis. Inhibitors or barriers were discovered through interviews, observations, documentation and experience, each causing significant amounts of waste (muda). By understanding how these inhibitors affect the product development lean principles, the course of transitioning to lean can be illuminated. The system effects of the barriers and inhibitors are also described using system dynamics. Finally, conclusions are developed in order to guide the company in its quest to become lean in product development and throughout the entire enterprise.

Thesis Supervisor: Deborah Nightingale
Title: Professor of Aeronautics & Astronautics and Engineering Systems

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Chapter 1: Introduction

Since the formal introduction of lean principles in North America, numerous companies have benefited from integrating lean in manufacturing. An example throughout several U.S. industries is the dramatic reduction of waste by decreasing or eliminating batch sizes in order to achieve one-piece flow down the production line. Other examples include manufacturing cycle time reductions, sequenced supplier shipment to align with production schedules and first-time quality using error-proofing or "poka-yoke" devices. These methods along with many others have helped numerous companies achieve overwhelming success on the plant floor. Lean has also extended to areas such as order-taking, delivery and accounts receivable/payable. It is nearly a universal agreement that practicing lean yields significant improvements that support reaching the unique goals of various industries.

Even with the noted success of lean production, there have only been small victories in applying lean to product development. These are typically referred to "islands" of success and have not grown significantly in size. This thesis studies a large global automobile manufacturer based in North America that has experienced considerable success in practicing lean principles in production but only minor or "islands" of success in product development. The company's competitive strengths include worldwide segment leadership, global product development capability and platforms, global distribution network, well-known brands, strong union relations and a strong balance sheet. These strengths have helped the company remain a strong force in the automotive industry however there is concern that if they do not cut the "fat" out of the development process, competitors could capture valuable market share with first-to-market new products.

There is general agreement throughout the company that improvements must be accomplished in order to stimulate the customer base, reach the financial goals and grow the business. Many believe that lean is the path to take in order to achieve this success. Unfortunately, lean is not a "plug-in" process that is immediately successful, especially in product development. It requires an entire organization to practice and live lean. In order to define value, identify the value stream, achieve proper flow, effectively pull and strive for perfection, the mindset must be in place and understood. This requires a vast shift in company culture and product development process. There are currently several issues, or lean inhibitors, throughout the culture and processes of the company studied. The affect of the inhibitors on lean integration must be recognized by leadership and employees of product development and acted upon in order to propel the transformation to lean and grow lean into the entire enterprise.

This thesis describes the lean philosophy and principles that provide a basis for the analysis of lean in product development which is presented in Chapter 2. Chapter 3 portrays the history of lean and its use in the automotive industry including how it has evolved in the company studied. The concept of a lean enterprise is also introduced in this chapter along with the approach that Japanese auto manufacturers are taking in product development. Most of the new research today focuses on expanding lean into new areas of industry with the ultimate goal of a lean enterprise. Chapter 4 provides a description of the product development organization within the enterprise. This includes the system used to progress and track programs and its evolution over the past 20 years, the organizational structure and philosophy and how they have changed with new company leadership and the cultural state of product development with descriptions of norms and artifacts. Recent developments over the past couple of years are discussed with respect to their suitability, acceptance and time to implement. In addition, the scope of thesis work is also

presented which details the phases of product development selected for analysis. Chapter 5 then begins the approach to applying lean principles in product development. New definitions of lean principles are developed specifically for this enterprise and the types of informational and behavioral wastes are reviewed. This allows for the framework in order to assess the current state of product development. In addition, a system dynamics example is introduced as a tool to study the enterprise system effects. Chapter 6 examines the lean inhibitor data gathered through research, interviews, observations and experience and divides it into five different groupings: overall process, culture, early program phase, middle program phase or launch phase. The data is then compared to the newly defined product development lean principles for a better understanding of how the principles are impacted by the different groupings. Data is evaluated against system dynamics modeling for a better understanding of the effects of the lean inhibitors. Chapter 7 provides conclusions and recommendations to the product development enterprise that allow the stakeholders to progress the transformation to lean without delay. Finally, Chapter 8 provides opportunities for future research that are not covered in the scope of this work.

Chapter 2: Lean Principles

The term "lean" was introduced in 1990 by James Womack, Daniel Jones and Daniel Roos in their book, *The Machine that Changed the World,* which studied the global automotive industry's manufacturing techniques. Lean was first used to describe Japanese automobile manufacturing, specifically the Toyota Production System, by John Krafcik while researching auto assembly plants in fifteen countries during his MBA degree studies at MIT's Sloan School of Management. Krafcik coined the term "lean" because it uses less of everything compared with mass production.[1] Since then, lean has become synonymous with efficient manufacturing throughout the world. In an effort to expand upon success of lean production, Womack and Jones published another book, *Lean Thinking*, in order to better guide the implementers of lean with a set of principles to follow. Further, the book introduces a new concept, the lean enterprise, which challenges companies to extend lean into areas other than just production and supply-chains.[2] This lean enterprise approach utilizes five basic lean principles to be followed.

2.1 Value

The first lean principle is to specify "value". Value of specific products and/or services is defined by the ultimate customer by how well they meet the customer's needs at a specific price at a specific time.[3] The value that is created is the reason that an enterprise exists. Many industries with products or services that result in favorable bottom-line financials may assume that they are succeeding in creating value although this is a misconception that needs a deeper look. In a presentation on Lean Thinking in 1999, Womack stated, "The fundamental objective is to shift the focus of management from the existing organization, technologies and assets to the product itself. This will allow companies to differentiate value from waste".[4] Many large

organizations lose focus of the product and customer through internal metrics and initiatives. By viewing all actions in terms of how value is affected and assessed by the customer will aid in focusing on the product itself. Specifying value is the first step in the application of lean principles. It is important to accurately identify value in order to eliminate waste from the system. Also, a big picture view of the product with respect to its requirements is essential in order to provide direction for the innovation of future products. The outcome of specifying value may lead a company to reinvent itself for its customers.

2.2 Value Stream

With the value specified, the next step in becoming lean is to identify the value stream map. This map identifies all end-to-end linked actions, processes and functions necessary to transform inputs into outputs in order to identify and eliminate waste or muda (Japanese for "waste"). The creation of the value stream map allows for easier identification of wasteful tasks and actions in the process. In generating the map, each action can be sorted into three categories: (1) actions that create real customer value; (2) actions that are required by the system (including product development, ordering, purchasing and other departments) but create no value and are held for further evaluation; and (3) actions that do not create value for the customer and are not required by the system which can be eliminated immediately.[5] It is surmised that significant waste from the third category can be removed immediately in order to clear the way to assess the second group. This mapping also clearly lays out the current state of the process such that required changes are easily recognized and modifications can be made for the future state.

2.3 Flow

After the value stream has been identified and waste has been eliminated, the remaining value-creating steps must flow. In order to achieve flow, the value-creating steps must move

continuously without interruption. The process of gaining flow should unveil more waste further optimizing the value stream. Womak and Jones advise that this principle will require "a complete rearrangement of your mental furniture".[6] Companies that utilize a batch and queue system need to rethink their entire production process. Batch and queuing parts and subsystems causes long wait times between processing and results in long lead times to the internal and external customers. These processes require a change to one-piece flow. With one-piece flow, the focus is on the product, not the machinery. Most batch and queue production lines have large equipment that favors large batch processing. One-piece flow focuses on "right-sizing" the equipment and locating it such that it requires minimal or no transfer space from one station to the next station. This not only allows the product to flow but also reduces the in-station process time and overall production time. This concept is not new in North America. Henry Ford changed his assembly process to a continuous manufacturing line in 1913 which resulted in a 90% reduction in assembly effort.[7] Unfortunately, as the product differentiated from the one Model T to various models, sizes and styles, the process strayed and developed several batch and queue subsystems. In the past few decades, Toyota has proven that one-piece flow with multiple product variants is attainable and reduces the overall cost.

2.4 Pull

As the product flows out the door, there must be a customer that needs it or there will be excess product in the marketplace that eventually gets pushed on potential customers. Pushing product is usually associated with discounted prices since the value of the product has diminished. This leads to the need for the lean principle, pull. Pull is described as not allowing a product to proceed to the next step unless the downstream customer requires it. In short, pull is accurately responding to the demand of the customer. Clearly, this is not a simple task.

Customer demand fluctuates as the economy changes, seasons pass and technology shifts. Companies must be relentless about understanding the needs of the customer and properly timing the entire value creation process to meet the customer demands. By doing this, demand can eventually stabilize when customers are confident that they can get what they want when they want it.[8]

2.5 Perfection

The perfection principle creates a never-ending cycle in the lean principles. This principle reminds the company to never stop improving on the lean principles. Each organization must systematically continue to improve value, flow, pull and waste elimination throughout the enterprise.[9] As the customer's requirements change, modifications in value specification will be required along with re-identifying the value stream that must flow and pull properly. Perfection must encircle the lean principles and challenge an enterprise to create value, find more waste to eliminate in the value stream, flow the process and parts faster and respond to the customer by pulling the products rather than pushing products on the marketplace.

All of these lean principles are meant to be applied to the entire enterprise. In learning the principles and the associated examples provided by Womak and Jones, the reader becomes familiar with how to employ the techniques in the manufacturing, order-taking and delivery areas but the process is somewhat fuzzy when applied to product development. In processes where information paths and flows include unpredictable iterations and decisions that have disproportionate affects on the system, the process of becoming lean becomes extremely complex to manage. Further, the culture of an organization plays a significant role in the adoption of lean. Without the proper mindset and behaviors from all stakeholders in an

organization or enterprise, lean will not be achieved. This thesis explores the challenges of a large North American automobile manufacturer's product development organization as they relate to process and culture. These challenges are barriers or inhibitors that must be removed before or during the lean transformation process.

Chapter 3: Lean Advancement

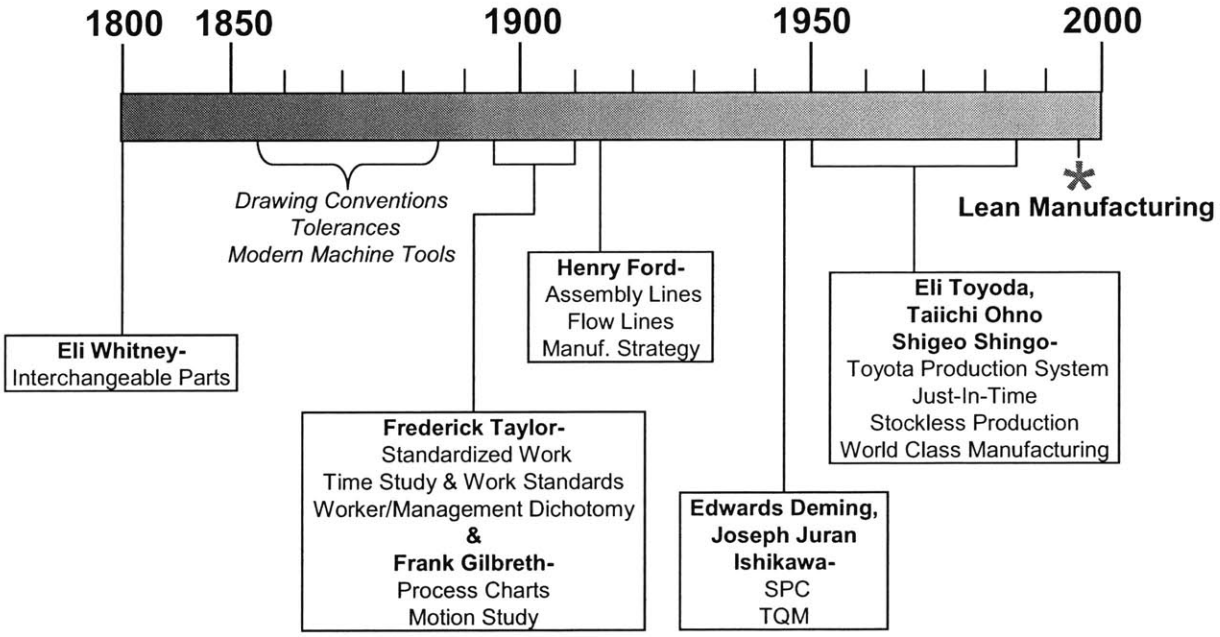
3.1 Background of Lean

The term "lean" was coined in a 1988 Master's thesis although the concept of lean was not new. Lean techniques date back as far as 1799 when Eli Whitney developed interchangeable parts when for a U.S. Army contract to manufacture 10,000 muskets for the unbelievably low price of $13.40 each. During the late 1800s and early 1900s, Frederick Taylor applied science to management and methods and Frank Gilbreth contributed motion studies and process charts that focused on non-value added elements. And, of course, there have been numerous references over the years to Henry Ford and his mass production system where manufacturing strategies that arranged people, machines, tooling and product to achieve flow.[10] Ford is known in many circles as the original lean thinker. In fact, in Ford's books, *My Life and Work* (1922), *Today and Tomorrow* (1926) and *Moving Forward* (1930), he conveyed his original manufacturing philosophy that included standardization and continuous improvement, waste elimination, continuous flow manufacturing, design for manufacture and just-in-time (JIT) production.[11,12,13] After nineteen years of Model T production, the Ford system faced many changes. With the introduction of multiple models, options and colors, the system didn't make the proper changes and began to break down. In addition, the advent of labor unions produced more conflict within the system.

Japanese competitors saw a way to take Ford's efforts and improve on them. After World War II, the statistical and quality works of W. Edwards Deming, Joseph Juran and Kaoru Ishikawa were introduced in Japan. Deming took his ideas of quality management and variation reduction to Japan (1947-50). During this period, he was working for General Douglas MacArthur's

Supreme Command, Allied Forces, Tokyo, as an adviser in sampling techniques.[14] (A sample of the results of Deming's work with the U.S. Bureau of the Census can be seen in Appendix A which shows how his techniques reduced variation and improved the quality of data for American life expectancy.) Eli Toyoda then combined the statistical and quality management techniques with his learning from a three-month trip to Ford's Rouge factory and worked with Taiichi Ohno and Shigeo Shingo to develop new innovations in production now known as the Toyota Production System. This system incorporates new and old lean concepts and methods. Figure 1 summarizes the timeline of the key lean events over the last century.

Figure 1: Timeline of Advancements in Lean[15]



The Toyota Production System became known as "lean manufacturing" because it did more with less. Since then, the details of the system became known to Western manufacturers and numerous companies have emulated the process on their factory floors. Major improvements have been made in areas such as process variation and waste reduction although the Japanese companies have held the lead in further advancing the lean concepts. The company studied in

this thesis has developed a production system similar to Toyota's system and they too have reaped large rewards since practicing lean in manufacturing. They have also been able to sustain the practices and skills required to carry out the system. The issue over the past several years centers on the slow or stagnant growth of lean into new areas of the company, in particular, product development. These missed opportunities are bound to further expand the gap with Japanese companies unless action is taken.

3.2 The Lean Enterprise

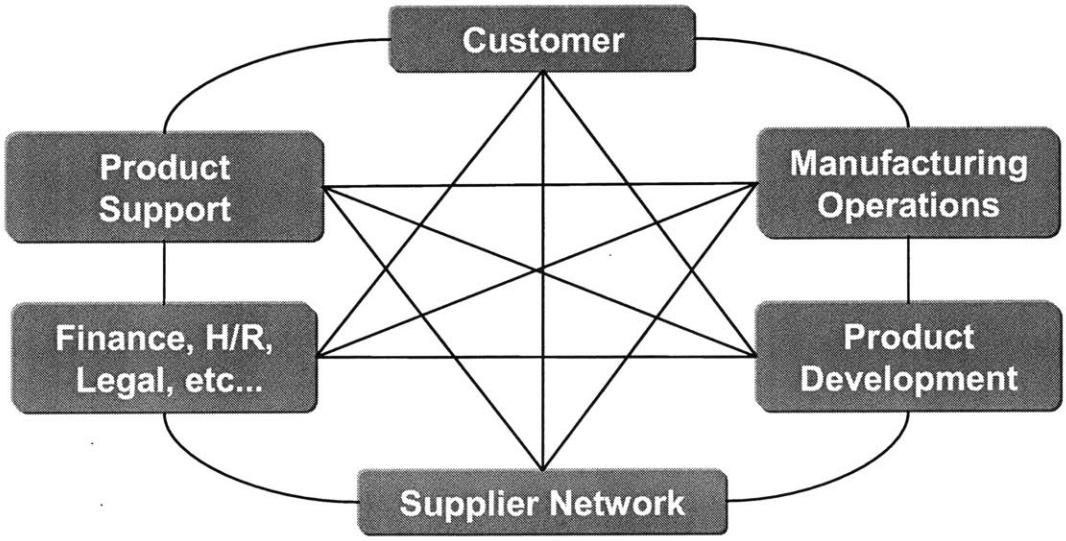
Lean is moving beyond the borders of manufacturing. In the past, companies have found success in implementing lean not only in manufacturing but also in areas such as order processing and delivery. The benefits of being lean were immediately recognized. Today, the tables have turned and there is no longer a quest to find sectors of a company that lean can be put into practice because lean really has no bounds. The goal at present is to become a lean enterprise. One may quickly run to a dictionary in order to understand the real meaning of "enterprise" in order to develop a boundary around a company although the term enterprise is meant to be broad and drive organizations to think beyond the walls of the buildings they work in. Certainly, for purposes of analysis and even implementation, the use of boundaries may help work towards particular objectives but the ultimate goal is to keep expanding the boundaries until everyone affected by the process or product is reached.

Womak and Jones define the lean enterprise as "Correctly specify value for the customer, avoiding the normal tendency for each firm along the value stream to define differently to favor its own role in providing it. Then identify all the actions required to bring the product from concept to launch... Next, remove any actions which do not create value... Finally, analyze the results and start the evaluation process over again."[16] This definition basically combines the five

lean principles and is intended for all of the firms along the value stream to be involved. This certainly expands the definition beyond the plant floor and into the areas where innovations are being integrated into new products but it remains end-user customer focused and requires further expansion in order to open the boundaries of lean.

The Lean Aerospace Initiative (LAI) at MIT has drawn on the expertise of Womak and Jones' *Lean Thinking* and redefined what a lean enterprise is. Their work was published in 2002 and is titled *Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative.* LAI's version reads "A lean enterprise is an integrated entity which efficiently creates value for its multiple stakeholders by employing lean principles and practices."[17] This definition takes the concept of a customer beyond the end-user. It incorporates all stakeholders in the process of becoming lean and introduces a new way to discover and assess value. In their explanation, lean is a process of eliminating waste with the goal of creating value for enterprise stakeholders.[18] These stakeholders must all work together to exchange information, parts and experiences with each other. Figure 2 represents the interactions of stakeholders in an integrated enterprise. No activity can be left out or the system will can not be optimized to create value.

Figure 2: Stakeholders in an Integrated Enterprise



LAI developed some guiding principles that build on Womak and Jones' lean principles. They did this by focusing on the goal of creating value and eliminating deep rooted waste. Their principles are as follows.

- Principle 1: Create lean value by doing the job right *and* doing the right job.
- Principle 2: Deliver value only after identifying stakeholder value and constructing robust value propositions.
- Principle 3: Fully realize lean value only by adopting an enterprise perspective.
- Principle 4: Address the interdependencies across enterprise levels to increase lean value.
- Principle 5: People, not just processes, effectuate lean value.

Also, LAI has provided informational guides that help teach the enterprise how to transition to lean, assess the current state and develop the future state. *Lean Enterprise Self Assessment Tool* (LESAT) is available to walk an enterprise through the tenets of lean and assess several different aspects of the transition to lean.[19] Developing and understanding the value stream can be an extremely complex task. LAI's *Enterprise Value Stream Mapping Analysis* (EVSMA) helps guide the user by beginning with a high level understanding of the enterprise in order to create the value stream map.[20] And recently, LAI is in the process of finalizing a *Product Development Value Stream Mapping* (PDVSM) manual that focuses on mapping a definable product development process that helps find waste, inefficiencies and non-value added actions.[21] The enterprise concept along with the extended principles and informational guides are used in this thesis to better develop a framework for assessing the ability of the process and culture in product development of a large automobile manufacturer to transition to lean.

3.3 Japanese Approach to Product Development

This section will discuss Toyota's approach to developing new products. In particular, the flow, principles and management of their system will be described. It is essential to understand how flow works in product development. Most large companies have a structured approach to product development that emphasize activities, procedures, controls, compliance and progress that are typically measured by the number of tasks completed. These systems are usually linear in nature from definition, design, prototypes to testing. If the results are not suitable, the team doubles back to an earlier point and starts over. Conversely, the Toyota system is non-linear and has a different course. Toyota's goal is to achieve a constant flow of new products, not to check the box for completed metrics. Numerous alternatives and design possibilities are set in motion and their interfaces are kept loose to allow for flexibility. If a new system proves unacceptable, the interface can always accept a different design and the unsuccessful data is captured and reused in future programs. The fundamental idea is to develop products by converging on a solution. The system requires engineers with strong technical backgrounds and leadership with good decision-making capabilities in order to achieve seamless product development flow.[22] During the process, Toyota takes more time in the early stage of development to define the solutions but can act quickly towards convergence.

