Optimizing the Selection and Implementation of Assembly Line Equipment at a Large Automobile Original Equipment Manufacturer

by

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B.S. Ocean Engineering, United States Naval Academy 1995

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

Master of Business Administration
and
Master of Science in Ocean Systems Management

In conjunction with the Leaders for Manufacturing Program at the Massachusetts Institute of Technology June, 2005

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ABSTRACT

Toyota Motor Manufacturing North America (TMMNA) is continuing to face an increasingly competitive automobile market. To meet these evolving market conditions, TMMNA has experienced rapid growth in demand for its automobiles in North America. To meet this demand, Toyota has rapidly grown from three assembly plants in the mid-1990's to its current total of six assembly plants (five in operation with one being built). This has led to many management challenges, including communication, knowledge sharing, and knowledge retention that many companies experience when faced with rapid growth.

In order to respond to these challenges, Vehicle Production Engineering (VPE) Assembly, a department within TMMNA, has attempted to develop a process through which it can standardize its processes and capitalize on best practices across the many North American plants. This thesis studied the process through which VPE Assembly develops and installs assembly line equipment for major automobile model changes. This study included observation of the Toyota product development process and how this process is carried out within VPE Assembly.

This research revealed that the assembly line equipment process employed by Toyota is well suited for this organization. However, there are improvements available that could improve the overall process and bring automobiles models to the market more quickly. Communication between the different plants could be improved. Additionally, much knowledge learned from completed projects is not being shared fully between the various plants. Suggested improvements to address these problems are discussed.

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Table of Contents

List of Tables and Figures

Chapter 1. Thesis Overview

"To the uninitiated, discussions about the Toyota Way can sound like bad dialogue from *The Karate Kid.*" (Chandler, 2005)

1.1. Project Motivation

Toyota Motor Manufacturing North America (TMMNA) is continuing to face an increasingly competitive automobile market. Customer requirements for increased quality and reduced costs have continued to place pressure on all automobile manufacturers. Toyota has responded to these pressures by working to lead the automotive market in terms of value and providing features that the customer desires. Theses market conditions and Toyota's response have resulted in Toyota Motor Manufacturing North America experiencing rapid growth in demand for its automobiles in North America. To meet this demand, Toyota has rapidly grown from three assembly plants in the mid-1990's to its current total of six assembly plants (five in operation with one being built). This has led to many management challenges, including communication, knowledge sharing, and knowledge retention that many companies experience when faced with rapid growth.

To meet these new challenges, Toyota Motor Manufacturing North America defined several goals for its organization over the next few years. The first of these goals, greater self-reliance, involves less dependency on Toyota Motor Corporation (TMC) in Japan for support and direct leadership. As a part of Toyota's drive to increase its share of the global automotive market by 2010, Toyota's focus has been on expanding markets in Asia and Europe. This has resulted on less focus on more established markets including North America. This has created added emphasis on knowledge management and communication because TMC is no longer to serve as the conduit where all information in North America can be accumulated and subsequently disseminated.

Additional corporate goals include improved productivity throughout the organization and quicker response to evolving market conditions. Toyota is world renowned for the efficiency of its manufacturing plants using the Toyota Production System (TPS). The hope of Toyota is to use this knowledge and lessons learned by this process on the plant floor in the offices and administrative functions of the company. Each of these corporate goals greatly contributed to the creation of my project.

1.2. Project Setting and Goals

The primary challenge of this project was to standardize/streamline the project management process by developing a department shikumi (essentially an operating procedure or methodology for completing projects or tasks, a way of doing things) for assembly process planning, product verification, and equipment development and implementation. Developing a department shikumi provides value to Toyota Motor Manufacturing North America via the following:

1. Standardized methodology
2. Quicker decision making and lower costs
3. Improved visual management of project management processes
4. Improved productivity to both new and experienced engineers due to the creation of a standardized shikumi
5. Improved productivity of administrative and project management personnel monitoring and leading projects
6. Quicker response to evolving market conditions