Toyota's approach which broadly considers a set of possible solutions then narrows the set of possibilities to converge on a final solution is called "set-based concurrent engineering" (SBCE). Duward Sobek, Allan Ward and Jeffrey Liker have identified three broad principles each with three different approaches that are associated with SBCE. Table 1 presents Sobek, Ward and Liker's principles and approaches of SBCE used by Toyota. The following principle descriptions were paraphrased from their article, *Toyota's Principles of Set-Based Concurrent Engineering.*[23]

Table 1: Principles of Set-Based Concurrent Engineering (SBCE)[24]

Principles of Set-Based Concurrent Engineering		
	1. Map the design space	• Define feasible regions • Explore trade-offs by designing multiple alternatives • Communicate sets of possibilities
	2. Integrate by intersection	• Look for intersections of feasible sets • Impose minimum constraints • Seek conceptual robustness
	3. Establish feasibility before commitment	• Narrow sets gradually while increasing detail • Stay within sets once committed • Control by managing uncertainty at process gates

The first principle is to map the design space. This is completed by defining feasible regions through the use of engineering checklists. Every group maintains checklists that include all functional and attribute data in order to discover what alternatives are possible. These checklists capture what is learned and can also be used in the future. U.S. companies typically use design standards that prescribe single solutions rather than describing a range. Next, through prototypes and simulations, the design trade-offs are studied in multiple designs. Whenever possible, engineers attempt to establish mathematical relationships in order to aid in decision-making. This practice allows for broader learning over the set of alternatives and ultimately reduces iterations and tweaking. Throughout the levels of design, it is critical to continuously communicate the set of design possibilities with other team members in order to converge on the best solution.

The next principle is integrating by intersection. Toyota uses three distinct approaches to systems integration. First, the teams must look for feasible regions of overlap to find a solution

acceptable to all. This means that the system must be optimized, not the components. Second, minimal constraints are imposed on the team and design in order to ensure flexibility for further adjustment. Toyota's thinking is "make each decision in its time" rather than a typical U.S. company's idea to "make decisions as early as possible to avoid confusion". The latter will result in more major changes downstream. Third, robustness is sought in the conceptual stage in order to progress the design faster. If a function can create a design that works well with all of the alternatives in another function's set, it can proceed further without waiting for additional information from that function.

The last principle is to establish feasibility before committing to a design solution. This principle is the heart of SBCE since it is focused on converging to a solution. During the process of narrowing the sets, the amount of detail increases in order to more fully understand the possibilities before committing to any one of them. This differs from U.S. companies which lay out the alternatives and just pick one. This practice allows team members to consider the most important alternatives in depth and gives time to influence the narrowing process. Once the set of options begins to shrink, it is important to stay in the funnel rather than jumping outside for a new solution. A good way to manage this is to always have a fall-back design within the set. Lastly, uncertainty is also reduced through a funnel process from gateway to gateway. Uncertainty includes both the size of the set remaining and the depth of knowledge acquired. These principles have helped Toyota develop products faster and capture the knowledge throughout the process.

Sobek, Ward and Liker also studied the management side of Toyota and found some interesting approaches in their system. One key emphasis is integration throughout product development which reaches all areas affected and works closely with counterparts. Toyota

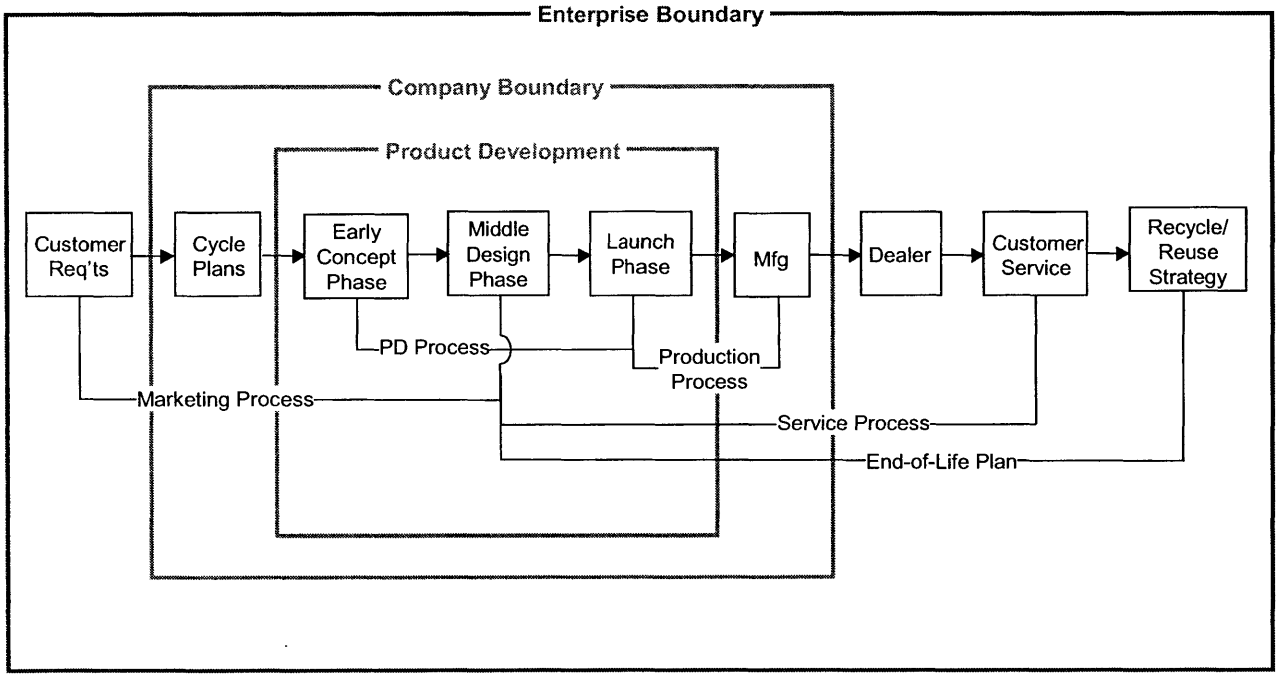
prefers a functional organization that is highly integrated in order to get products to market faster. Their managerial approach revolves around six processes. Three of them emphasize human interaction: mutual adjustment (reaching agreement), direct supervision (knowledge is scrutinized), and integrative leadership from one responsible chief engineer. The other three are forms of standardization: standard skills, standard work processes, and design standards. The combination of diligently practicing all of these processes helps reinforce the entire system. Toyota enjoys a tightly linked product development system that combines deep technical depth with cross-functional efficiencies. This balance allows Toyota to achieve rapid development of products due to integration within and across projects.[25]

Chapter 4: The Product Development Enterprise

4.1 Product Development Overview

The automotive industry is a large mature industry where the dominant design has been established. Over the past several decades, the disruptive events in the industry have been process efficiency gains by Japanese producers. These improvements are now widely known as lean manufacturing. The new challenge is to integrate lean techniques throughout the entire enterprise to achieve maximum efficiencies. Many initially view the enterprise as the company itself although that view is incorrect. Figure 3 shows the enterprise boundary for the company studied in blue. This enterprise includes functions and processes from customer needs, development, manufacturing, dealers and service to recycling plans. It is a truly holistic view of the enterprise. The company boundary does not control a large portion of the enterprise although they must satisfy the stakeholders of the whole enterprise in order to achieve success.[26]

Figure 3: Enterprise Boundaries



Within the company boundary is the product development function. This function is the heart of the company's innovation. All of the key processes overlap and interface with the product development system. The portion of a product's life requires a significant amount of time to plan, design and execute in order to deliver the results to the stakeholders. There are numerous levels of analysis, tradeoff and interaction that occur in attempt to produce a vehicle that will meet the end-user customer requirements. This study focuses on the product development segment of the company, in particular, the system and the underlying cultural aspects of this organization. The view is holistic to include how product development deals with all of the stakeholders in the enterprise with regard to process and culture. Hence, the organization is called the product development enterprise.

4.1.1 System

The product development system has evolved over the company's life. In the past twenty years, there have been four unique systems introduced each reducing a product's time to market. Table 2 provides information on the systems used and proposed since 1985. The company launched the first system in the mid-1980s to take advantage of competitive techniques and reduce the time to market by 30%.[27] This system was the first to actively use customer data to develop vehicles. Its aggressive goals required fundamental changes in management and technology innovation within the company that were vastly different from their traditional approach.

The second system was introduced in 1992 with a major update in 1993 (2a). This system focused on increasing quality, lowering costs, reducing cycle times and a stronger eye on the customers' needs. Time management was a key enabler in the new system in order to execute a program in a reduced amount of time. Dedicated product teams were formed and co-located in

order to improve the interactions among groups. Another new approach was to involve suppliers in the system by engaging them in the process from the early planning stage to production. Consequently, this required early decisions in sourcing new components and systems. All of these efforts were to allow for fast information flow and decision-making to produce high quality, low cost automobiles that meet or exceed customer's expectations in the shortest time possible.[28]

Table 2: Evolution of the North American Auto Manufacturer's Product Creation Process[29]

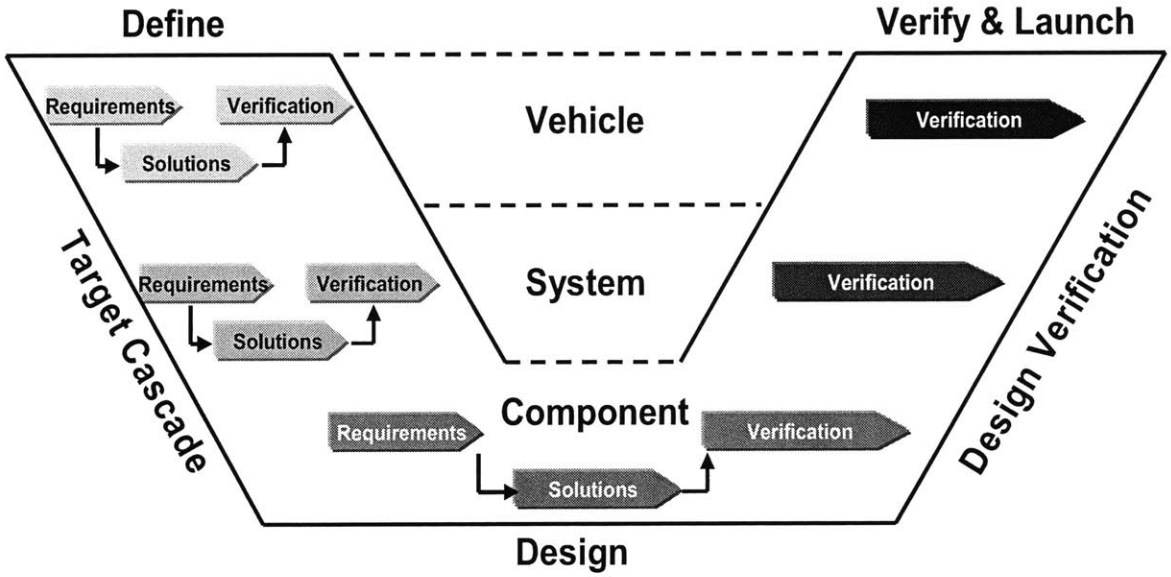
Product Development System	1	2	2a	3	4
Year Implemented	1985	1992	1993	1996	2005 (Planned)
Time to Market*	72 months	68 months	65 months	43 months	~28 – 34 months
Integration Region	North America	North America	North America	North America & Europe	Global

** For equivalent program complexity*

The third system uses the basis of systems engineering to guide the process. The pillars of the system include systems thinking, concurrent engineering, teamwork, target-driven design, reusability, reliability, package and vehicle attribute focus. Further, decisions are required to balance the timing, resources and program content which allow the system to be product focused.[30] For example, target-driven design uses a cascade of targets through the vehicle. Figure 4 depicts the system using a diagram shaped like a "V". As targets are cascaded, vehicle, system and component level requirements are defined. Once the final plan is established, the

design and development of the vehicle is continued and verified up the right side of the "V" until the product is ready for launch. Another key enabler for this process is the standardizing of the sub-processes within the system. By standardizing within a program and across multiple concurrent programs, parts can be reused, costs can be leveraged and lessons can be shared for optimal results.

Figure 4: Systems Engineering "V" Based Product Development



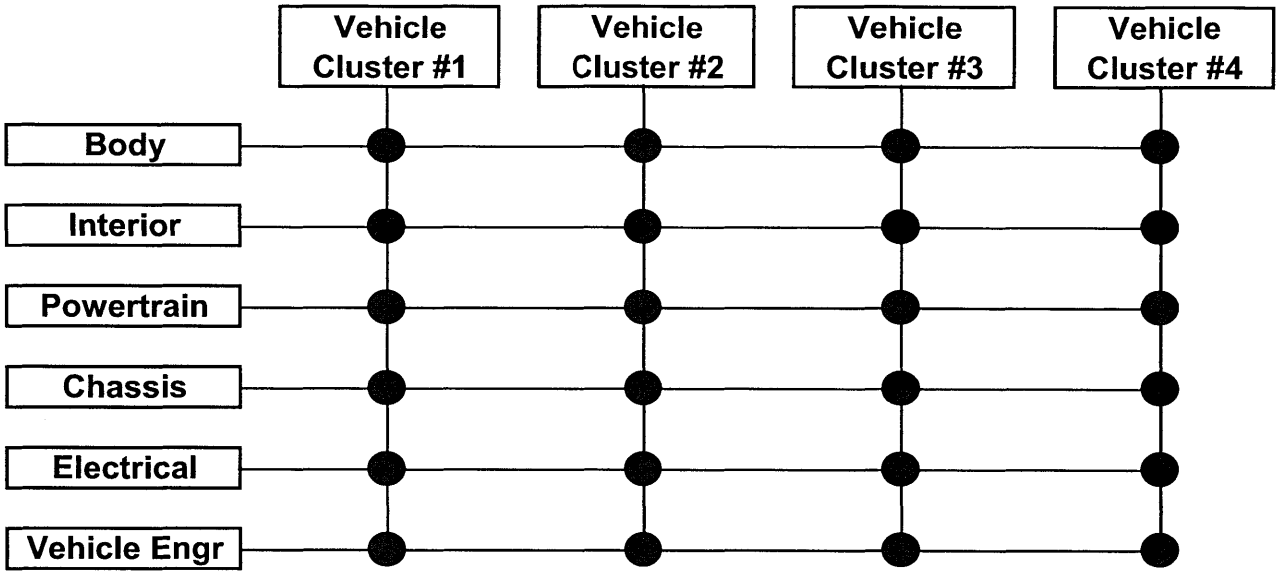
The fourth and last product development system has not yet been implemented in the company. Process teams are currently working towards putting it into operation in 2005. The process heavily emulates a Japanese counterpart's system and will be used globally when implemented. This system will attempt to eliminate large amounts of waste thus saving several months of development time. Lean will be an important factor in the system and collaboration amongst functions, organizations and continents will be essential for success. Some enablers of the process include front-loaded decisions, resources, analysis and failure mode identification in addition to synchronized prototype builds that effectively feed information from one build to the next. Another crucial aspect will be the reuse and sharing of parts and commodities across

multiple vehicle lines. Certainly, this system will require carefully planning to maintain common interfaces along with strong supplier relationships. This system will also test the current culture of product development with respect to the ability to transition into a new process quickly and whether the current behaviors can be changed to accommodate the new system. For this reason, there was great motivation to understand the deep-rooted cultural characteristics that may inhibit success of a new lean product development system.

4.1.2 Organization

The company is extremely familiar with reorganizing. Every few years, there is typically a reorganization that causes a major shift in management, structure and location. This frequent change can result in wasteful movement and excessive churn over time. The last major reorganization occurred approximately three years ago and changed the product development group from a program team-based to functional-based organization. Figure 5 illustrates how the current functional groups interact with the vehicle groups or clusters. Each vehicle cluster houses approximately six models that a functional group supports. Also, the vehicle programs within each cluster communicate through dedicated functional program management teams that interface daily to communicate the specific requirements and associated timing.

Figure 5: Functional-Based Organization



During the last reorganization, a new program was launched to regain technical competence throughout the functional organizations that has weakened over the past decade. The excessive transfer of personnel combined with relatively short periods of time-in-position and increases in outsourcing led to a decline in technical expertise. The new program established a system that rewards deep technical excellence rather than broad job experience. Each engineer develops a technical maturity plan that identifies training and skill sets that are required to meet their objectives. In addition, senior engineers act as mentors to advise the less experienced in designing for quality, commonality and reuse.[31]

4.1.3 Culture

The company culture in product development has evolved over several decades. Time, process and change of leadership have altered many aspects of the culture but there are still some components that have endured through the generations. The general environment has always had a family feel. Even when employees moved to new positions every couple years, groups have embraced new members. The company has a long history with many significant

accomplishments that generates a deep sense of pride in each employee. There is a low turnover rate amongst employees that rivals the best rates in industry. This low rate is attributed to the employees' passion for designing automobiles. In nearly every facet of product development one can find employees that are involved with restoring, refurbishing or racing vehicles in their personal time. Many others simply enjoy the thrills of being a spectator of the sport and history that automobiles provide.

Company performance has a large impact on the disposition of stakeholders in the product development enterprise. During favorable financial years, the employees feel confident and proud of their work. Regardless of personal performance, the profit sharing benefits can reach lofty levels that tend to reduce skepticism in the organization. When performance is perceived by external organizations as weak, leadership is quick to tighten spending and insist on improved results. These actions typically unnerve several layers of management which creates excessive stress at all levels of product development. This stress creates mistrust and resistance towards new policies that can consume large amounts of time as they are discussed around the coffee pots. For the past few years, internal company surveys show that high levels of stress are experienced by a significant portion of the workforce. Committees are generally formed to address the issue although they rarely have a lasting impact.

There is a strong parent-child relationship culture within product development. Employees feel compelled to seek permission to proceed with specific design concepts, direct suppliers to provide certain information and assess the status of development. Empowerment is not practiced widely especially in the upfront portion of the process which results in a reluctance to take hold of a situation and move quickly. In the downstream end of the process, numerous issues are led by management and eager engineers get involved to help "fight the fires". The good firefighters

reap much praise at the end of a launch due to the perception that they are results-oriented people.

There are many cultural artifacts that are seen throughout product development. Named and numbered parking spots for higher levels are found at nearly every building in the company. Signage on the buildings has changed numerous times over the years and reflects the initiatives of the latest chief executive officer. Current strategy diagrams are frequently found in high-level email communications and these notes are generally filled with optimism towards current and new products regardless of the state of the business. Meetings also have interesting cultural norms. There is tendency to keep ones calendar loaded with meetings that cover an entire day. The meetings may or may not be attended but they either act as lockouts to complete work or the impression of business or importance. The starting time of the majority of meetings is at least five minutes late and often run over the allotted time. When program teams meet with executives, there are pre-meetings that take place to rehearse the material. The goal at most meetings is to be able to answer a question before it is asked. Higher management levels feel obligated to search for errors and ask questions until an answer is not known. Working level employees have named this practice "stump the chump". Any assignments that are given at these meetings rarely take into account the current workload versus the importance of the assignment although these new tasks are given the highest priority until the next meeting.

Cost is also a dominant factor in the culture. There are great efforts to reduce cost in all areas of product development. The system rules are often bent in order to accommodate cost reductions even if timing is put at risk due the pressure to lower product cost. This pressure is also pushed to suppliers where they are expected to provide a percentage of cost reduction on their parts year over year. This approach no doubt alters initial quotes by suppliers in order to

compensate for future reductions or hidden costs. This thesis reviews how the current culture translates and grows into the process and behaviors within product development.

4.2 Scope of Analysis

As discussed in Section 4.1, this thesis studies the product development enterprise with respect to process and culture in order to better understand how the process is interpreted and used. The product development system has over a dozen distinct milestones with deliverables and metrics associated with them. It is impractical to breakdown lean inhibitors into each milestone since each program operates at a different pace due to unique complexity. For the purposes of this work, the product development system has been separated into three major phases that best describe the key shifts in progress, people and activities. These phases consequently contain nearly equal number of milestones which allows for a rich study in each segment. The first phase is the early concept definition phase, the second phase focuses on core design and the last phase transfers design to manufacturing during a launch. Each phase is described in the following sections.

4.2.1 Early Phase: Concept Definition

The early concept definition phase combines the corporate strategy with government regulation requirements and customer feedback. The corporate strategy includes technology trends, competitor analysis and company cash flow. Marketing, planning and engineering play a key role in this stage. The concept information flows to the engineering staff which is supported by research and development. At this point, the concept definition can make several iterations through the marketing, planning and resource preparation steps in order to meet the company's financial goals with the resources available for the program.

The identification of customer needs, corporate needs, and government requirements occurs in parallel in order to optimize the results. There is often iteration between the corporate and customer needs identification since corporate needs can change due to the changing economic climate. Government or regulatory requirements are typically nonnegotiable during this phase once the general strategy and class of vehicle are determined. The customer needs have a tendency to fluctuate as new data is processed from a prior model year, competitive information is accessed or financial goals are changed. There are initial concept designs and prototypes that are completed to prove out the program assumptions. The entire package must be a viable business case before full resources are assigned to progress the program. Some specific deliverables of this phase are as follows:

- Resources identified and planned.
- Customer satisfaction data reviewed and incorporated.
- Marketing strategy completed.
- Variable cost and investment status and plans meet the targets.
- Targets agreed upon and cascaded.
- Quality discipline plans completed.

The program specific work begins in this phase until solid program assumptions are taken forward for approval to proceed. This phase contains several iterations of target agreements and business plans in order to satisfy all of the constraints in the system. At the point when the plan is agreed to and the initial data meets the intent, the program is officially supported by the company.

4.2.2 Middle Phase: Core Design

As a program transitions into the core design phase, resources from research, marketing and planning drop off. Engineering leads this portion of a program and is responsible for carrying out the plans and reaching the agreed targets. It is extremely important to work closely with all stakeholders during this phase in order to minimize major changes to the designs. When the designs are settled, prototype builds test the assembly feasibility and functional aspects of the system. Designs can go through iteration loops in order to optimize the design. Once the designs are agreed upon, verification and validation testing takes place to confirm that the designs meet the specifications and targets. If a test fails or does not comply with targets, iterations take place that can affect several subsystems which may create risk and ultimately jeopardize an optimal design. The verification process has close ties to quality disciplines in order to collect data to demonstrate reliability and robustness. In general, the design phase is the primary phase that combines interests of all groups and requires the proper interface and integration of the pieces. Below are some key deliverables that are completed in this phase:

- Prototype plans completed.
- Final bill of materials completed and released.
- Design Failure Modes Effects Analysis (DFMEA) completed.
- Manufacturing and assembly readiness assessed.
- Package compatibility confirmed.

This phase can take over fifteen months to complete. Numerous support activities including prototype coordinators and manufacturing feasibility representatives are involved to help engineers deliver their designs. Suppliers play a key role in providing robust designs. Many

components are designed and released directly by suppliers with a company engineer shadowing the process. A huge challenge in this phase is the overlapping of tasks including component design, prototype builds, data collection and new customer data. A key goal is to manage the interactions to allow for proper decisions to be made before the designs go into the launch phase.

4.2.3 Launch Phase: Transfer from Design to Manufacturing

The launch phase of a program is typically entered before all of the validation testing is completed. Depending on the scalability of the program, there are two to five "pre-production" builds to validate the manufacturing processes and capability. As a larger number of vehicles are produced, the affects of production variation can also cause more design iterations. This phase is critical to meeting the planned end-user production date. Quality is observed at each step, including management sign-off drives to achieve concurrence to proceed through the next gateway. Some requirements of this phase are as follows:

- Prototype confirmation tests analyzed.
- Production build readiness assessment.
- Final component release completed.
- Supplier manufacturing process validated.
- Emission certification approval received.

This phase involves a transfer of leadership from engineering to manufacturing. In doing this, several engineers are sent to the plant site to aid in the manufacturing hand-off. There is typically a clash of cultures at the onset of a launch. New design engineers can have difficulty adapting to the manufacturing procedures, time requirements and management style. The atmosphere at the plant is 'fix everything now' and there is little tolerance when questions go

unanswered for more than one day. Engineers and suppliers are expected to arrange for support twenty four hours a day and seven days a week when working on issue resolution. In addition, manufacturing follows a unique process that requires engineers to become involved during issues. Much of the process overlaps with the product development system except the format and timing of reporting is different. There is no choice but to move quickly in making changes hence permitting designs that may not be fully optimized. At the end of launch after all of the issues are resolved, the vehicles are given the approval to ship from the plant, they are immediately transported to the dealers. There is typically a small group of engineers that remain at the plant for approximately three to six months to manage further improvements due to the inefficiencies that were allowed during launch.

4.3 Applications of the Analysis

The scope of this study was limited to the product development process and the culture within that process to find the key barriers and inhibitors in implementing lean within the organization. The analysis viewed product development as its own enterprise in order to define the stakeholders and identify the interactions. Other groups in the company can use this approach to understand where their inhibitors are and how they affect the lean principles. Lean principle definitions may need to be modified to suit the area studied although many of the same methods can be utilized by groups such as marketing, planning, service, manufacturing, purchasing, finance and dealers. Once the inhibitors are known throughout the entire enterprise, the plans to remove them can be constructed. It may be that many of the same inhibitors are common in several areas of the enterprise. As lean transformation progresses throughout the company, value delivery and waste elimination will become infectious. With the barriers broken down, there is no end to improvements within an enterprise.

Chapter 5: Approach to Applying Lean Principles

As lean is integrated into companies, there has been increasing success. Lean typically begins with manufacturing as there are clear rules to follow and a wealth of resources to aid in implementation. Companies have also grown lean manufacturing to lean functional areas creating "islands" of success. As the "islands" interact with other functions, lean continues to grow to include product development, marketing, human resources, purchasing and so on. After large amounts of waste are identified and eliminated, the company transitions its focus from minimizing waste to creating value. Large scale value creation evolves through enterprise integration and eventually includes the entire enterprise and all stakeholders including industry, government, suppliers and employees.[32] The sooner the entire enterprise is engaged, the faster the benefits are revealed.

As previously discussed, the company studied has successfully integrated lean in manufacturing and has shown minor success in small functional areas within product development; although, progress has been very slow and there is little growth of lean that includes interactions and multiple stakeholders. An approach to successfully kick off product development lean integration is required to accelerate lean transformation. According to Deborah Nightingale, LAI director at MIT, in order for an enterprise to accelerate lean transformation, organizational and cultural change must be considered and carried out, metrics for motivating desired behavior must be in place and mechanisms to diffuse and sustain lean changes implemented.[33]

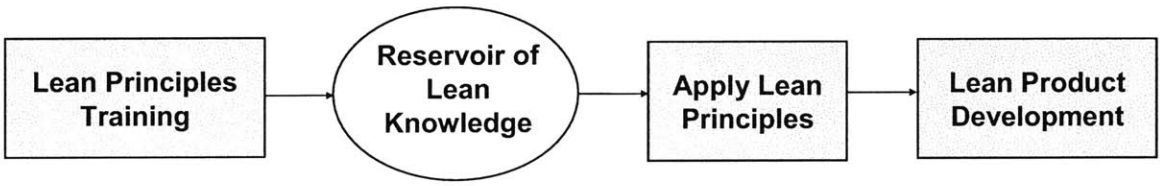
This thesis approach concentrates on the actions needed to accelerate lean transformation in product development by applying the framework to the three key stages of a program. In order

to do this, the five lean principles need to be defined for product development. Unique definitions of the lean principles and identification of waste will allow analysis of the enterprise.

5.1 Lean Transition Characteristics in Product Development

Many lean transition efforts fail in areas outside of manufacturing for several reasons. One explanation is the use of mental models, both by management and employees. Figure 6 depicts a linear mental model that is often followed for new programs. For transitioning to lean product development, this model begins with an organization's realization that the people are not trained in the practice, therefore funding must be secured to train management and employees before the lean transition can occur. As training occurs, it is assumed the organization is now thoroughly and equally qualified in the fundamental knowledge of lean principles. The valve is then turned to apply this knowledge in product development. Often, "pilot" projects are begun to address some obvious issues. This low-hanging fruit typically receives a great deal of management attention and exposure. When the resulting benefits are tallied, the project is hailed a success in achieving lean product development. At that point, it is expected that all future projects exhibit similar results.

Figure 6: Linear Mental Model of Lean Transition

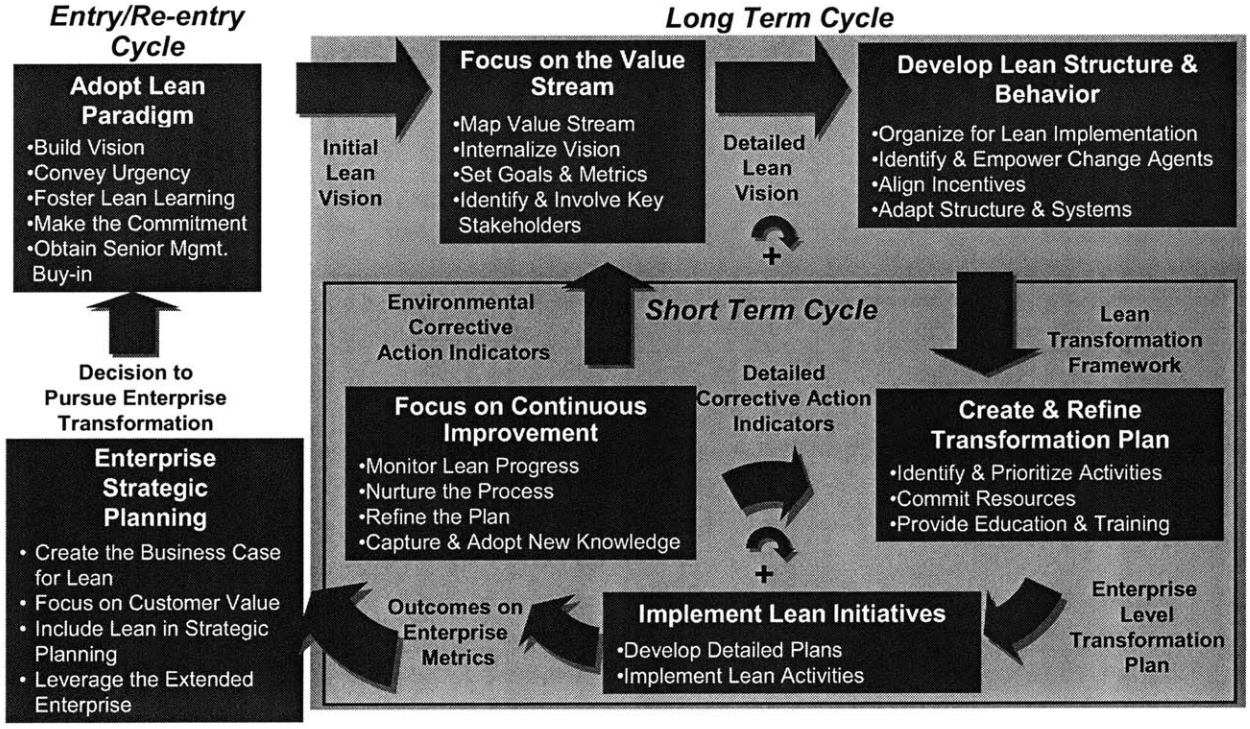


Unfortunately, this linear mental model is not enduring nor does it practice continuous improvement (kaizen). After the large-gain, short-term projects are depleted, the smaller successes get overlooked which considerably stifles the energy. The reservoir of knowledge then begins to age and it is no longer in the forefront of one's thoughts. Soon it becomes a chore to

fulfill a metric and gets coined a "program of the month" by the employees. This company has numerous examples of the application of the linear mental model which further demonstrates the need to understand the lean models and framework before proceeding down an ineffective path.

Before the company can benefit from lasting lean product development success, it must understand all of the ground rules for lean integration. Figure 7 presents a framework for lean enterprise transformation from MIT's LAI book, *Lean Enterprise Value*. Through three interdependent cycles, the figure shows a flow of steps required to initiate, sustain and refine lean through the adaptation process. The roadmap includes the strategy, leadership, internal and external relations and structural aspects that are required to enter the short-term and long-term cycles. This thesis will focus mainly on the culture and process disciplines needed in the entry cycle in order to form a foundation for achievement in all three cycles.

Figure 7: Enterprise-level Transition to Lean Roadmap[34]



The linear mental model noted above fits into the "Implement Lean Initiatives" box on the Transition to Lean Roadmap. This company, like many others, has been inclined to start at this point that is paradoxically in the short-term cycle which can explain how this approach can turn lean transition into a "program of the month". It is imperative to have leadership commitment and thoroughly understand the lean principles as they relate to the enterprise in order to properly set priorities and gain momentum throughout the journey. The remainder of this chapter attempts to characterize how this product development organization will need to interpret the five key lean principles and waste identification in order to break down the cultural and process barriers in order to profit from lean results.

5.1.1 Specifying Value

As described earlier, Womack and Jones' lean principle, specify value, is simply to see value as defined by the end-use customer.[35] Through the use of physical metrics, this definition can be somewhat straightforward to translate into the production environment. Further, since the product typically goes directly to the end-use customer shortly after production is completed, the value in manufacturing can be determined with relative ease due to the shorter route to end-use. In product development, the end-use customer is certainly important in specifying the value of the products although there are many complex relationships that lead to that customer. Further, it is difficult to grasp what product development needs to do to properly communicate how to specify value and take action on it. There are numerous stakeholders in the product development enterprise and not only do the technical aspects require value specifications but the cultural portion must be considered due to the intricacy and influence that the culture exhibits within the enterprise.

In an effort to address the cultural side of lean integration, M. L. Emiliani's *Lean Behaviors* publication applies lean behaviors to the lean production principles.[36] Emiliani explains that there are thousands of mundane and sophisticated things required to deliver a product that are of little interest to the customer although it is the essence of what companies actually do. So it is of no surprise that value gets specified from the views of engineering, finance, marketing...which fosters a self-serving environment as it reinforces organizational power and influence. This leads to numerous examples of behavioral waste including conflict, destructive politics and unclear expectations (a detailed list of Emiliani's consequences of fat behavior can be found in Appendix B along with comparisons of behavior attributes). He explains that specifying value in interpersonal relationships means to understand the wants and expectations or the people that we interact with. And by seeing the value of words and actions through the eyes of colleagues, it can enable the reduction of wasteful interpersonal behaviors. Emiliani's insights into the cultural and behavioral piece of the enterprise can not be ignored and ought to be incorporated in developing value specifications in any enterprise.

Womack / Jones and Emiliani both provide a judicious definition and philosophy for specifying value as it relates to production and interpersonal interactions though it may still be unclear for a product development enterprise. And Nightingale expands the concept of the customer to include all stakeholders. Let's begin with understanding the stakeholders of product development this company. The following is a list of the key stakeholders that were determined using the methods described in Enterprise Value Stream Mapping & Analysis (EVSMA)[37]. Also, since each stakeholder views value differently, the following demonstrates some examples of the value expected from the enterprise.

Product Development Stakeholders[38]

- *Customer: Production* – Clear process specifications, ease of assembly, common parts and technical support.
- *Customer: End-use* – Cost of ownership, reliability, performance capabilities, technology affordability, service and safety.
- *Employees* - Compensation, pleasant/safe work environment, job security, career development, respect, respected in community, low stress, empowerment, manageable workload and rewards & recognition.
- *Corporate Leadership* - Stock options, bonuses, profitable enterprise and growth.
- *Shareholders* - Increasing stock values, dividends and influence.
- *Suppliers* – Clear requirements, innovation, revenues, fairness and relationship.
- *Government* - Taxes, regulatory compliance and jobs.
- *Society* - Concern for environmental and social issues and personal mobility.

In order to specify value correctly for product development, all of the stakeholders need to be considered. The value will vary from program to program as the end-use customer has different values based on the marketing segment. The programs will also vary in areas such as government regulation requirements and technology due to the constantly moving targets that the stakeholders induce. Like production value, the product must meet the customer's needs at a specific time. For product development, the timing factor is also a critical element of value. Regulatory actions are phased in over time and must meet the required timing in order for a vehicle to be legally sold. In order to benefit from new technologies, it is critical to be early-to-market otherwise the valve depreciates exponentially.

Specifying value in product development simply means realizing the program's expectations and technical challenges while holding timing as sacred. It means understanding the goals and key targets of the program, comprehending the extent of technology innovation required and truly committing to the timing as if your life depended on it. Decisions can not be made without involving the people who will be delivering the outcome. If the expectations are unrealistic or are not valued by the stakeholders, they need to be discussed and negotiated early in the process. Negotiations must not be powered by political agendas or short-term fixes if product development is to achieve value specification. Viewing the value of the commitments to program expectations and technical challenges at a holistic level through our stakeholder's eyes can enable the reduction of wasteful directional change and design iterations.

5.1.2 Identifying the Value Stream

The next lean principle is identifying the value stream. This means that all of the specific actions required to produce a product must be fully understood, and then the whole process must be optimized by the elimination of waste.[39] While Womack and Jones include the task of designing from concept through detailed design and engineering in their definition, the examples are scarce and many companies choose to focus on the other two tasks they describe, order-taking through delivery and raw materials through finished product. It is not that there is no benefit from identifying the value stream in the design phase rather it is extremely complex and, again, difficult to measure. In manufacturing, one can stand in a facility and watch a value stream. It's all happening right in front of you ready to be documented with every detail. The ordering system through delivery may not be easy to watch but there are plenty of steps documented through sophisticated systems that are simple to retrieve for analysis. In product development, there is a mix of documented systems and ad-hoc systems that are used to develop

the process specifications over a long period of time. It is nearly impossible for one or a few people to observe the process and capture all of the steps. Moreover, the steps are not the same from program to program or technology to technology.

Emiliani describes the value stream identification as an understanding of what people do and why they do it. This approach assumes that behaviors are usually closely linked to the functions that people perform. The pressures on and off the job have an effect on their execution of the tasks resulting in value added and non-value added behaviors. While some behaviors that add no value are unavoidable, other non-value added behaviors can be eliminated. Functional groups that do not interact with their stakeholders and cross-functional counterparts add high levels of waste into the process. This can result in waste such as test failures and design iterations. By seeing the enterprise as a whole rather than their functional group, groundwork can be established that can aid in understanding what others do and why they must do it. This is not a simple task. It involves trusting your co-workers and counterparts, information sharing and awareness of the consequences of local behaviors.

Identifying the value stream in product development means to understand the cross-functional communication required to achieve seamless access to knowledge and data throughout the entire process. It is important to recognize all stakeholders and organizational sectors as equals in order to properly identify the value stream. If one stakeholder or sector is deemed insignificant or another holds high levels of power or influence, the value stream may become misrepresented and will ultimately cause confusion and skepticism which will lead to resistance of identifying the genuine value stream. With large enterprises including this company's product development, this task becomes an important piece to manage. Another essential piece to understand is the unavoidable waste. Since there will inevitably be unavoidable waste in a product development

value stream, it is important to understand the difference between real value and perceived value in the process in order to minimize the unavoidable waste. Of course, any evident waste must be eliminated immediately and without blame of the person or group that owned or acquired the wasteful practice. Collaboration of all stakeholders during this phase is critical to the success of executing this lean principle.

5.1.3 Allowing Value to Flow

Flow can be very different to evaluate in production versus product development. In production, the flow is that of the components that make up the end-user physical product while product development flow involves massive amounts of information and data streams that are difficult or impossible to follow in many cases. Womack and Jones describe flow as getting the value-creating steps to move continuously without interruption. From raw material to finished goods, the operation should produce one piece at a time as it flows through the process. This means that the product should not be paused or over handled in a process, for example, painting all of the green parts then shift over and paint all of the red parts. This may seem counter-intuitive but by doing production in batches, there are inevitably long wait times, larger inventories and excessive handling of the parts. These wasteful activities increase the probability for damage, quality issues and scrap which leads to more waste. When applying the flow principle to end-use product, it is assumed that the actions and activities that add value do so precisely such that they meet a specification and can be measured and adjusted if there is any discrepancy.[40] In product development, the actions and activities as a result of human thought can be much more difficult to measure and adjust.