In order to standardize a best practice method of carrying out production engineering processes for either new model changes or equipment modifications, this project focused on the selection and implementation of assembly line equipment. This process is a portion of the product development process. To study this process, a Design Structure Matrix (DSM) analysis of the entire equipment development process was conducted. Additionally, process mapping was used to define the interactions and processes involved in selecting and installing assembly equipment in support of a new model launch. Other aspects of the production engineering process including project planning, seibi, cost tracking, safety tracking, quality tracking, and periodic reports were observed and in some cases scheduled for follow on investigation. Training was provided on using the DSM process to analyze these other aspects in order to determine the effects of changes to the process and to determine where Toyota should focus follow-on improvement plans.

1.3. Executive Summary of Results

1.3.1. Problem/Challenge

The problem was fairly clear; Toyota needed to leverage the best practices of each North American facility in order for its growth in North America to continue. Toyota Motor Manufacturing North America could no longer depend on assistance from the Toyota Motor Corporation and had to leverage the best practices of its facilities. Communication between the many existing and new plants was not efficient. Knowledge was likely being lost due to changes in the historical methods by which knowledge was collected and disseminated. The challenge was determining how exactly to overcome each of these problems and how to implement these changes in this organization. Much of this thesis deals with the research process that was carried out, the tools that were utilized, and how challenging it is to implement a change process within an organization.

1.3.2. Approach/Method

I utilized several methods including Interviewing, Benchmarking, Data Analysis, Process Mapping, and Design Structure Matrix (DSM) analysis to characterize problems and processes. I found that both Process Mapping and Design Structure Matrix analysis were particularly useful in outlining the complex process that Vehicle Production Engineering Assembly carried out. Both of these analysis tools proved to be effective methods of outlining and understanding the equipment selection and development process. DSM was very useful as a tool to standardize a best practice method of carrying out production engineering process changes. Additional aspects of the production engineering process including project planning, seibi, cost tracking, safety tracking, quality tracking, and periodic reports were also investigated in order to get a complete picture of the assembly equipment selection process.

1.3.3. Results/Solution

The results of this internship and thesis were two key contributions. First, this project developed a model for a coherent VPE assembly line equipment development process and a method for experimenting with process improvements. This process, called a shikumi, is essentially a way of doing things. Its format allows for the standardization of a process, identifying how the process should be carried out. The key to this project was to ensure that the shikumi was fairly brief so that it can be easily understood, communicated, and remembered by Toyota team members. The associated Design Structure Matrix Model provides several simulated improvements, which, if implemented, could result in a 30% reduction in the lead time for assembly line equipment selection process.

The second contribution to Toyota Motor Manufacturing North America was the opportunity to thoroughly study the VPE Assembly process. This study reveals several weaknesses and strengths in TMMNA's approach to organization and capability development. Several key managers and engineers thoroughly understood their portions of the process but few understood their individual impact on the overall process. Most VPE personnel understood that the push for greater self-reliance meant that changes were likely to occur. Few understood the impact on communication and knowledge management that this change caused. Several managers knew that they needed to change to standardize and improve their processes to continue to improve productivity but didn't know how to do it. This study has laid the foundation for a possible way that VPE Assembly could approach this change initiative as they proceed with the continued evolution of their department shikumi. This thesis also provides several suggestions for how to improve the process in the future.

While this study was conducted at Toyota Motor Manufacturing North America, the lessons learned are applicable to many companies in numerous different industries. An example of this is a large shipbuilding project where design, planning, and execution are closely linked. Similarly, the Design Structure Matrix and associated model could be adapted to better optimize these types of projects. All in all, the lessons learned through this internship and project can be easily applied to many different industries.

1.3.4. Conclusions/Key Lessons Learned

During this project, I learned several important lessons. Among these are:

1. Communication is extremely vital for any organization. It becomes even more critical for a learning organization.
2. It is vital to thoroughly understand the issues of every stakeholder within a process before proposing any changes.
3. When implementing a change initiative it is critical that you involve the correct people within the organization to embrace and take ownership of the change.
4. A learning organization often has large amounts of hidden knowledge based on experience. This creates natural hurdles for new personnel to learn and slows the pace at which an organization can grow quickly.
5. It is human nature to initially disregard possible solutions from other entities if the drawbacks of the current process are not clearly understood. People can only accept change once they discover the shortcoming of their current process or product.