Emiliani's *Lean Behaviors* defines flow as behaving in a manner that minimizes or eliminates delays or stoppages in the work performed by others. He describes how inconsistencies in

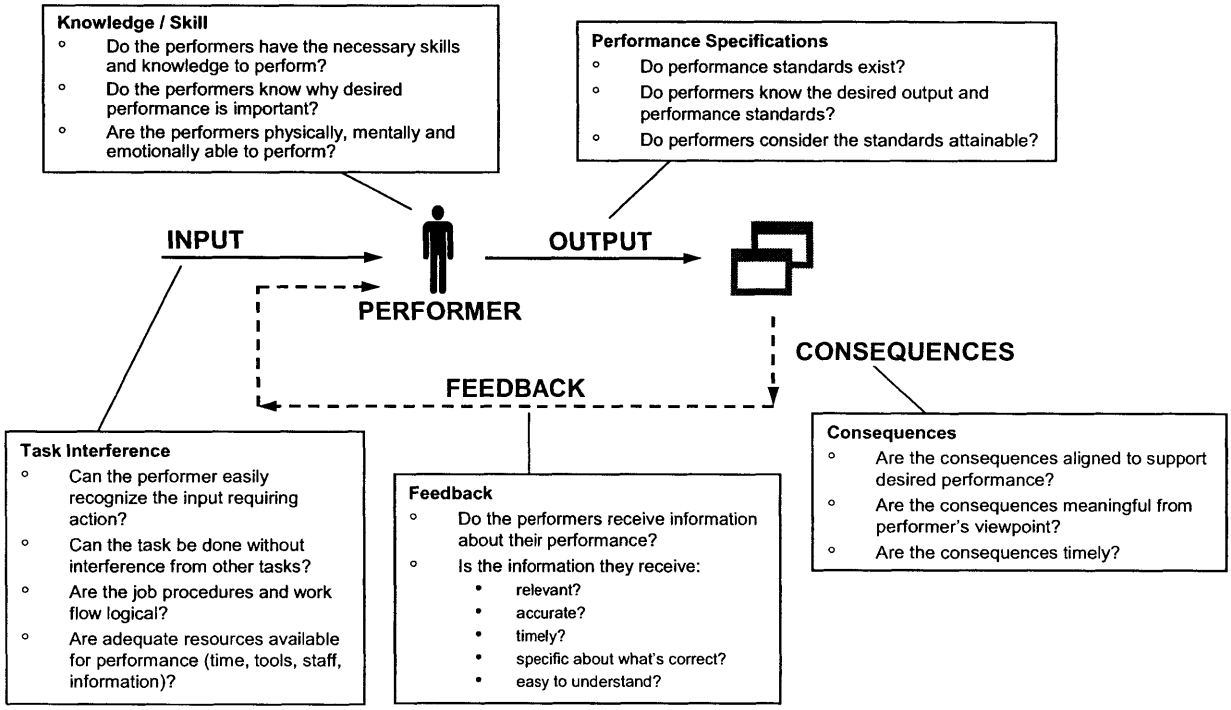
behaviors will create queues that threaten responsiveness to changing conditions. An example is a managers inability to "walk the talk" which creates waste due to massive confusion which causes employees to delay their work while trying to figure out what is really being said. Frustration is common among companies that experience these inconsistencies in behavior. While it is certainly not a simple task to change behaviors, it is critical to properly flow leadership direction, information and data.[41]

Flow may be the most complex lean principle to implement in product development. There are literally thousands of tasks that need to be completed in the process. With the help of Gantt charts and other software, the tracking of these tasks has vastly improved over the years although the steps required to perform each task can be varied in quality and completeness. Cross-functional interactions are also crucial to the success of achieving flow except for the fact that interactions can be extremely difficult to track or evaluate. It is well-known how effective cross-functional interactions and efforts are in a complex environment and there are numerous methods and practices that have been developed to aid in achieving its success.

One method of assessing intellectual or informational flow is called the Human Performance System as described by Geary Rummler and Alan Bache.[42] This method attempts to describe a system's view of how and why humans perform in the manner and with the behaviors that they do. Figure 8 shows the Human Performance System and how it ideally works if all of the questions are answered positively. The system centers on the performer which can symbolize any employee or stakeholder in an enterprise. This performer must have the proper skills, knowledge and makeup to create valuable output while understanding why their performance is important. The inputs to the performer must be recognizable, logical and timely flows of information and data without interruption or lack of resources to act on. The output by the

performer must then adhere to attainable standards that he/she understands. Next, there are consequences of all output produced. Ideally, the consequences are aligned to the desired performance, meaningful to the performer and timely in their execution. Lastly, feedback is required for the performer and must meet basic criteria to continue desirable performance.

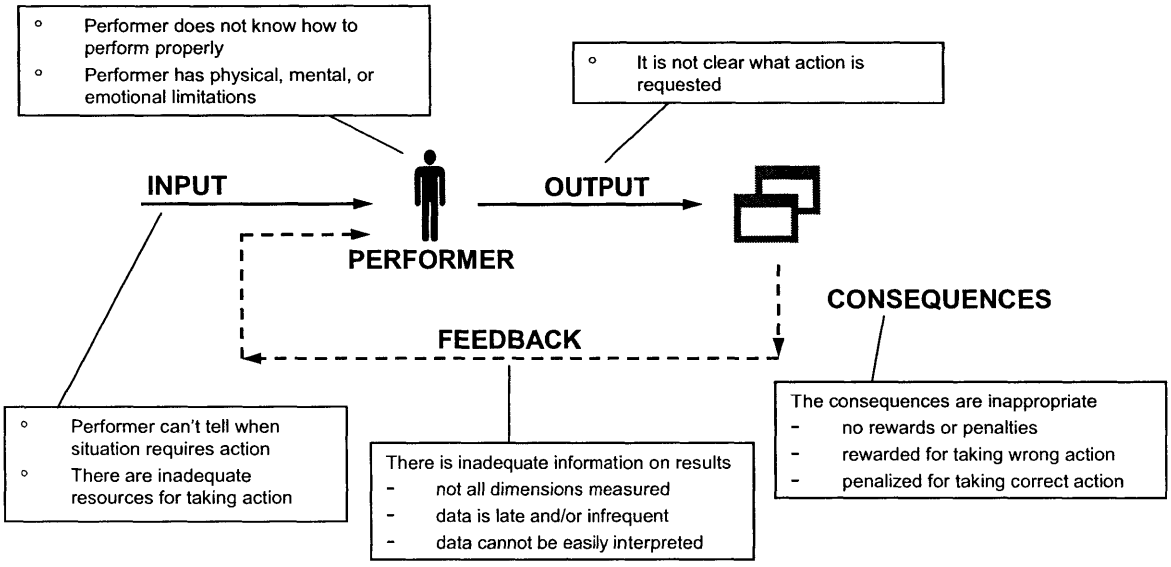
Figure 8: Rummler and Bache's Human Performance System



If any of the questions are answered with a negative result, a breakdown in desired performance results. Management is responsible to ensure that each component of the model is carried out properly. Without management's support and direction, situations will arise that will cause a breakdown in the system in which one or any combination of the potential variations illustrated in Figure 9 are present. When issues arise within any component of the system, the team should recognize the breakdown and analyze what caused it. Problems such as wrong, unclear or ill-defined targets, inconsistent feedback or lack of positive consequences for the

performer are all examples of how the system can fail. And a failure can easily perpetuate into other activities and performers causing undesired output to grow exponentially.

Figure 9: Variations of Human Performance System



Product development can benefit from this multidimensional analysis of flow. By reviewing how the physical information flows along with behaviors that cause delays can expose key barriers in implementing lean. Items that may be labeled as personal behavior issues can then be analyzed using Rummler and Bache's Human Performance System to determine the root cause. The goal of product development's flow is to ensure that knowledge and inputs are attained at the proper timing and commit to them with minimal change. With this objective, productivity can achieve considerable improvements and attempts to identify the obstacles that impede progress will strengthen.

5.1.4 Pull the Knowledge and Behaviors through the Process

Pull is defined by Womack and Jones as responding to the demand of the customer. It is simply letting the customers tell you what they need rather than pushing the products on to them.[43] This definition is very clear when applied to the end-use product. It is easy to see

examples of products being pushed into the marketplace all around us. In the auto industry, the result of pushing products is large incentives in the form of rebates, price cuts and low interest. These large discounts can distort the actual demand for the product if it were to be pulled through the process. With pull, one can see the true demand for the products which helps an enterprise adjust the designs to create the right products for the customer in the future.

Emiliani applies the definition of pull to behaviors throughout the enterprise and states that we must recognize that people operate under many different mental models which require us to adjust our styles or approach often. The meaning behind this definition is exemplified by thinking of people we interact with as customers and adjusting our approach to meet their demands rather than responding with a fixed mental model or mindset which rarely meets expectations. The latter results in attempting to forecast people's (often management's) behaviors based on our own behavior and historical consequences in order to reach your desired result. Although, forecasting a behavior is pure waste due to the time and inaccuracies it involves. If lean behaviors are followed, there could be considerable improvements in waste by reductions in iterations and ambiguity.[44]

In product development at this company, knowledge and behaviors are required to be pulled through the process. To achieve pull in product development, the ability to provide timely and accurate response to the needs of the program is required. These needs should ideally be laid out in advance as part of a program plan although reality suggests that there will be urgent situations that will also require appropriate responses. Over time, these emergencies must be reduced in order to succeed in pulling properly. The application of the lean principles naturally aids in the reduction of these urgent situations and as these are set aside, expert knowledge and proper behaviors can then be seen more clearly and exemplified for learning throughout the enterprise.

Key areas that need to be considered in assessing and improving pull are roles and responsibilities, cross-functional teams, management reviews and program timing.

5.1.5 Pursuing Perfection

Through practicing the previous four lean principles, the final principle, perfection, is the ultimate goal. Womack and Jones describe perfection as systematically continuing to improve value, flow, pull and waste elimination in production.[45] Their book, along with most companies, has only focused on the order-taking and production areas of the enterprise, which centers the definition on general production. The same needs to be applied to product development. Emiliani's definition on perfection is quite similar except it focuses on behaviors and is stated as systematically identifying and eliminating behavioral waste. Product development will require a parallel definition to systematically identify and eliminate waste in developing products. The thesis attempts to identify key aspects of process and behavior that limit the achievement of perfection in product development.

5.1.6 Summary of Lean Principle Definitions and their Application

The three approaches to assessing and implementing lean principles for production, behaviors and product development are summarized in Table 3. For each lean principle, the unique definitions can be compared. While the highest level of the principle is common amongst the three approaches, there are differences in how each area is evaluated. It is necessary to develop unique lean principle definitions for an enterprise or segment of an enterprise in order to reduce confusion during the integration process. If one only views the production definition, the product development function may not see the task as relevant since there are not yet physical products to apply the definitions to. And by only focusing on the behavioral definitions, the task

may be perceived as strictly enhancing the soft side of the business. In the case of product development, a combination of the behavioral and product development process specific definition is required to clearly teach the role of lean in the enterprise.

Table 3: Lean Principle Applications

Lean Principles	Lean Production[46]	Lean Behaviors[47]	Lean Product Development
Value	Value is defined by the end-use customer.	Understand the wants and expectations of the people that we interact with.	Realize the program's expectations and technical challenges while holding timing as sacred.
Value Stream	Understand all the specific actions required to produce a product, and eliminate the waste.	Understanding what people do and why they do it.	Understand the cross-functional communication required to achieve seamless access to knowledge and data throughout the entire process.
Flow	Get the value-creating steps to move continuously without interruption.	Behave in a manner that minimizes or eliminates delays or stoppages in the work performed by others.	Ensure that knowledge and inputs are attained at the proper timing and commit to them with minimal change.
Pull	Respond to the demand of the customer.	Recognize that people operate under many different mental models which require us to adjust our styles or approach often.	Ability to provide timely and accurate response to the needs of the program.
Perfection	Systematically continue to improve value, flow, pull and waste elimination in production.	Systematically identify and eliminate behavioral waste.	Systematically identify and eliminate waste in developing products.

5.2 Identifying Waste

By applying the lean principle definitions previously described, waste can begin to be identified in the product development process. In order to find the waste generators, both the process and culture need to be analyzed. Waste will be reviewed in the three major stages of product development and will be compared to understand where waste is being passed along or created. Taiichi Ohno identified seven types of waste, or *muda*, which were focused on production wastes. The wastes are described as *defects or mistakes* in the product, *overproduction* of product not needed, excessive *inventory* of raw materials or in-process batches, unnecessary *processing* of the product, unnecessary *movement* of people, unnecessary *transportation* of goods and excessive *waiting* times to process the product.[48] Many of the wastes can be directly translated into waste in areas other than the manufacturing floor while others have been developed specific to information and behaviors. Table 4 lists Ohno's seven waste descriptors with examples relating to informational and behavioral aspects.

Throughout the analysis, these areas of waste will aid in beginning to review and expose the cultural and procedural issues that are causing excessive amounts of waste in product development. The desired outcome is to not only identify where these examples are preventing the lean principles to be practiced but to commence the mindset of lean transformation at this company.

Table 4: Examples of Informational and Behavioral "Seven Wastes"

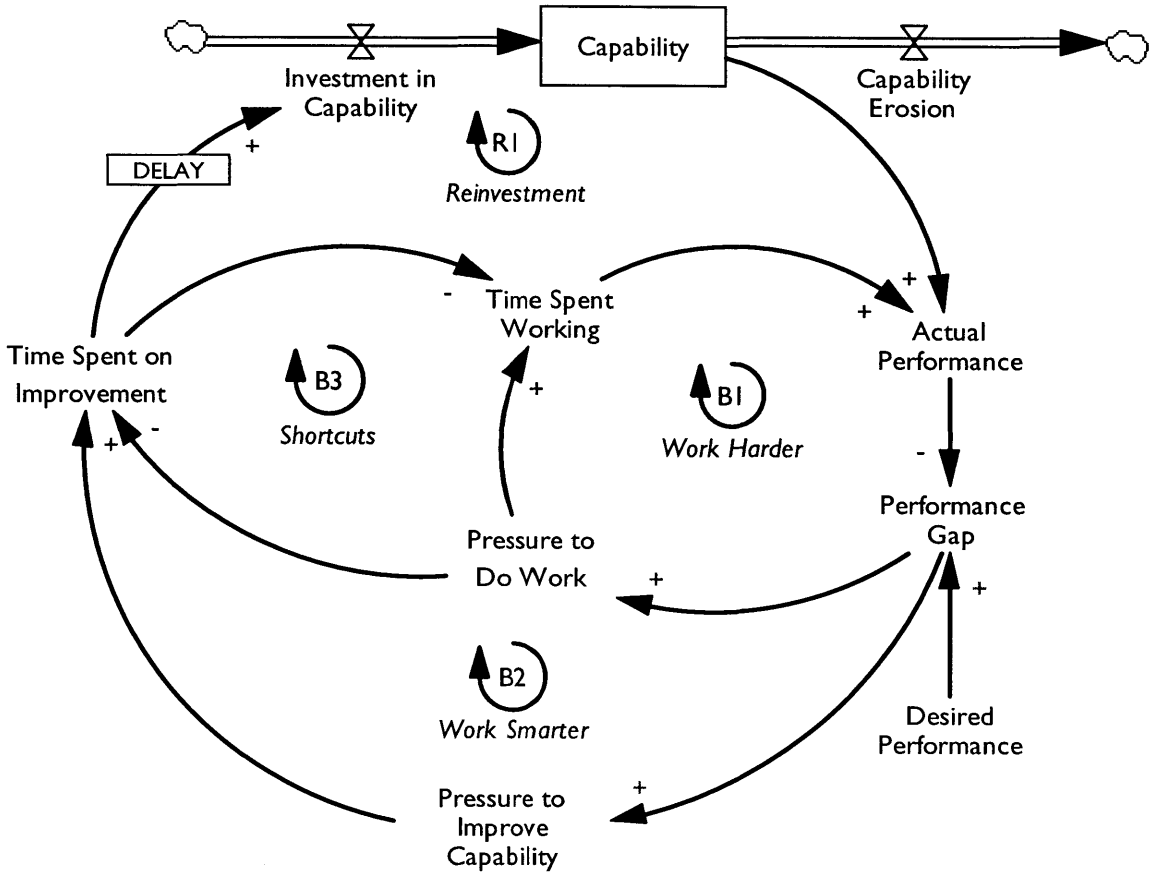
The "Seven Wastes"	Informational[49]	Behavioral[50] (sorted)
Defects	• Haste • Lack of reviews, tests, verifications • Need for information or knowledge, data delivered	• Ignorance • Confusion • Few improvement suggestions • Annoyed stakeholders
Over-production	• Creation of unnecessary data and information. • Information over-dissemination • Pushing, not pulling, data.	• Micromanagement • Many procedures • Transactional focus • Destructive politics
Inventory	• Lack of control • Too much in information • Complicated retrieval • Outdated, obsolete information	• Management secrets • Disappointing employee surveys • Employees stuck in functional area
Processing	• Unnecessary serial production • Excessive/custom formatting • Too many iterations	• Conflict • Low turnout at meetings • Appearance over substance
Movement	• Lack of direct access • Reformatting	• Crisis management • Employee turnover • Repeated mistakes • Relentless pace
Transportation	• Information incompatibility • Software incompatibility • Communications failure • Security issues	• Broken promises • Poor listening skills • Unclear expectations • Little or no feedback
Waiting	• Late delivery of information • Delivery too early (leads to rework)	• Calls not returned • Slow response to changing conditions • Delays in action

5.3 System Dynamics of Product Development Lean Principles

Since it is difficult to quantify the effects of procedural and cultural inhibitors in product development, system dynamics may help identify how the inhibitors reinforce or balance the system. The long-term effects can then be explained or forecasted based on the current progression. An attempt can also be made to determine the strength of the reinforcing or balancing loops. The intent of this thesis was not to develop a new system dynamics model but to utilize an existing model to aid in discovering important barriers to becoming lean in product development.

MIT's Nelson Repenning and John Sterman developed a model that may help explain the system effects of failing to take the Human Performance System into account. The analysis of process and cultural lean inhibitors in product development in relation to their model may assist in explaining and identifying how the short and long-term issues affect the ability to gain the capability to become lean in an organization. Figure 10 shows Repenning and Sterman's "Capability Trap" model which is made up of one stock with inflow and outflow and four key loops, three balancing and one reinforcing. Assessing the model as it relates to lean capability can help one determine the effects of culture on the lean transition process. By understanding how and what reinforces lean capability and the pressures and issues that steer an organization away from building lean capability, the road to becoming lean can be predicted and smoothed with this knowledge.

Figure 10: The Capability Trap (Repenning and Sterman)[51]



Through this system dynamics models, the analysis can be enhanced to explain how the process and cultural lean inhibitors affect the lean transition process. They may also be used to assess the impact of waste in product development. Waste that is evident in product development with initiatives to help reduce it may not take into account the issues that are producing even more waste. The intent of this model is to explain how waste increases when there is a lack of awareness of the reinforcing fat processes and behaviors.

5.4 Benefits of Lean Transformation in Product Development

Many companies have had failed attempts in lean transformation due to a variety of reasons. Although, it is important not to be discouraged by previous failures and to view the failures as

learning experiences while driving down to the root cause of the failure. Key issues that can lead to an unsuccessful transformation include not having an enterprise focus, concentrating on short-term fix areas and failing to confront the leadership and people issues. Without a systems view of the transformation process, it is difficult to reap the benefits of a lean enterprise.

By committing to a long term transformation plan throughout product development and growing it to the entire enterprise, it is guaranteed that there will be immense improvements everywhere you look. Benefits such as fewer design iterations, higher throughput, elimination of firefighting with permanent solutions to recurring program issues, coordinated and motivated teams, less supervision with more empowerment, improved response times, stronger competitive advantage, higher reliability and delighted stakeholders and employees. There is absolutely no reason not to strive to become a lean enterprise but no one claims it will be an easy trek. The next chapter will make an effort to analyze aspects of product development that make the transformation unnecessarily difficult and reveal the key lean barriers.

Chapter 6: Analysis of Product Development

6.1 Product Development Lean Principles

The lean principles defined in Chapter 5 will support the investigation of identifying barriers and obstacles in process and culture in product development at the company studied. Through interviews, process data and cultural evidence, the analysis will find the key barriers throughout product development. Nineteen interviews were conducted both formally and informally and included individuals at various levels of the company ranging from executive leadership to working level engineers. Interview data resulted from direct questioning and offerings of opinions and assessments of the current state of the process and culture. The current product development process for new products can take 43 to 52 months depending on the "scale" of the program. Scale is defined by the level of complexity involved for powertrain and body while taking into account long lead time aspects of the changes. Over this length of time, there are three major phases in the process, the early planning phase, core design/development phase and launch phase.

This analysis will take into account process and cultural lean inhibitors that are common throughout a program and inhibitors that are specific to a phase being executed. By applying the lean product development definitions to the inhibitors, the principle(s) that are affected can be delineated for further evaluation. The analysis attempts to compare the process and cultural lean barriers for significant differences and impacts on the principles. Also, by weighing the inhibitors of the different phases against the lean principles, one can better understand how to approach the lean transformation process throughout product development.