1.4. Overview of the Thesis Chapters

The thesis is broken down into the following chapters:

Chapter 2 provides a general overview of Toyota Motor Manufacturing North America.

Chapter 3 discusses the organizational structure and culture of Toyota Motor Manufacturing North America

Chapter 4 provides a review of selected product development related literature and a review of observations that I witnessed at Toyota

Chapter 5 outlines the shikumi initiative process and steps taken to implement it.

Chapter 6 examines the implications of the shikumi process

Chapter 7 provides summary and final recommendations.

1.5. Thesis Overview and Summary

This chapter provided a basic overview of this research project and thesis. It outlines the project motivation, the goals that were set, and the results of this project. Further, project methodology is introduced and lessons learned are outlined. All of this sets the stage for further discussion in the following chapters. The next chapter provides a general overview of Toyota Motor Manufacturing North America and its operations there.

Chapter 2. Overview of Toyota Motor Manufacturing North America

2.1. A Short History of Toyota Motor Corporation

From its beginning in the late 1800's, when Sakichi Toyoda began to experiment and produce manual weaving looms to the modern worldwide automotive giant of present day, the history of Toyota has been an interesting story of great successes and challenges. This history has been well documented in several books and papers. Two books provide a very through and succinct discussion of the history of Toyota. These books, The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer by Jeffrey Liker and The Evolution of a Manufacturing System at Toyota by Takahiro Fujimoto provide a great background in Toyota's successes and challenges throughout its history.

2.2. Toyota in North America

Very broadly speaking, Toyota's operations in North America are divided into three separate organizations:

Toyota Motor Sales (TMS): responsible for the marketing, sales forecasting, and sales of Toyota automobiles. This organization serves as the conduit through which Toyota directly interacts with its customers. In general, both Toyota Motor Manufacturing and Toyota Technical Center regard Toyota Motor Sales as their primary customer.

Toyota Technical Center, USA, (TTC): responsible for product development, product engineering, styling and design. An increasing number of these functions are carried out at the two facilities in North America located in Ann Arbor, Michigan and Torrance, California. Nonetheless, the vast majority of the design functions continue to be carried out by Toyota Motor Corporation in Japan. This organization uses market research provided by Toyota Motor Sales to develop automobile products that will meet the public's product demands.

Toyota Motor Manufacturing North America (TMMNA): this organization includes all organizations outlined below in section 2.3. This organization is responsible for the manufacturing processes and production of automobiles. A further discussion of TMMNA follows.

2.3. Toyota Motor Manufacturing North America

2.3.1. Toyota's Manufacturing Operations in North America

Toyota Motor Manufacturing has developed rapidly in North America over the last two decades. Toyota founded its first North American manufacturing venture, New United Motor Manufacturing, Incorporated (NUMMI) in 1984 as a joint venture with the General Motors Corporation[1]. Following the success of this venture, Toyota founded Toyota Motor Manufacturing Kentucky (TMMK) in 1986 as its first wholly owned manufacturing plant in the United States. Rapid growth of Toyota's North American market share has led to the development of new manufacturing plants in Canada (TMMC, 1986), Indiana (TMMI, 1996), Mexico (TMMBC, 2002) and Texas (TMMTX, 2003). All told, Toyota currently operates five (including NUMMI) car and truck assembly plants in North America with one plant currently under construction:

Table 2-1: Toyota Manufacturing Plants in North America

Name of Plant	Location
Toyota Motor Manufacturing Kentucky (TMMK)	USA
Toyota Motor Manufacturing Canada (TMMC)	Canada
Toyota Motor Manufacturing Indiana (TMMI)	USA
Toyota Motor Manufacturing Baja California (TMMBC)	Mexico

[1] Due to the joint nature of ownership between the General Motors Corporation and Toyota, New United Motor Manufacturing was not included in much of the analysis conducted in this thesis. Indeed, due to the special nature of its ownership and operation, it is often not considered a true Toyota plant by employees. While it is occasionally used and referenced during improvement projects, the wholly-owned Toyota manufacturing plants are usually utilized.

New United Motor Manufacturing (NUMMI)	USA
Toyota Motor Manufacturing Texas (TMMTX)	USA (under construction)[2]

Additionally, Toyota currently operates seven engine and parts plants in North America (Bodine Aluminum operates three separate plants):

Table 2-2: Toyota Engine and Parts Plants in North America

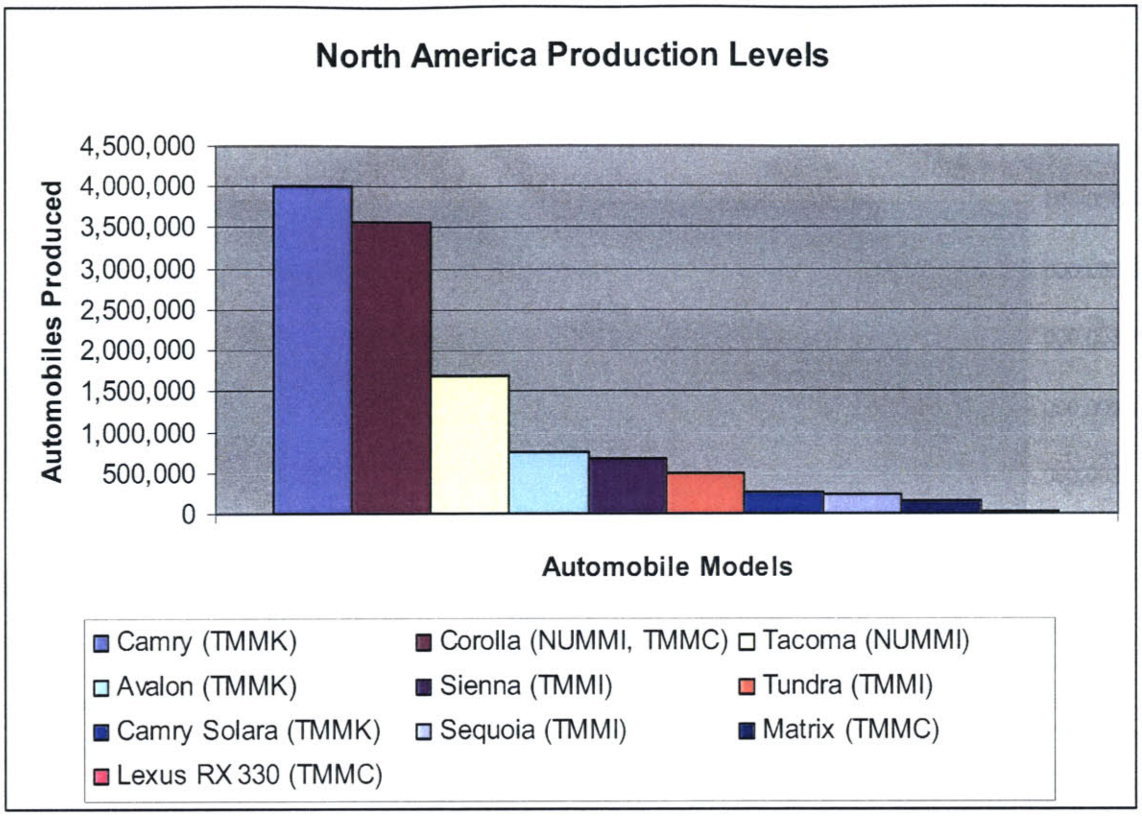
Name of Plant	Location
Toyota Motor Manufacturing Alabama (TMMAL)	USA
Toyota Motor Manufacturing West Virginia (TMMWV)	USA
Canadian Autoparts Toyota, Inc. (CAPTIN)	Canada
Bodine Aluminum, Incorporated (BODINE)	USA
TABC, Inc. (TABC)	USA

2.3.2. Toyota Automobiles Produced in North America

Toyota currently produces ten automobile models in North America. Those current models are outlined in Figure 2-1 below.