The results can then be applied to models such as the Human Performance System and Capability Trap representations discussed in Chapter 5. This allows for a systems view of how the results impact the enterprise which can help clarify the steps that need to be taken in adopting lean principles and eliminating waste.

6.2 Parallels in Process

The first step in the analysis involved the identification of issues in the product development enterprise. These issues were collected during interviews, observations in daily business, evidence from past programs and personal experience within the system. Most issues provided real-world examples of the informational and behavioral wastes found in Table 4 in Chapter 5. All of the issues were then sorted with efforts to better understand whether the issue is procedural, cultural or program phase specific in nature. This section focuses on the process issues that are common throughout the product development phases. Since this company is planning to roll out a new product development system that imitates a Japanese counterpart's system, it is critical to understand the underlying unofficial practices that are utilized throughout the current process that may be detrimental to the success of the new system.

The lean inhibitors that are common across the three phases of product development are summarized in Table 5. There were nine process specific obstacles that had similar effects in the early, middle and launch phases of a program. Each inhibitor was assessed against the lean principle definitions for product development to identify the dominant areas of impact. This is shown by a check under the associated lean principles listed on the right side of the table. In this study, each lean inhibitor affected an average of 3.2 of the 5 product development lean principles. This average is the highest of all of the studies performed and indicates that process issues have wide reaching affects on the transition to lean. When making changes to process, it

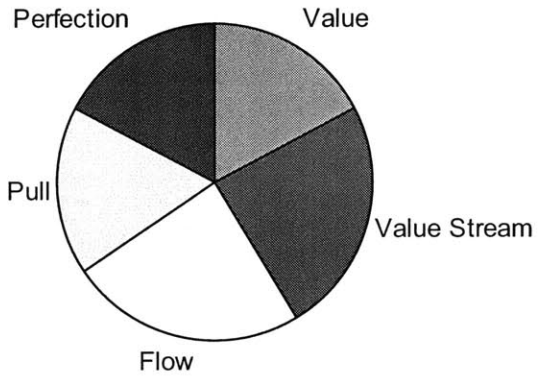
is imperative to understand if the change will resolve the issue throughout all of the lean principles or only focus on one aspect. Also, changes that bring about completely different processes need to realize the current inhibitors and be able to dissolve them as the new process takes effect. To do this successfully, careful implementation planning will be required.

Table 5: Lean Process Inhibitors throughout Product Development

Process Lean Inhibitor	Description	Value	Value Stream	Flow	Pull	Perfection
Changing Processes	A continuous stream of new sub-processes are rolled out claiming to be more efficient and user-friendly. Although, lack of trust for the new process causes use of the old process in conjunction with the new resulting in duplication of work.		✓	✓	✓	✓
Metrics	New metrics are regularly added in every product development process. The equity of the metrics is often not aligned to the objectives of the process.	✓	✓			✓
Over-control	New processes and metrics throw a program into a state of over-control. This causes a deep lack of trust and fear of negative consequences at all levels.	✓	✓	✓		
Blame	There is a need to find the person/group to blame when a problem occurs. Whether it is process discipline, part failures, cost overrun, unavailable prototype or no-build situation, it is assumed that it is caused by a particular unit.			✓	✓	
Compressed Timing	When issues arise, the common response is to fix the problem but compress the timing so it fits the schedule. The result is bending the rules of the process with workarounds.	✓	✓	✓	✓	
Interferences	Numerous high level presentations can divert work from the prescribed process. Other interferences include unrelated meetings, excessive e-mail and lack of training to complete a task.		✓	✓		✓
Process Complexity	It is often unclear if the process is being followed. Since all previous programs deviated from the process it has lost much integrity. The process is very detailed but lacks operational clarity.	✓	✓	✓	✓	✓
Sub-processes	There are numerous process and tools that have been put in place in order to support the system. Although, many of the processes overlap each other and do not provide timely feedback.		✓	✓	✓	
Wrong Metrics	Metrics tied to management performance reviews distort the benefits of an initiative. For example, if a pilot process/training is successful, an initiative to implement it throughout 100% of product development is launched. The focus soon shifts from quality results to the metric of the percentage of departments/people that have implemented the initiative.	✓				✓

By arranging the process data by its effect on lean principles, the pie chart shown in Figure 11 illustrates the impact of the process inhibitors on the lean principles. The data shows to be fairly evenly distributed over the five principles. Value Stream and Flow have a slightly higher effect, 24%, versus 17% for Value, Pull and Perfection. Since the process is heavily engaged in the Value Stream and Flow of new product development, it is not surprising to see higher percentages in these areas.

Figure 11: Process Lean Inhibitor Impact Breakdown



Many of the process inhibitors act together in an organization. For example, wrong metrics directly relates to new metrics that are created and relied upon for performance assessments. When personal performance reviews are at stake, achieving the metrics can exhibit management over-control and finding blame when there are issues. Another example can be described for the product development process complexity. The process is difficult to follow when there are several interferences in one's work. The build-up of these interferences eventually causes a need to compress timing in order to meet the program goals.

In general, the process inhibitors center in over-processing in a short amount of time with many watchful eyes on the process. When there are issues in the process, control is tightened

and responsibility is often identified. While the overall process inhibitors do not pinpoint a specific area of lean that needs to be addressed, the issues show that waste is being produced throughout the process which indicates that the benefits of transitioning to lean would have a significant impact on the enterprise.

There is concern in implementing a new product development process that is dependent on the ability to adhere to program timing. Many of the lean process inhibitors have caused delays in timing or call for compressed timing that creates ad-hoc process changes. Japanese counterparts are strict in holding timing as a sacred entity while this North American auto manufacturer has tended to hold cost as sacred and allow late changes in order to reduce variable cost on a vehicle.

In order to understand the drivers in the system, a study of the cultural side of the enterprise needs to be performed. The next section addresses the company's current culture that has evolved over the past several decades. By considering the common behaviors within product development, the ability to decipher the problems and their drivers will improve due to a holistic view of the system.

6.3 Cultural Norms

The study of behaviors can be complex to analyze and quantify. Through interviews and observations, there were numerous opinions and perceptions of how employees approach the system and learn to negotiate through it with minimal negative consequences. The cultural lean inhibitors that were taken forward for evaluation were items that were common throughout the investigation and had specific examples of the course followed and resulting outcome.

Table 6 summarizes the data from the interviews, observations and experience that were classified as cultural lean inhibitors and are universal throughout product development. Similar to the process inhibitors, the cultural items were compared with the unique product development

lean principle definitions from Chapter 5 and the specific principles affected were documented with a check for that inhibitor. Throughout the investigation, it was noted that product development culture does not vary significantly from overall company culture.

There were 16 cultural inhibitors identified that were evident throughout the three major phases of a program. While not every program exhibits each cultural issue, these inhibitors can be found in the vast majority of the teams. The average number of lean principles affected per cultural inhibitor was 2.6; just 0.6 less than the process inhibitors. This reinforces the need to remove all of the cultural barriers since resolving only a few will not strengthen the system if one or more of the lean principles is ignored.

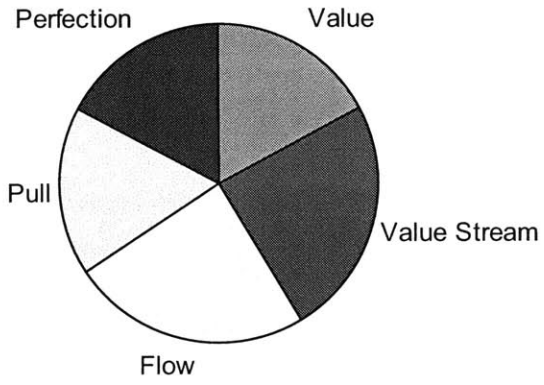
Many of the cultural inhibitors also grow on one another. For example, undue leadership character can instill fear into an organization which drives lack of trust and high stress levels. Or the case of unclear roles and responsibilities where new tasks come about and are assumed to be absorbed by an activity without reprioritizing work. Eventually, the activity or person is over-tasked (due to a "tragedy of the commons" effect) and confused. Stress is affected with only the hope of another reorganization that may change the rules yet again.

Table 6: Lean Cultural Inhibitors throughout Product Development

Cultural Lean Inhibitor	Description	Value	Value Stream	Flow	Pull	Perfection
Fear	Fear is evident throughout product development which causes anxiety in making decisions, behavior forecasting and consequence avoidance.		✓	✓	✓	
Leadership Balance	Leaders spend much time and effort protecting themselves and their bosses rather than emulating the company's defined leadership behaviors (see Appendix C).	✓	✓	✓		
Rewards	The current rewards are not aligned to lean behaviors. There is a strong reinforcement in rewarding the "firefighter".		✓	✓	✓	✓
Leadership Character	Many leaders have strong opinions on how to progress their organizations which affects the decision making process and allows little input from the working level.	✓	✓			
Deficient Employees	Rather than dealing directly with deficient employees, the employee is passed on to another area in hopes that others will resolve the issues.			✓		✓
Stress	Internal company surveys show stress as the number one concern among employees, although, leadership actions do not reduce stress.		✓	✓		
Exposure	Employees are encouraged to be involved in high exposure situations in order to show ones firefighting abilities.				✓	
Incentive Alignment	Merits and bonuses are not aligned to performance. For example, if a program was well-executed in a year with poor financial results, the merit/bonus is low. And if a program was poorly executed in a year with good financial results, the merit/bonus is good.	✓		✓	✓	
Communication	High level communication is carefully constructed "happy talk". While the optimism is appreciated, employees want to hear the truth. Hence, employees see this as concealing the true state of the company which results in cynicism towards leadership.	✓				✓
Level Talk	The comfort level of a conversation is directly related to the leadership level of the other person leading to a "talk by level" culture.	✓	✓			
Over the Wall	Work that one is not rated on can tend to be pushed to the next area for clean up. While this happens at all phases of a program, the launch phase is burdened with the most issues and failures.		✓	✓	✓	
Tragedy of the Commons	When dealing with managing workers time, it is assumed that all employees can fully engage all new policies, meetings and processes without affecting there prime performance. Over time, it proves to overload workers, adding more stress and degrading performance.			✓	✓	✓
Reorganizations	Reorganizations do no affect company culture since they are part of the culture. Employees expect that there will be a shift in management every few of years. Since the rules change when the bosses change, new policies are assumed to be short-lived.	✓	✓	✓	✓	✓
Roles & Responsibilities	In contrast to Japanese competitors with manufacturing leadership and understood roles, this companay is led by engineers with constantly changing roles.	✓	✓			
Lack of Trust	Over-control is built into the system due to the lack of trust in the enterprise. This causes a growth in metrics, high level meetings and sub-processes.			✓	✓	
Definition of Success	Success is not defined by how well the process was executed, rather, how well the vehicle performs in the marketplace through profits and sales volumes.	✓				✓

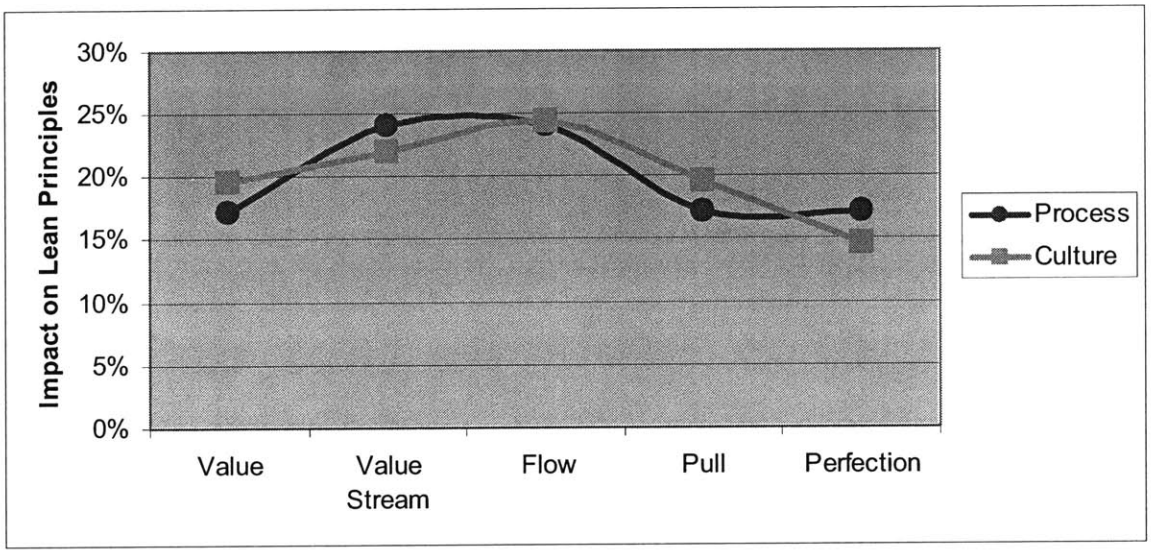
Similar to the process inhibitors, the data was plotted to understand the affect on the product development lean principles. Figure 12 shows the breakdown of the cultural data. The result is a fairly even distribution over the lean principles with a slightly higher impact on Value Stream and Flow, 22% and 24% respectively, 20% for Value and Pull and 15% for Perfection. This data suggests that the cultural barriers affect all aspects of lean integration without singling out a specific principle.

Figure 12: Cultural Lean Inhibitor Impact Breakdown



A closer look at the breakdown with a comparison of the process and cultural inhibitors shows similar results. Figure 13 produces nearly identical results with respect to the affects on lean principles. One might deduce that Value Stream and Flow principles require the most attention in a lean transformation process but in reality, the results are not significantly different from Value, Pull and Perfection. At this juncture, it is apparent that further study is required to understand how and where lean inhibitors are ingrained in the product development system in order to effectively remove them. The following section will review the effects of applying the principles at different phases of a program.

Figure 13: Process and Culture Lean Inhibitor Comparison



6.4 Key Differences Across the Three Stages of Product Development

In evaluating the company's process and culture in product development, there were several inhibitors that were more prevalent at a certain time or milestone in a program. These items were broken down into the three stages of a program with the dominant themes: early systems decisions, core discipline and downstream management. The following sections explain the characteristics of the inhibitors to becoming lean and attempts to show a relationship to the lean principle it effects. By studying these differences across the cycle, we can be aware of how they affect lean transformation and give consideration to them in order to accomplish the objectives.

6.4.1 Early Systems Decisions

The beginning phase of a program takes place over five major milestones beginning with a program kick-off through the point where the program is officially approved for production. Prior to kicking off the program, there are several groups that are active in determining prime appearance concepts, features, powertrain configurations, emission technologies and vehicle

strategy. These functions continue their involvement throughout the early phase until their responsibilities are either handed-off or diminished. During these milestones, it is required that one set of assumptions be taken forward for development and production.

Several lean inhibitors were unique to this early phase of programs. Table 7 lists these issues and classifies them with respect to the product development lean principles. Many of the items in the table are rooted in a combination of process and cultural issues. While some of the inhibitors are apparent in other phases of a program, these twelve showed to be dominant in the earliest phase. In reviewing the effects of these early phase inhibitors on lean principles, the number of principles affected per inhibitor was 2.4. The effect is slightly lower than the cultural inhibitors and 0.8 lower than process inhibitors yet still shows that the company can not focus on a single lean principle to improve since each inhibitor is likely to affect more than one.

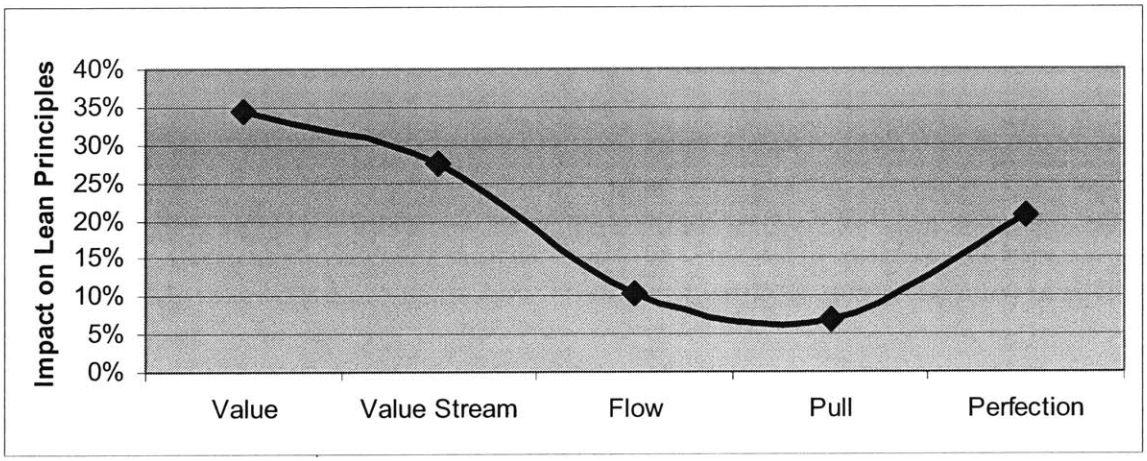
The theme of the data suggests that the inhibitors result in setbacks in decision-making early in the program. A problem such as holding too many alternatives on a list for an extended period of time affects the optimization of the entire system which may cause functional groups to refine their parts without understanding the holistic interfaces and consequences. An issue like this can be due to the program's central focus on cost. Since past programs have allowed timing be compressed or delayed in the name of cost reductions, new programs follow the same path. Other issues that affect decision making include ineffective communication between groups that are physically spread out and commitments to the executive level to achieve certain targets that may not align with system success. There are numerous examples of early decision-making issues whose effects have carried out through the launch phase and some have shown in warranty once in the hands of the end-use customers.

Table 7: Early Phase Lean Inhibitors in Product Development

Early Phase Lean Inhibitor	Description	Value	Value Stream	Flow	Pull	Perfection
Reinvention	Previous strategies are not well communicated / documented for reuse.	✓	✓			✓
Excessive Alternatives	There are often an excessive number of alternatives and technologies carried forward in a program. The process for reducing alternatives is unclear and drawn out, often resulting in the only viable option being the one that meets the timing.	✓	✓			
Systems	Decisions for changes in existing vehicles lack a systems view resulting in vehicle implications. New product system architecture decisions tend to fluctuate.	✓	✓			
Optimize a Part	Within functional organizations, there is a tendency to optimize a component / subsystem within the "chimney".	✓	✓			
Cost Focused	Over the course of the early phase of a program, cost is evaluated multiple times causing key decisions to be overturned. If time runs out on other viable alternatives, the resulting product may not be desired but deemed acceptable in order to continue the program.	✓	✓			✓
Location	During this phase, the teams are spread out and decisions that require multiple departments to reach a consensus (ex. engineering, marketing, research, purchasing and manufacturing) require much information transfer. High level meetings can take weeks to organize and prepare documents.		✓	✓	✓	
Illusion of Fewer Issues	The perception of having the time to sort out issues since the program is in the early phase leads to lighter assessment of the deliverables. This illusion of having fewer issues is carried into the decision process misleading the decision-makers.			✓	✓	
Teflon	The inability to adhere to decisions in the early phase causes failures throughout the process. The new product development system will rely heavily on maintaining the early decisions.	✓	✓			✓
Just in Case	Early in a program, it is common for engineering to overstate requirements. Through experience, an engineer believes that if a part or function is removed, there is great praise for saving the associated cost. Although, if needs are added, there are penalties as a result.	✓				✓
Moving Forward	There has not been a program that has achieved all of the requirements of the current product development system. Plans are developed to meet the deliverables but are often incomplete or not followed up on depending on the exposure level of the deliverable.	✓		✓		✓
Commitments before Reality	Early commitment by high levels are made before the facts can support a decision. The result is numerous hours, weeks and months attempting to achieve the obligation.	✓	✓			
Being #1	When leading in the marketplace, there is confusion on what to do next. The company has become good at understanding how to follow the best-in-class leaders which jeopardizes a product that is in the lead.	✓				✓

These decision-making inhibitors have an interesting effect on the product development lean principles. Figure 14 plots the distribution of the data from Table 7: Early Phase Lean Inhibitors in Product Development. The Value principle is clearly impacted more than the other four. With ten of the twelve inhibitors exhibiting an impact on Value, it's evident that efforts to realize a program's expectations and technical challenges while holding timing sacred are not following an acceptable course. Achieving the Value principle requires coordinated decisions to be made at the proper time in order to allow for the process to successfully advance. The data also shows that the Value Stream and Perfection principles are significantly affected in the early phase. It is surmised that the strong impact on Value disperses to the Value Stream causing cross-functional interaction shortfalls which limit the ability to accomplish seamless access to knowledge and data. On the other hand, issues in Perfection add to the breakdown in achieving Value. By not having a systematic feedback mechanism that identifies past wasteful practices in order to aid in decision-making, Value is compromised which multiplies the impact of the lean inhibitors.

Figure 14: Early Phase Lean Inhibitor Effects on Lean Principles



It is important for the lean transformation effort to understand how to approach the initial phase of a program. Appropriate and accurate decision-making must be recognized as a key

enabler in the process in order to have a positive influence on Value, Value Stream and Perfection. Previous failures in decision-making have a variety of causes that are unique to each circumstance although common in nature, tying back to the inhibitors. It is critical to consider and comprehend all of the stakeholders' concerns in order to negotiate a successful strategy for a program. By adopting the product development lean principle definitions and maintaining awareness of all stakeholders' requirements, the early steps in the process can develop and mature without the effects of changing direction.

6.4.2 Core Discipline

After a program is approved for production through the milestone that produces viable prototypes, the nucleus of the vehicle development is in process. The targets that were cascaded from the early phase are used to design and develop subsystems and components. At least two prototype builds take place to initially test the designs and direct further changes leading to the prototype build that emulates production objectives and tests for design verification and durability. This middle portion of the program requires timely information flow and coordinated teamwork in order to reach the launch phase with minimal failures.

Table 8 summarizes the lean inhibitors in the middle phase of the product development process. There were eight inhibitors that showed to be dominant in this core development phase. When categorized against the lean principles, each inhibitor affected 2.8 of the principles which was slightly higher than the early phase effects. Similar to the review of process, cultural and early phase, it is critical to take in consideration all of the product development lean principles before taking action on alleviating a middle phase issue.

Table 8: Middle Phase Lean Inhibitors in Product Development

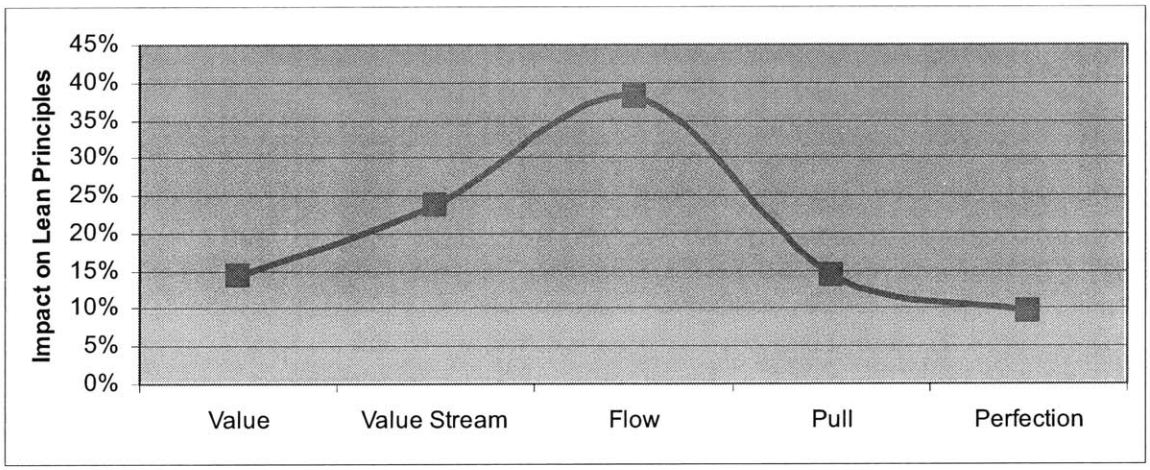
Middle Phase Lean Inhibitor	Description	Value	Value Stream	Flow	Pull	Perfection
Interaction	Cross functional teams can take an excessive amount of time to establish and there is often poor meeting attendance and inadequate communication.		✓	✓		
Feedback	Timely response and interpretability of data are key factors in receiving effective feedback. It is common for data to take an unnecessary long time to be communicated and understood by the associated activities.			✓	✓	✓
Discipline	Previous programs set a precedence for progressing through milestones without meeting all of the requirements which can lead to failures downstream or in other functional activities. Or worse, mistakes are hidden with the rationale that they can be fixed quickly in order to catch up to the next milestone. Either way, programs are often delayed as a result.		✓	✓		✓
Coordination	Processes, prototypes, test facilities and meetings all need to step to a cadence in order to fulfill the requirements. There are repeated instances of overlapping processes, conflicting prototype schedules, lack of test facilities and excessive meetings that generally worsen issues.	✓	✓	✓		
Asking for Help	There is generally a weakness in asking for help by engineers. There are multiple reasons for this issue including fear, negative consequences and management interference.	✓	✓	✓		
Rules Change	Changing the rules is often a result of not following the process. Since the official deliverable can not be met, an agreed method is utilized that may completely change the course of action for an engineer.		✓	✓	✓	
Metrics	Metrics are aggressively pursued in this core development stage rather than ensuring proper data flow. This check the box method causes a program to be progressed loosely.			✓		
Management Drives	During the core development phase of a program, the process calls for planned management drives. This practice acts as a built-in guarantee that there will be late changes.	✓		✓	✓	

Examination of the middle phase lean inhibitors reveals a concentration of issues in core discipline. Inadequate cross-functional interactions and lengthy data feedback loops can cause frustration in the development process. This coupled with the strong focus on meeting program metrics can lead to careless assessments that overlook the need for accuracy and completion of

the deliverables. The result is a lack of discipline in meeting milestone requirements due to changing process rules in order to meet the timing of the next set of deliverables.

Plotting the data with respect to product development lean principles yields the graph in Figure 15. With all eight of the middle phase inhibitors affecting the Flow principle, it is not surprising to see a peak in the graph. Out of all five principles, issues in Flow account for 38% of the effects of core development. The Value Stream principle is also an area that needs attention capturing 24% of the impact. This data points to a considerable issue in the assurance of proper cross-functional teamwork, knowledge transfer and timely inputs in the process.

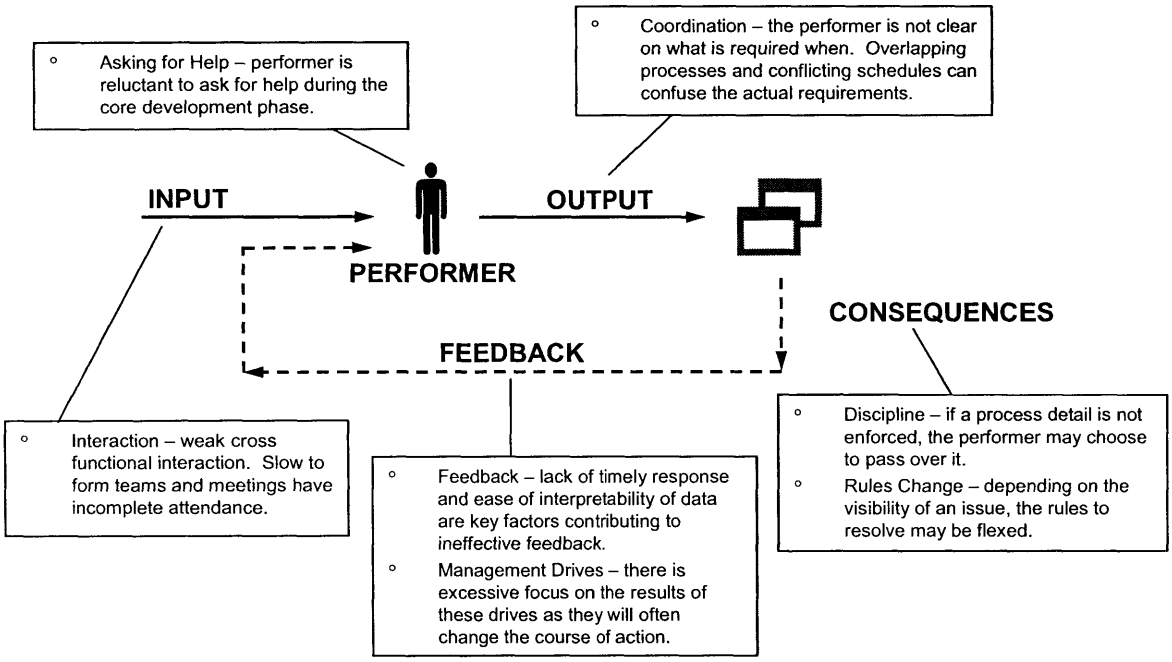
Figure 15: Middle Phase Lean Inhibitor Effects on Lean Principles



The effects of not achieving flow in manufacturing can be seen on the plant floor. Idle machinery and high reject rates can be measured, modified and watched for improvement. In product development, the flow is informational and is much more difficult to analyze. Often, the issue is found much too late to correct without delaying key milestones. There is also a strong human behavior aspect that needs to be considered. A view of the Flow principle using Rummler and Bache's Human Performance System is shown in Figure 16. All eight of the

middle phase inhibitors were placed in the model to illustrate how they affect Flow from the human side.

Figure 16: Flow Effects on the Human Performance System in the Middle Phase



Following the diagram starting with "input" exhibits a holistic view of the impact of improper Flow. Input is affected when information or data is not communicated to the performer due to weak cross-functional interactions. The performer himself/herself may wait a long period of time if there is reluctance to ask for help. This reluctance may be due to the fear of unknown consequences that may include poor performance reviews or management interference. The output from the performer may be delayed due to lack of hardware or facilities due to coordination issues out of his/her control. If the performer knows that it is common to skim over or lightly document a detail that is not scrutinized, he/she may also choose that practice to save time since there are no consequences. The performer may also hold back on producing output if there is a chance that the requirements will be flexed to accommodate program timing. Feedback

to the performer can be frustrating to deal with. If long-awaited data analysis is finally received but difficult to interpret, it can lead to errors in design that get carried forward to the launch phase. Another issue is the practice of management drives. One interviewee commented that management drives were "a built in guarantee for late changes". When the feedback from a drive is received by a program team, there are spikes in workload due to an all-hands effort to understand and resolve the issue for the next scheduled drive. The success or failure of the process centers on the performer's actions and responses. If the performer becomes disgruntled with lack of input or negative consequences, his/her behavior may become worse over time. It is critical for management to understand how and why employees' performance increases or decreases in order to take the proper steps to make sure Flow is being accomplished.

Achieving discipline in the core development of a new vehicle has numerous benefits that Japanese auto manufacturers are in the process of proving. The ability to achieve Flow by optimizing Value Streams and balancing all of the principles will allow for swift recognition of design issues that require changes to components and subsystems. The changes can then be implemented and verified before the launch phase of the process.

All of the examples mentioned point to issues in core discipline. However, it is not adequate to blame the employee and insist on better performance. A holistic view of the issues needs to be taken into account in order to correct the problems. The new process that the company is planning to convert to in the near future will assume that discipline is well-managed. Management is aware of many current discipline issues although it is unclear if there is a plan to successfully challenge it. Interviews revealed mixed views on whether engineers have the necessary skills and motivation to accomplish effective Flow in product development. It will be

imperative to understand the underlying basis for proper Flow before a new process is rolled out to the enterprise in order to achieve success.

6.4.3 Downstream Management

The launch phase of the product development process is kicked off with testing of the design. Verification results are reported and analyzed in order to support the start of activities and training for launching a new vehicle. There are approximately four major pre-production builds during this time that continue testing designs for function and durability. Launch issues are tracked on a daily basis with several report-out meetings that include various levels of management. The launch phase is the most dynamic portion of the program. Information is based off of physical parts and failures get a high degree of scrutiny. During this phase, manufacturing gradually becomes more involved by assessing the assembly feasibility of the engineered parts. The last six months of a program is led by the manufacturing organization with the product development team supporting the needs of the plant.

The nine prevailing inhibitors of product development during the launch phase are summarized in Table 9. Similar to the other studies, each inhibitor typically affects more than one lean principle. In this case, 2.3 principles are affected per inhibitor. Even though this average is the lowest in the study, it still reinforces the need to consider all of the principles when attempting to improve lean performance since nearly half of the principles are affected with each inhibitor.

The number of management personnel involved in the launch phase was observed throughout the investigation of lean inhibitors. Multiple daily meetings and frequent launch reviews force high levels to become intimately familiar with minute details of major issues. Issues are captured in an automated tracking system and it is not uncommon for the launch phase to generate 2,000 individual issues that require root cause analysis. Once the root cause is

determined, a design change is often required. Data studied by the purchasing organization has shown that the average new part typically undergoes three to five changes during launch. Major or numerous changes that require new or modified tooling put the program timing at high risk making Job #1 delays inevitable.

Table 9: Launch Phase Lean Inhibitors in Product Development

Launch Phase Lean Inhibitor	Description	Value	Value Stream	Flow	Pull	Perfection
Heavy Management	Management from multiple facets of product development and manufacturing is involved in a launch. All rules are abandoned in attempts to win the launch battle. Managers stepping in to do the work drives a wedge between leadership and engineers. Also, the number of meetings to discuss and re-engineer the parts increases to twice or three times daily.	✓		✓	✓	
Resources	Launches are treated as all-hands events. Resources are approved due to the emergency nature of launch.			✓	✓	
Suppliers	There is a belief that the only way to get a supplier to respond is to continually press them and threaten re-sourcing for the next program.				✓	✓
Management Drives	These drives continue in the launch phase of the program resulting in even more late changes.			✓	✓	✓
Design Changes	The late failures, assembly and quality issues can result in up to five changes per new part.		✓	✓		
Delays	The realization of delaying Job #1 comes to a head thus lengthening the launch process. Due to the heavy management involvement and increased number of issues, the stress levels and fatigue are intensified.				✓	
Cost Reductions	To further exacerbate the issues, design changes that reduce cost are approved for incorporation. These late changes have shown to cause quality issues in the field which can negate any savings previously gained.			✓	✓	✓
Rules Change	Due to the number of late changes, the rules of the process change. The urgency to resolve issues is at its most extreme state which allows emergency work-arounds.		✓	✓	✓	
Lessons Learned	At the end of launch, the lessons learned are collected. Although, they are often not comprehensive due to the small number of team members involved in the effort. Also, lessons are not effectively implemented on future programs.					✓
Red Results	An excessive number of programs are rated red or yellow during this phase of the program. Reports that show new program status are sent to vice president levels which drive even more management involvement.	✓		✓	✓	

As in the middle phase, there are also management drives during the launch phase. Although, with multiple vehicles produced during pre-production builds, the process is intensified and design changes are certain. It is not uncommon for engineers to spend numerous hours trying to understand the issues identified that relate to drivability of the vehicle. It can be extremely difficult to duplicate these issues. And in some cases, if it is determined that the drivability experience meets design intent, it is not a simple task to inform the manager that he/she was mistaken due to the cultural issues previously discussed.

In order to quantify the inhibitor, Red Results, a large cluster of vehicles was analyzed over a three month period of time. During the launch phase, programs are tracked by a new model team and the weekly results are sent to the vice president level. Each launch program is given a rating, green, yellow or red. Green indicates that the program is on track to plans. Yellow means that the program is not on track to plan but there is an accepted recovery plan that will meet the program objectives. Red is defined as an issue that has no acceptable plan for recovery, hence, production timing is at risk. This study also split the launch programs into two groups, major programs and minor programs. At the beginning of every program, a code is assigned that specifies the scale of complexity of the program. For this study, the top third of the complexity scale was considered major programs (ex. new sheet metal design and/or new powertrain) and the bottom third of the scale was deemed minor. Table 10 shows the results from the study.

Table 10: Launch Phase Program Study – Reported Status

Reports:	Green	Yellow	Red	% of Data
All Programs	23%	27%	50%	100%
Major Programs	9%	30%	61%	18%
Minor Programs	26%	26%	47%	82%

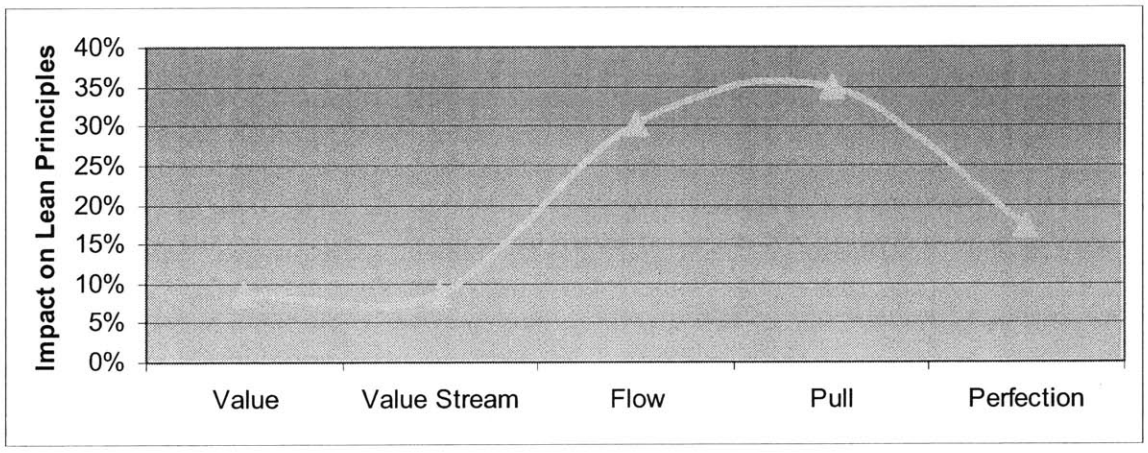
There was an average of 17 total programs analyzed over the time period with a total of 173 data points. Out of all of the programs, only 23% were on track to plan and all of those programs were considered minor. A minor program typically involves quality improvement and cost reduction actions that do not alter the architecture or fundamental systems of a vehicle. A yellow rating ranged from 26% to 30% for programs of any complexity level. This is a significant portion of the programs that require product development engineers to lead the resolution of design or manufacturing issues. Most alarming was that half of all programs in the launch phase were rated red with 61% of major programs having issues without adequate plans to meet the program objectives. With manufacturing playing an important role in this phase, they insist on full support or "24/7" activity to resolve the issues. Manufacturing's patience wears thin in this stage which causes higher levels of management to be contacted soon after an issue is surfaced in order to guarantee that the proper assistance is in place to find a quick solution. Not surprisingly, resource requirements quickly spiral out of control leaving early and middle phase programs lightly supported, hence, causing more red programs as they enter the launch phase. During a particularly high profile launch, the company's executives communicated that a "few hundred" engineers were sent to an assembly plant nearly 300 miles away for six to nine months to ensure a successful launch. Compare this staggering number to Japanese counterparts that send less than 20 product development engineers to a launch and it is clear that removing the inhibitors in product development must be taken seriously in order to be competitive.

Another example of a launch inhibitor is allowing design changes that save variable cost in the vehicle. During a time that the design should be solidified with no changes that are not safety or quality related, management permits design changes for cost reduction benefits. This further exacerbates the resource requirements and unnecessarily churns the designs and assembly

feasibility. In addition, the design verification may be hurried which risks vehicle quality. In fact, a 1998 through 2003 internal study found that 14% of all recalls and service programs were due to cost reduction design changes. Undoubtedly, if a cost reduction action results in a recall, the cost savings are never achieved and can impact future customer satisfaction.

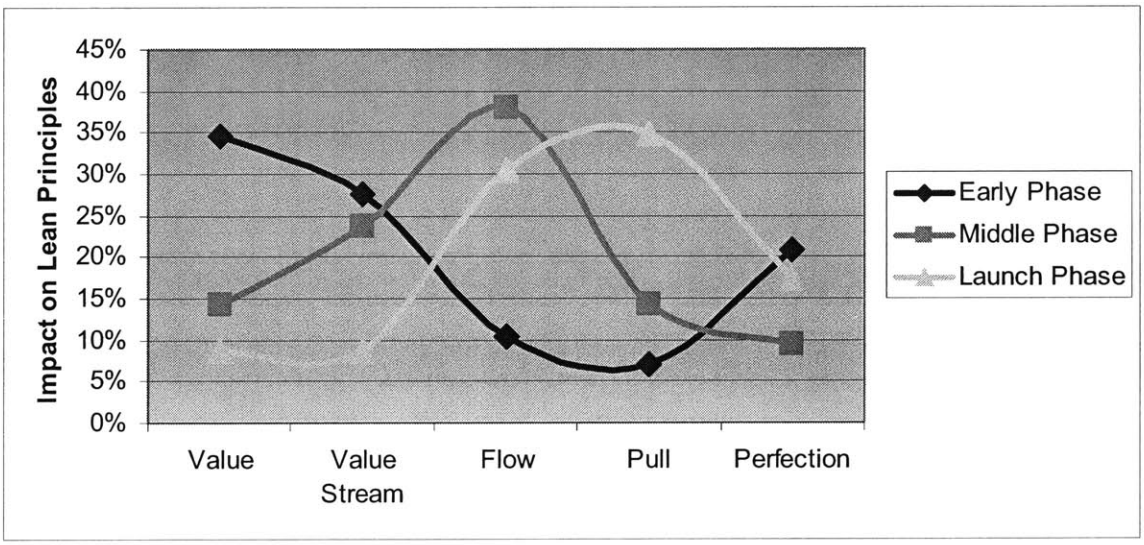
Launch timing pressures cause the inhibitors to greatly affect Pull. Since Pull requires timely and accurate response to a program, design changes and rule bending have a negative impact on Pull. There is certainly a response to the issues during launch. Heavy management and numerous resources are the immediate response that endures through the entire phase. Figure 17 graphs the impact of launch phase inhibitors on the lean principles. Not only is Pull acutely affected at 35% but the impact on Flow is significant at 30%. Flow is enabled when there is minimal change and the data for launch has extensive evidence of excessive change. The launch phase generates the most measurable data in comparison with the other two phases due to its go or no-go environment. There is no shortage of metrics during launch although the numbers do not always trigger the correct improvements in the system.