[2] Of interest is an article in The Wall Street Journal on February 22, 2005 by Norihiko Shirouzu indicating that Toyota Motor Corporation is likely to add two more North American assembly plants by 2010. This expansion will continue to expand the importance of Toyota's operations in North America.

Figure 2-1: Toyota Automobile Models Produced in North America[3]

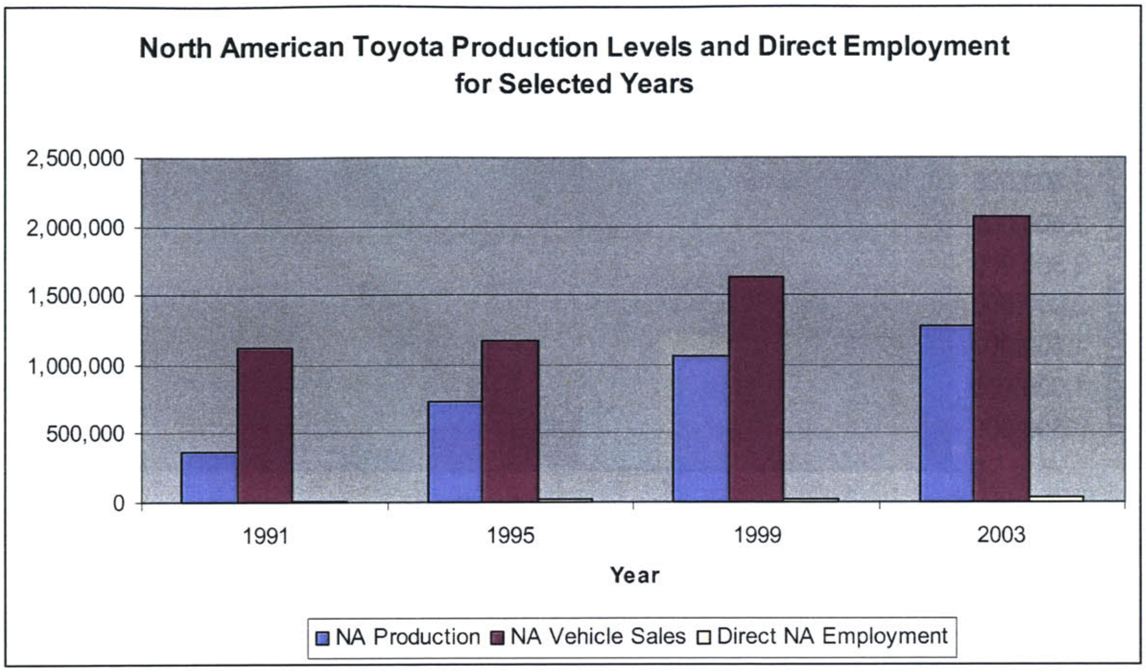


2.3.3. Toyota Employment in North America

Toyota production levels and direct employment in North America have increased steadily over the past decade. North American production levels and direct employment in comparison to North American vehicle sales are provided in Figure 2-2.

[3] Information obtained from the Toyota website, www.toyota.com.

Figure 2-2: North American Toyota Production Levels and Direct Employment for Selected Years[4]



These production and employment figures demonstrate Toyota's commitment to produce automobiles in the market where they intend to sell those automobiles. While still many of the automobiles sold in the North American automobile market are produced outside North America, this number is decreasing steadily. This further demonstrates TMC's desire for TMMNA to achieve greater self-reliance and less dependency on TMC for support.

2.3.4. Toyota's Development of Manufacturing Plants in Japan[5]

Toyota built its manufacturing plants around a central geographic area in Japan. Nearly all plants are centered near Toyota City. While knowledge sharing and communication would be fairly easy due to the close geographic grouping of the plants near Toyota City, the plants did not often interact with each other, choosing to keep best practices in house.