Figure 17: Launch Phase Lean Inhibitor Effect on Lean Principles



By comparing the launch phase to the early and middle phases, the results show an interesting effect relative to the lean principles. Figure 18 shows the three stages plotted on one graph. The effects of the different phases on the lean principles progress through the order of the principles in the same order as the phases of a program. In the early stage, Value and Value Stream are heavily affected. In the middle stage, Value Stream and Flow see the most impact and the launch phase shows Flow and Pull as the victims. Perfection acts as a tail to the data by increasing in the launch phase and circling back to affect the early phase.

Figure 18: Comparison of Early, Middle and Launch Phase Effects on Lean Principles



By studying the enterprise in three major phases, the effects of process and cultural inhibitors on the product development lean principles were comprehended at a new level. Rather than overwhelming the workforce by focusing equally on each principle throughout product development, each phase can take into account the data and why it is important to focus on the principle definitions and apply them in practice. During the transformation to lean, this knowledge can help focus efforts on breaking down the barriers that are holding back the progression of lean in product development.

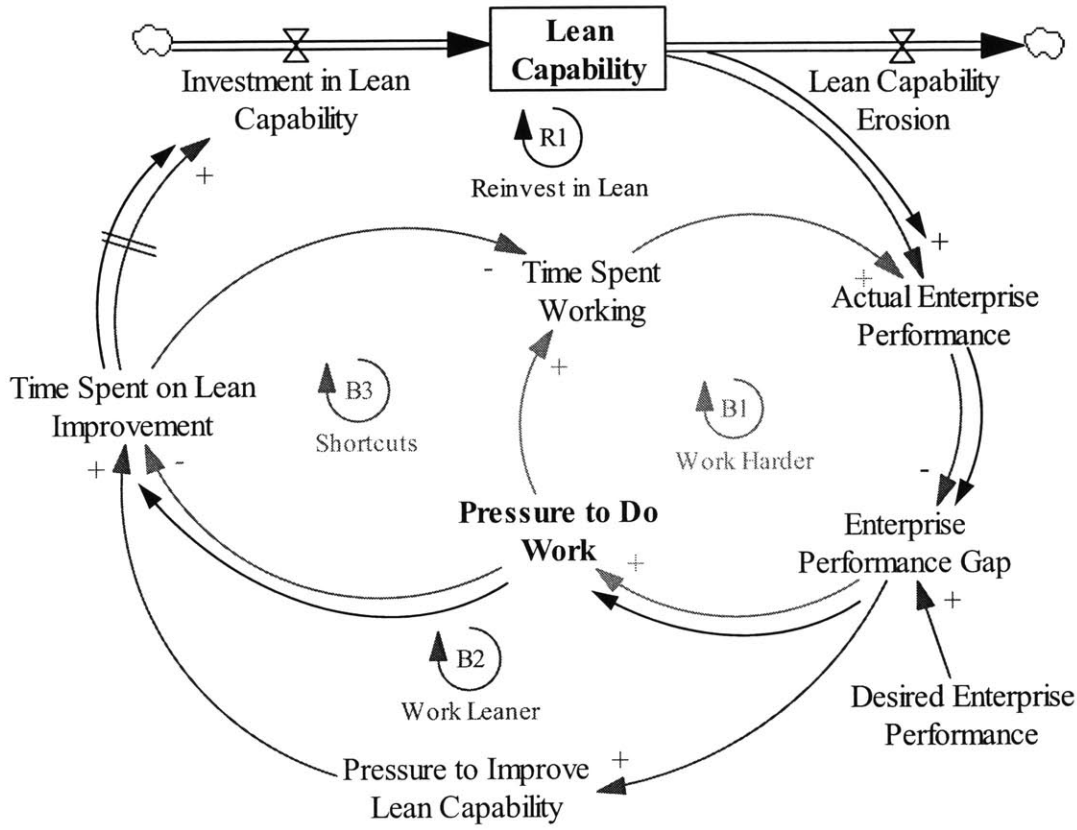
6.5 System Dynamics Effects

Viewing the lean product development inhibitors using Repenning and Sterman's system dynamics model, "The Capability Trap", described in Chapter 5 can help explain how the current state of the enterprise will have great difficultly in achieving and benefiting from lean principles. It is important to understand how an inhibitor not only prevents success in the process but also how it affects the system in the short and long term. The actions this company takes to improve performance and break down the barriers will require careful thought on how the system will react. In the past, attempts to improve performance included reorganizations, over-committing the workforce and introducing fear of failure. All of these tactics failed and are currently inhibitors themselves along with many others.

The Capability Trap model was reconstructed to show the model as a lean capability stock in Figure 19. The main goal is to improve enterprise performance by eliminating the performance versus target gap. By using lean as an enabler in reducing the performance gap, the stock of lean capability needs to be increased and investments such as training and mentoring in lean principles increase the enterprise capability. As lean is practiced, the actual performance improves thus reducing the performance gap. This path follows the model depicted in Figure 6: Linear Mental Model of Lean Transition but lean capability doesn't end there. It must be strengthened for further improvement. By following the B2-Work Leaner balancing loop in blue on Figure 19, management then realizes the performance gap is narrowed by practicing lean principles, the pressure to improve capability increases along with time spent on improvement which in effect eventually increases the investment in lean and capability overall. This cycle allows the actual performance to eventually match the desired performance until the desired

performance bar is raised to the next level. Continued investment in lean capability facilitates increases in capability while restricting the performance gap from increasing.

Figure 19: Reconstructed Capability Trap for Lean Transformation



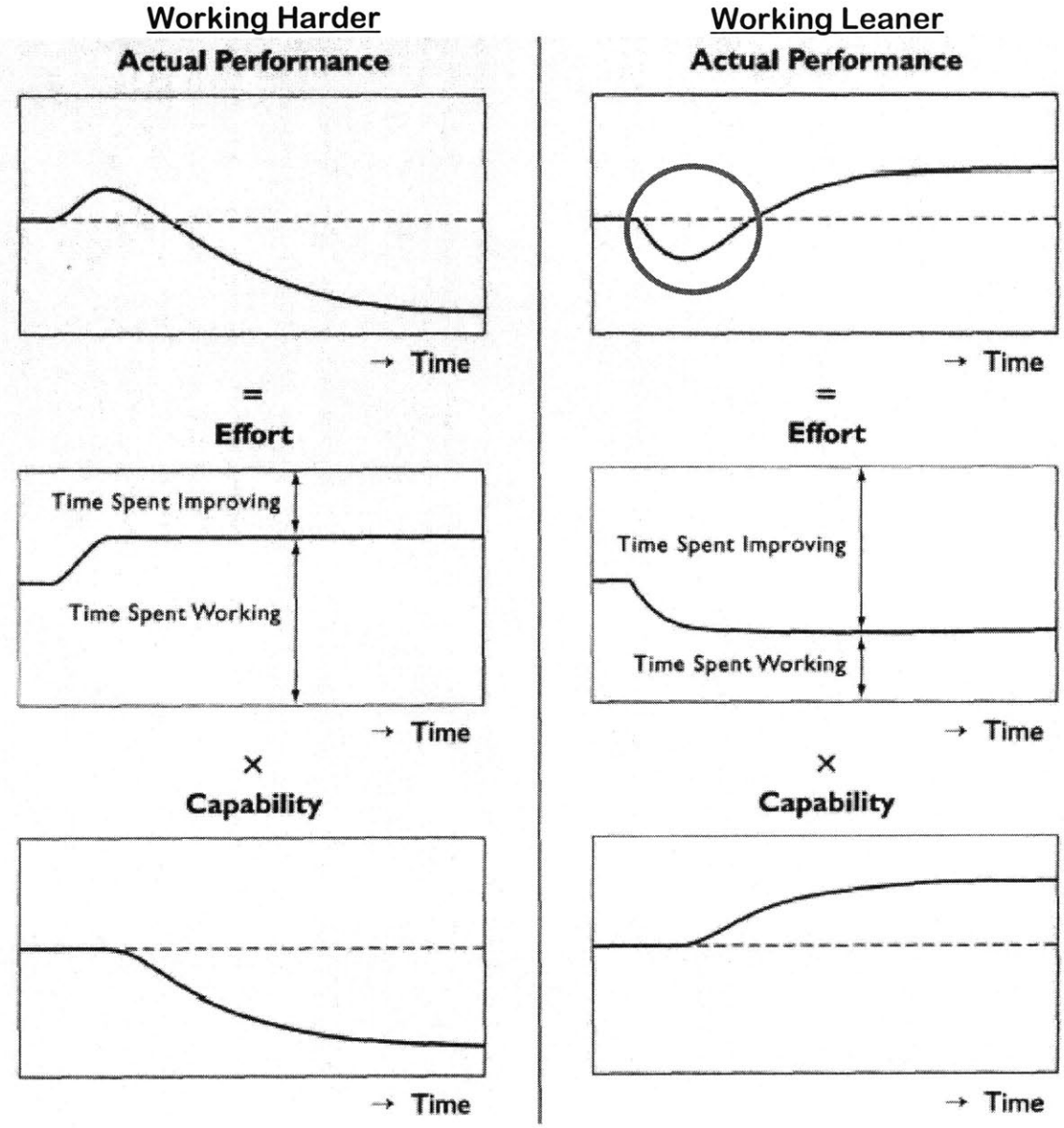
Inhibitors have the opposite affect on generating lean capability. For example, designs that are changing frequently cause the pressure to do work to increase in order to fix the problems due to management mandate or increased fear. Hence, the time spent working on design changes increases to improve the enterprise performance thus narrowing the gap as shown in the B1-Work Harder balancing loop in red which is commonly known as firefighting. Since lean capability does not erode immediately, the short-term results are positive so management continues to increase the pressure to do work. The time spent on lean improvement then decreases in order to further increase the time spent working, increasing actual performance.

This is shown as the B3-Shortcuts balancing loop in green in Figure 19. Eventually, the investment in lean capability valve closes allowing lean capability erosion to drain the stock.

The critical factor for this automotive manufacturer in this system dynamics representation is the pressure to do work or firefighting. If management does not realize the impact of increasing this pressure, then lean capability can never be achieved. Since issues such as launch design changes do not decrease overnight, the proper balance must be maintained in order to complete the work and increase the time spent on lean improvement. By doing this, the R1-Reinvestment loop in black reinforces the need for lean capability allowing the stock to further increase.

Figure 20 shows Repenning and Sterman's graphical results of effects of working harder and, in this case, working leaner. Clearly, over the long term, working leaner yields the desired results while working harder widens the performance gap. The difficult decisions in building lean capability are related to the possible short-term performance decline circled in red on the graph. In a large, complex industry, how long is the "short-term"? Managers tasked with improving performance will have little tolerance for any initiative that threatens the bottom line for any length of time. This emphasizes the need to carefully plan the lean transformation by identifying significant areas of waste and eliminating them while lean capability is being developed in order to offset the performance impact in the early adaptation stage.

Figure 20: The Capability Trap Results (Repenning and Sterman)[52]



By understanding the system feedbacks that increase or decrease the level of lean capability, the Transition to Lean Roadmap from Figure 7 can be planned and optimized in order to achieve maximum capability in practicing lean throughout the enterprise. System dynamics can play an important role in realizing the potential of investing in lean by growing this model to account for

the company's specific elements that may affect the variables with positive or negative consequences.

Chapter 7: Conclusions and Recommendations

This chapter presents a summary of the conclusions resulting from the research conducted. This thesis reviewed the traditional lean principle practices in manufacturing, developed new definitions for lean principles in product development and applied them to enterprise's process, culture and stages of development. The conclusions are those consequent to interviews, observations, analysis and literature reviews during the study. A brief description of each conclusion is provided to explain each item. The lean transition process will require that action be taken in order to integrate lean in this sector of the company that yields large quantities of information flow. Recommendations are presented to support the transition process and aim towards positive implications of incorporating lean. Unless noted, the recommendations made are relative to improving all of the product development lean principles, Value, Value Stream, Flow, Pull and Perfection. Conclusions and recommendations are as follows.

Leadership

In order to transform the enterprise to become lean, it must start with a commitment among all of the leaders. In product development, lean knowledge is sprinkled throughout the organization without an overriding force behind implementation. The first step of transformation is to persuade the highest levels in the company that a lean product development enterprise is necessary for future business success and make sure they know what is required and how to lead the change. The company has defined proper leadership behaviors although this research suggests that all behaviors are not necessarily carried out. Leadership can also immediately implement new behaviors and styles to start the momentum of lean. For example, making decisions with the people who deliver the outcome can foster new trust. Lean will not be

embraced by the product development community if it is an initiative that is suddenly announced with new metrics and mandatory training. The change will be more effective if it includes actions and communication from employees rather than introducing a dictated process. Also, leadership must not allow alteration of the current process such as timing compressions, blame finding and over-control. Shortcuts and naïve assumptions that derail the process have created a culture of accepting non-conformance. There is an opportunity to exemplify a newfound discipline with the new process release next year. Following the new process without deviation and without shadowing it with the old process will help adjust the behaviors and allow for the practice of lean principles. Leadership must fully embrace lean principles in order to rally for support within the enterprise. Their daily actions must also exemplify the expected process and behaviors of the employees.

Drive out Fear

Fear is rampant throughout the enterprise causing a host of lean inhibitors to worsen as it increases. While many interviewed and observed do not view themselves in a fearful situation, their response to management and actions for resolution clearly exhibit a fear of consequence. The consequences feared include appearance of ignorance, increase in workload, poor performance reviews and promotional blockades. The current management style which generates fear will not be successful in a lean enterprise. This is not to say that the current management will not be successful rather the current approach is not producing a response that is fitting for a lean environment due to the excessive amounts of waste from fear. Employees with 25+ years of experience remember the days when fear was not prevalent and many leaders were extremely approachable. Retrieving some of this history and using it to building a trusting relationship between leadership and employees will allow enormous gains in adopting lean principles.

Stick to Decisions

In order to properly define value, identify the value stream and allow for flow, it is imperative for leaders to make well-informed decisions and stick with them. Since the automotive process is a lengthy one, it is tempting for management to see a new opportunity pop up as the process is midstream. Soon, he/she is directing that a new item be implemented with compressed timing. This behavior leads to multiple changes, unknown failures and lack of trust. In lean enterprises, it is imperative for leadership to be capable and informed enough to make decisions once with minimal or no change later on. If leaders change positions, an agreement must be made to proceed with the previous decisions. Further, the decisions that are carried forward must be communicated to the entire team.

Communicate Reality

While it may be discouraging to hear about missed targets or failures within the enterprise, most individuals interviewed prefer to be informed about the real state of the company from company leadership rather than relying on the media articles that often generate unnecessary rumors. Rumors coupled with executive emails filled with perceived company successes create confusion as to the actual status of the enterprise. Communication must be truthful and accurate. Optimism is obviously required in order to overcome obstacles but, more importantly, the focus needs to be on what the enterprise is doing to remove lean inhibitors. The communication also needs to address cultural aspects of product development. Without addressing the "fat" behaviors and communicating examples, transitioning to lean will not be possible.

Sensei

The company typically begins a new process with training for the employees in product development. After several days of sitting in a large classroom listening to a speaker, it is assumed that each employee is ready to practice the new process. Further, the metric of

percentage of employees trained becomes the goal rather than how well the techniques are grasped. This, of course, is not an effective method when attempting to integrate lean into a large enterprise. It is recommended that a sensei, "coach" or "mentor" in Japanese, aid in the process. Multiple sensei will be required in order to cover the entire enterprise. It will be important for a sensei to pay special attention to the leadership behaviors and communication. Removing lean inhibitors such as heavy management, interference, fear, stress, unsuitable incentives and excessive workload will require thorough consideration of every decision and directive before it is communicated. Unlike many other new processes, management will need a complete understanding of how to transition to lean and fully embrace the principles as management behavior is the catalyst in changing enterprise culture.

Simplify

The automotive industry is extremely complex by nature. With this, there is no need to further complicate the system with duplication, reformatting, unnecessary metrics and other non value-added steps. All excess practices, processes and directives that do not abide by the lean principles must be shed from the enterprise. This action will require leadership to drive the simplification of the system. This includes discontinuing numerous colorful high-level presentations and the pre-meetings that take place to rehearse and soften the delivery. Also, the new front-loaded product development process is on the verge of being rolled out for implementation. There must be a committed effort to use only the one new process rather than shadowing it with the old process as a security blanket. Simplification is essential to success in a lean world and efforts must be made in every avenue of product development.

Respect for Discipline

The current process involves many adjustments to targets and changes to designs due to the relentless pursuit of cost reductions. Obviously, reducing cost is critical to the financial health of

the business but the system effects are likely producing more costs than are being saved. Multiple studies have shown that implementing lean principles can reduce waste by more than 50%. Much of this waste reduction results in cost reduction although it may not fall into the calculated purchase price of a component. Overall, it results in money that the company did not need to spend. By centering on discipline in the process and methods that engineering uses to develop new products, waste can begin to be filtered from the process. All programs must respect the timing as a fixed entity that doesn't assume that compression or delays will be acceptable. A strong foundation in discipline will enable cultural changes throughout the enterprise.

Make Use of Experience

Many new processes are developed in a separate department of people with various backgrounds. There are typically high numbers of agency employees at the working level and the management is rumored to be ousted from their previous positions due to previous poor results. While the rumors are usually unfounded, they often help create the misconceptions that get embedded into the culture. By utilizing the most experienced and respected stakeholders in developing process changes, real improvements can be generated. It will be important for these stakeholders to be part of cross-functional teams that work together to develop new processes and also spend time with engineers that are in-process to keep the hands-on mentality alive when developing a new process. Since many have lived through many "program of the month" initiatives along with numerous leadership changes, they are aware of what actions need to be taken in order for the concept to endure over the long haul. As the process gets implemented, these experienced personnel will need to lead the transfer of knowledge throughout the implementation and beyond.

Empowerment

Employees at lower levels in the enterprise consider their relationship with management to be similar to a parent-child relationship. This atmosphere is exemplified with pre-meetings for high-level events, approvals for everything from drive evaluations to travel and management speaking for the workforce on issues in their department. The current environment causes either severe frustration for employees that are driven to complete tasks in a timely manner or withdrawal from the scene allowing management to do the work. Many of the frustrated employees resort to withdrawal after several instances of experiencing the stress and disappointment. Management must not interfere with their employees work much less take over the tasks rather they should act as teachers and guide the employees towards optimum results. In order to encourage empowerment throughout the enterprise, employees must be well-placed in positions where they possess the skills required to thrive in the job while learning new tools and techniques including lean principles. Management must realize the benefits by eliminating pre-meetings that waste valuable resources, streamlining approval processes and going straight to the source of knowledge to learn of progress on key issues. Empowering all employees and stakeholders will strengthen the foundation of a lean enterprise and compel employees to internalize the change.

Long and Short-term Plans

The company has seen islands of success in practicing various lean principles in small localized areas. Growing lean throughout the product development enterprise and beyond is required to reap maximum benefits. Both long and short-term plans must be completed in order to progress the transition to lean. Short-term plans should aim for "low hanging fruit" type waste that can easily be removed from the system. This type of waste will likely be annoyance tasks that were required although provided little to no value. These tasks should be identified by

stakeholders at all levels of the organization coupled with communication that jobs will not be eliminated by the effort. During this phase, sharing the results, positive interactions and synergies that spotlight the successes of lean will drive strength into the transformation. This strength will be required to move the long-term plan into action. The long-term plan will include intense focus on the value stream for creating maps and careful consideration of the organizational structure in order to align people in a way that fosters lean behaviors.

Teach Lean

Most stakeholders have been introduced to lean through manufacturing examples and involvement throughout the enterprise. Lean is fairly new in product development and there are few who fully understand how it translates into a design environment that deals primarily with information exchanges multiple iterations. The product development lean principles, waste categorization and system effects from this thesis along with other lean tools must be taught throughout the enterprise in order to create a base knowledge that all stakeholders associate with. The teaching can be in a classroom but must extend beyond in order to gain hands-on experience soon afterwards. The learning will be continuous and should be discussed among teams on a regular basis. This will also aid in encouraging the transfer of knowledge and cross-functional awareness.

Lean Capability

Long-term capability to practice lean is essential to success. Past process linear mental models that believe training builds a reservoir of knowledge that is later applied to succeed in a new method will need to change. The system dynamics of building lean capability must be understood in order to stop the vicious cycles of firefighting and shortcutting in product development as discussed in Chapter 6. Understanding all of the cycles that enable growth and loss of lean capability and actively pursuing the proper cycles and flows will allow for the

system to become balanced and the ability to gear up the cycles that build lean capability. This system knowledge and response will generate the power to shift a culture towards lean behaviors.

Lean Metrics

There are numerous metrics that are tracked with new additions added on a frequent basis. Many of the metrics are measurements of micro-stages of a process allowing for management to over-control a program. This practice causes excess time to be wasted in the process by program management personnel that are relentlessly pursuing metrics rather than reasonably guiding a program. The integration of lean will require that all metrics be assessed for necessity. Any loose or non-value added metrics must be removed from the system. The new set of metrics will undoubtedly be much lower in quantity than the starting set. Also, future improvements should include reviews of metrics for further reductions and clarifications.

Cross-functional Teams

It is well-known throughout the enterprise that cross-functional teams are required to exchange information and negotiate trade-offs although the quality of interactions are simply not effective. In fact, in an internal root cause analysis study on 192 campaigns from October 1998 through February 2001 showed that 35% of all campaigns were caused by failed system interactions[53]. Clearly, cross-functional teams must be embraced throughout the enterprise and contain real interactive data and communication rather than a check-box verification of whether the team is conducting recurring meetings on a calendar. Also, whenever possible, co-location of the team members is preferred. Japanese companies use an "obeya" concept ("large room" in English) that utilizes a large space with a cross-functional team working in a continuous session rather than weekly meetings. They are able to shorten the product development cycle by having constant communication and quick feedback resulting in the achievement of optimum results.

Resources

The resources committed to chasing late failures and design changes are staggering in all calculations. Rework that is discovered in the middle and launch phases of a program can easily cost 100x to 1000x more than if it were found in the conceptual phase and 10x to 100x more than if it were found in the early development phase of product development. As previously discussed in Chapter 6, the enterprise currently sends up to a few hundred people to a launch site where Japanese counterparts send less than 20. The enterprise must recover these resources in order to properly execute the front-end of a program. With the onset of a new process in the near future that is front-loaded, it is critical that resources are available and dedicated to achieve success. Without this, the new process will struggle to meet its objectives.

Reorganization

Reorganization is part of the culture at this company. The enterprise expects a major reorganization announcement every two to three years that includes significant shifts in leadership. There is little warning other than rumors that jobs may be changed, moved or displaced. If one is lucky, their current position and department benefits from the new organization where others that aren't so fortunate undergo a complete dismantling of their current team and face the unknown. It is believed that the current organization of product development will require adjustment in order to efficiently practice lean principles but once completed, it is recommended to stop reorganizing. After the new organization gains a strong foothold, agreed fine-tuning in order to increase lean competence should be the only modifications permitted.

Incentives

Current incentives are more closely aligned to overall company financial performance rather than personal or team performance. If the company has a good year, profit-sharing dollars are allocated to all employees by level with a small percentage of it designated for discretionary

performance increases. In a bad financial year, the effects spread into multiple areas of misalignment. These areas include high workloads that demand overtime without pay due to a reduced number of contractual employees, lower levels of tools and resources to properly complete a job due to cost reductions and lower merit increases for everyone including the top performers due to a small allocation to the merit "pool". In order to motivate and encourage employees to practice lean principles, the incentives must be aligned to the behaviors and performance of the individuals and teams. Eliminating waste and creating lean products will consequently save money throughout the enterprise allowing for monetary incentives to be distributed to the "leanest" performers. In addition, it is important to assemble non-monetary incentives that strive to cultivate the desire to achieve lean.

Career Rewards

There has recently been a freeze on promotions from working level to the first rung of management throughout the organization for the past year and a half. This freeze has halted what has long been a popular method to climb up the ladder. Firefighting or high-exposure problem-solving has spotlighted employees for career enhancement opportunities. Management justifies these promotions by stating that those who deliver results will be promoted. The main difference between firefighting and delivering timely results is that the firefighter is involved with multiple levels of management and meetings that facilitate an environment to sell himself/herself as opposed to diligent employees that quietly meet the program requirements. When frustrated employees complain about the situation, they are often advised to seek out a position that offers opportunity for exposure. When the current promotional freeze is lifted, it is recommended that the promotion of firefighters be discontinued. The new reward system should promote those that have exhibited the knowledge of lean through effective practice and behaviors along with specific qualifications of the position.

Stop Checking the Box

Many well-intended processes, initiatives and metrics degrade into a box checking reporting exercise. Whether it is tied to performance reviews, required for milestone completion or intended to track responsibility, when the overriding importance is focused on percent completed rather than the quality of execution, it quickly turns into a "check the box" process. Anything that falls into this category should be removed from the process metrics. If it is deemed too important to be removed, then the uniqueness of the item should be captured by data. The enterprise must use caution in creating new data compilation in order to avoid creating unnecessary data checks. Workload must be taken into account along with the effects of the inadvertent data.

Management Drives

The management drive process step was shown to be a significant inhibitor in the middle and launch phase of product development. These drives are breeders of late design changes that can not be properly contained by the program. Of course, management is entitled to drive prototype and pre-production vehicles and ask questions to better understand the new vehicle although new direction must be carefully considered. The development engineers use mounds of data, benchmarking and experience to formulate the look, feel and comfort of a new product and a manager that may be familiar with a certain class of vehicle may not immediately distinguish the market needs and wants of the new product thus requiring changes. The management drives need to be discontinued or reduced in stature. If employees are to be empowered to use their expertise and experience to meet the target requirements of the program, then their decisions must be carried forward and not reversed by a single management drive. It is suggested that low-key drives with the development engineers be conducted in place of the current high-profile event.

Response to Waste

There are frequently new processes, proposals, formats and meetings that are implemented into daily routines in product development. Many of these new items cause workload to be increased due to the time required to complete. Often, the new items are a duplication or unnecessary expansion of parallel work or meetings although, for many reasons, the new items are not challenged on creating more waste in the system. Employees either work more hours to include the item in their routine, ignore it or weakly support the item until it loses momentum and eventually breaks down. This cultural response must be reversed in order to introduce a lean environment. New tasks or meetings that are wasteful must be dealt with immediately in a respectful manner. Stakeholders need to speak up and stop new waste from entering the system by using lean principles and behaviors to guide them in their justification. The interaction must not be accusatory or spiteful rather a reasonable discussion of how best to meet the requirements of the programs.

Lessons Learned

The current process utilizes the concept of lessons learned, a reflection on a program at various milestones, although it tends to lack proper feedback. New programs may attempt to review previous program metrics and issues but they often find that the past issues may not be relevant to the new program due to specific details of the problem. It is critical that the root cause of each lesson learned be identified in order to properly pinpoint the period of time and the action or decision that created the failure or behavior to occur. More importantly, clear communication of the lessons learned needs to be conveyed throughout the enterprise with a commitment to preventing a repeated situation.

In order to begin the transformation to lean, an enterprise must face the harsh reality that is deeply ingrained in the culture and processes within. In this study, a myriad of barriers and inhibitors to becoming lean were identified and discussed. The required change and resolution to lift each barrier will take time to accomplish although many can be broken down in a very short timeframe. The conclusions and recommendations have been provided for use to initiate the transformation and integration of lean into the product development enterprise. It is intended for teams of stakeholders to discuss their view of the current state of the enterprise and incorporate the recommendations that affect their area in order to begin the transformation process. Through use of the approach, analysis and conclusions, teams will be able to build their awareness of "fat" behaviors and processes to identify new inhibitors that may affect their locale. With this knowledge, proceeding to take deeper steps into the integration of lean can be achieved. By confronting the obstacles that prevent competitive standing in the automotive industry and embracing the product development lean principles, value can be specified through realization of a program's expectations and technical challenges within the allowed timing, the value stream can be identified with the proper cross-functional communication that produces seamless access to knowledge and data, flow will be ensured when knowledge and inputs are attained with proper timing and minimal change, pull will be achieved when timely and accurate response to needs is provided and striving for perfection can systematically identify and eliminate waste when developing new products. The success of a lean transformation requires all stakeholders to embrace the concept and work together to achieve real results. The benefits of lean integration are enormous and far-reaching. Beginning the process with an open mind and blame-free environment will allow for the eradication of unhealthy behaviors and practices and the implementation of waste-eliminating process and culture throughout the enterprise.

Chapter 8: Future Research

This thesis has studied the cultural and procedural inhibitors that may prohibit a successful lean transformation in automotive product development. All of the inhibitors highlighted have a unique effect on the lean principles. By understanding how an inhibitor acts on a particular lean principle or several lean principles, the enterprise can plan for correction and feedback to ensure the inhibitor is removed from the system. Proposed conclusions and recommendations were provided to present a host of changes that can be addressed and put into practice in the initial phase of a lean transformation. While conducting this research, there were several aspects of lean that were outside of the scope of this thesis although it is believed that the enterprise could further benefit from these actions through future investigation and implementation. The following items are a suggested list of potential future research.

Product Development Value Stream Mapping

Value Stream Mapping (VSM) is just beginning to be practiced in small areas of the product development enterprise although it requires much more effort in order to significantly progress the value stream principle. Studies that develop VSM and educate the enterprise on how to create, use and expand them would help facilitate progression of the tool to achieve efficiency in the process. Massachusetts Institute of Technology's (MIT) Lean Aerospace Initiative (LAI) is in the process of developing a "Product Development Value Stream Mapping (PDVSM)" manual to assist enterprises in creating and improving their value stream maps[54]. Upon final release of the manual, the enterprise should distribute the guideline to the stakeholders as a teaching tool. Case studies can also be conducted to gain knowledge of new discoveries that the manual may not contain.

Lean Enterprise Self Assessment Tool (LESAT)

MIT's Lean Aerospace Initiative has developed an assessment tool, LESAT, in order to understand an enterprise's present state of "leanness" and its readiness to change. Several portions of the data and analysis presented in this thesis have used the LESAT tool to extract the current process and cultural inhibitors. A full assessment including hands-on LESAT training would allow for a broader scope of change to be identified in order to better plan for lean transformation and integration. Exercises such as capability maturity models for enterprise leadership, life cycle processes and enabling infrastructure plans are developed by leadership levels with a facilitator guiding the process[55]. Studying the self-assessment of the enterprise can help expose new cultural and procedural inhibitors that must be addressed in order to achieve lean in product development and throughout the entire enterprise.

Extend the Enterprise

As product development transforms into a lean enterprise, other organizations and stakeholders should be included in the enterprise boundaries until the entire enterprise is involved. The sooner this occurs; lean can be allowed to grow at faster rates with larger benefits. Research that assists in incorporating organizational functions such as purchasing, manufacturing, marketing, sales and finance along with external stakeholders consisting of dealers, government agencies and suppliers to name a few will help the enterprise gain the knowledge and experience needed to succeed.

Develop a Unique System Dynamics Model of the Lean Transformation

The "Capability Trap" system dynamics model developed by Repenning and Sterman that was discussed in Chapters 5 and 6 provided insightful examples of how an organization can gain and lose lean capability over time if lean behaviors are not practiced. Research that develops a unique model of the enterprise and calculates estimated increases and decreases in lean

capability, performance, work pressure and other variables would allow for all stakeholders to relate to the cycles and be actively involved in pursuing the required changes to reverse the direction of the results when necessary. This model can include distinctive aspects of the enterprise including the inhibitors presented in this thesis. By further studying system effects of the lean transformation and building lean capability, a new understanding of how to adjust the system to benefit the enterprise can be recognized. The model and data could also be utilized to communicate results to high levels within the company.

Study the New Product Development Process

In 2005, a new product development process will be introduced to the enterprise that will allow for development cycles to be reduced by as many as 15 months. There are currently efforts to correlate the old process to the new process although this change will not be absorbed overnight. The new process depends on a cultural shift that includes lifting barriers like those presented in this thesis in order to cut time out of the cycle. This process should be tracked in order to quantify how the new process breaks down the process and cultural inhibitors and whether the inhibitors were truly eliminated or minimized. The on-going results should be communicated to all stakeholders in order to adjust the implementation and to provide improved value definition, value stream identification, information flow, pull response and incremental perfection.

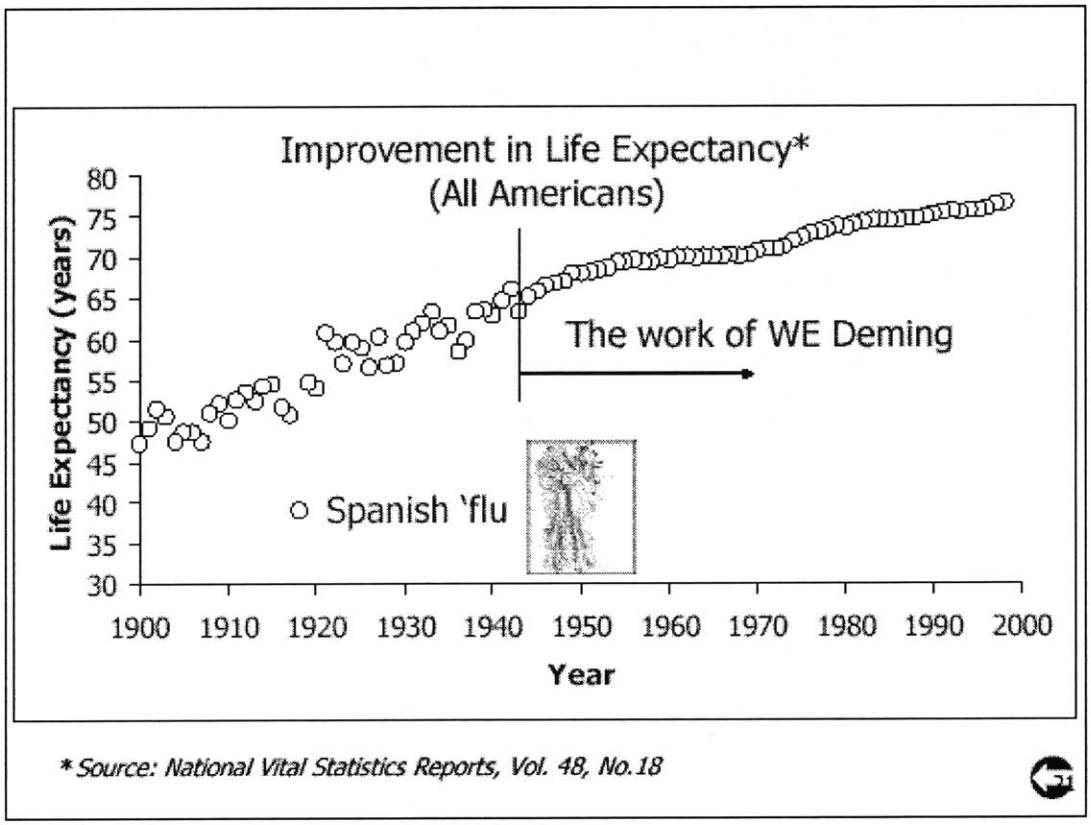
Perform Case Studies of Lean Integration to Foster Perfection

During the incorporation of lean, there will be numerous opportunities to study the efficiency and effectiveness of changes. By investigating these changes, lessons and techniques can be learned and communicated to teams that are beginning to formulate change and teams in-process of making changes. The research should also include benchmarking the cases with Japanese counterparts and other competition in order to reasonably quantify the progress and outcome of

each case. Further, these case studies can be used to illustrate an approach to achieve the lean principle, perfection, and encourage others to perform more analysis.

Appendix A

Example of W. E. Deming's Statistical Work with the Census Bureau after World War II:



Appendix B

Emiliani's consequences of fat behaviors:

"Fat" Behaviors Commonly found in the Workplace	
• Threats, real or implied	• Low trust
• Micromanagement	• Talk not walked
• Disappointing employee surveys	• Management secrets
• Few improvement suggestions	• Few rewards
• Employees stuck in functional area	• Ego-driven decisions
• Scarcity mentality / limited resources	• Department or functional focus
• Low turnout at meetings	• Unmet stakeholder needs
• Calls not returned	• Relentless pace
• Annoyed stakeholders	• Poor listening skills
• Slow response to changing conditions	• Broken promises
• Employee turnover	• Elitism
• Rumors	• Delays in action
• Transactional focus	• Confusion
• Crisis management	• Destructive politics
• Failure not tolerated	• Declining market share
• Unclear expectations	• Fear Ignorance
• Little or no feedback	• Blind obedience
• Appearance over substance	• Reduced loyalty
• Favoritism	• Mistakes repeated
• Many procedures	• Conflict

Emiliani's Comparison of behavior attributes:

"Fat" Behaviors	"Lean" Behaviors
Confusion	Self-awareness
Unnecessary commentary	Humility
Irrelevant Observations	Compassion
Random thoughts	Suspension
Self-imposed barriers	Deference
Ego	Calmness
Irrationality	Quietude
Revenge	Reflection
Inaction	Honesty
Positions	Benevolence
Interpretations	Consistency
Uncertainty	Generosity
Negativity	Patience
Excess	Humor
Gossip	Understanding
Sarcasm	Respect
Preoccupation	Listening
Ambiguity	Observation
Extreme flattery	Trust
Cynicism	Sincerity
Subjectivity	Equanimity
Bias / prejudice	Objectivity
Deception	Discipline
Selfishness	Rectitude
Pride	Wisdom
Criticism	Balance

Appendix C

Company Leadership Behaviors defined:

LEADERSHIP			
◊ ***Integrity*** *(Does the right thing)* • Exemplifies honesty and maintains trustworthiness • Keeps one's word despite the consequences • Exercises principled judgment, especially on the tough calls ◊ ***Courage*** *(Takes action in the face of challenge)* • Offers new ideas that question the status quo • Takes risks in championing better ideas • Demonstrates originality, independent judgment, and self confidence, even in stressful situations ◊ ***Durability*** *(Perseveres despite hardship)* • Maintains originality and creativity in staying the course to achieve agreed upon objectives • Shows tenacity and boldness in securing and using resources • Maintains inspiration, focus, intensity, and persistence, even under adversity	◊ ***People Development*** *(Teaches, develops and motivates people)* • Values and confidently promotes a diversity of new ideas and a diverse workforce • Acts to enhance the creativity and professional development of self and others • Treats everyone with fairness and respect regardless of position or social consequences ◊ ***Teamwork*** *(Collaborates to achieve results)* • Demands team-oriented behavior and insists on personal accountability for such behavior • Values team members with different ideas, points of view, and backgrounds • Acts to breaks down barriers and chimneys to innovative team ideas ◊ ***Communication*** *(Exchanges information and ideas that impact and influence others)* • Listens completely, and then confidently speaks up on the issues • Provides concise, compelling, innovative evidence to support positions • Demonstrates sensitivity to language and cultural communication requirements	◊ ***Desire to Serve*** *(Demonstrates personal commitment)* • Seeks new ways to ensure customer enthusiasm • Determined to achieve the objectives and act in company's best interests • Accepts willingly the challenge of different functional and geographical assignments ◊ ***Drive for Results*** *(Gets the job done)* • Develops challenging, innovative objectives and accepts personal responsibility for accomplishing them • Prioritizes resources, inspires performance and measures outcomes • Negotiates agreements that move the business forward ◊ ***Systemic Thinking*** *(Sees beyond the details)* • Thinks cross-functionally about ideas that impact the business • Boldly pursues ways to improve processes and incorporate new ideas • Inspires systemic change efforts that make a difference	◊ ***Business Acumen*** *(Understands the essential requirements of our business)* • Knows the global business operations and the global business context in which the company operates • Knows the basic business principles used to achieve quality, customer, and profit outcomes in a global environment • Demonstrates functional and technical proficiency ◊ ***Innovation*** *(Applies learning for competitive advantage)* • Demonstrates adaptability and flexibility in evaluating creative ideas • Applies lessons learned from successes as well as failures to inspire new ideas • Dares to dream about and implement new ways of doing business ◊ ***Quality Methods*** *(Understands what it takes to do quality work)* • Shows passion for achieving quality • Measures and monitors quality on an ongoing basis. • Demonstrates resolve for meeting customer quality requirements

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