[4] Information obtained from the Toyota website, www.toyota.com.

[5] Information in this section is the result of numerous interviews and discussions with a wide variety of individuals both within Toyota and outside the organization.

It was generally fairly easy for personnel to move from one plant to another and to carry their best practices to a new facility. The information that they carried between different sites was fairly limited and piece meal. Despite their proximity, each Japanese production facility developed and evolved over time to be extremely unique using processes that were best fitted for their unique circumstances. Proximity knowledge sharing ensured that the overarching best practices were shared but each plant created its own unique culture.

2.3.5. Toyota's Development of Manufacturing Plants in North America[6]

When Toyota developed new North American facilities, particularly the car and truck assembly plants, they often used existing plants in Japan as the model for the new plants. Essentially, Toyota would select a plant in Japan and use it as the blueprint for the plant in North America. This including copying nearly everything about the plant, including physical size, layout, and even manufacturing processes. This process allowed Toyota to develop a new plant based on an existing plant which was producing at a high level.

While this initially was very successful, as Toyota's operations grew in North America this process resulted in plants in North America that were dissimilar. The North American plants closely mirrored their Japanese sister plants but were unique compared to each other. This development has resulted in different manufacturing sites utilizing different project management and manufacturing processes. When assistance or guidance was required, the plants would turn to Toyota Motor Corporation and their sister plants for guidance. The sharing of best practices between the different North American plants did not occur. Although personnel did occasionally move between different sites, it was not nearly as often as in Japan due to the larger geographic spread of the plants. Toyota's decision to use a "copy exact" method of plant development for expansion in North American resulted in a process where North American plants did not

[6] Information in this section is the result of numerous interviews and discussions with a wide variety of individuals both within Toyota and outside the organization.

generally share information with each other. Instead they looked to TMC for help and guidance.

This process continued until Toyota Motor Manufacturing North America (TMMNA) was established in 1996 as the manufacturing headquarters for North America. The establishment of Toyota Motor Manufacturing North America consolidated many of the administrative and production support functions into one central facility. This also resulted in a central focal point for all operations. With less support and assistance coming from Toyota Motor Corporation, TMMNA has become the focal point for the collection and distribution of best practices in all areas of manufacturing operations in North America. Unfortunately the processes to collect and disseminate this information are not well developed at this time.

2.4. The Focus on Manufacturing

At the core of Toyota Motor Manufacturing North America is its focus on manufacturing. Throughout the organization, the focus of all personnel is to support manufacturing operations at each of the manufacturing plants. This common focus works to unite the entire organization and greatly aids in the decision making process.

2.5. The Language of Toyota

This focus on manufacturing has led to a very unique culture based on a common language used by employees throughout the company. Indeed, the processes and language used at the TMMK plant is certainly similar to the observations laid out by Researchers Steven Spears and H. Kent Bowen in their paper *Decoding the DNA of the Toyota Production System*. Repeatedly, I experienced events where I was asked to present information. The basis for these discussions always centered on the processes that many of us learned while studying the scientific method. Initially, team members are told to go to the source (Genchi-Genbutsu) to find out for themselves what the baseline is. This allows team members to determine what the current status is and see the problem for themselves. The next step involves collecting facts, not data, concerning the problem to be analyzed. Personnel are then told to look at the problem and propose possible countermeasures, a hypothesis, to respond to this problem. They then test their hypothesis using scientific controls. After this test, if a hypothesis is found to respond well to a problem, it is accepted as a countermeasure. However, it is never considered a total solution and will continually be reviewed to see if a more effective countermeasure exists.

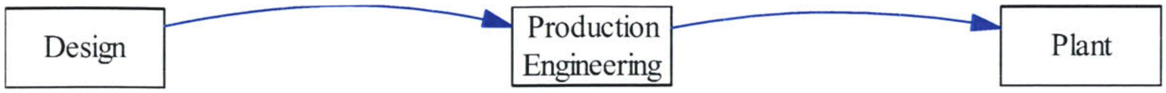
While this description seems very formal, many of the discussions in the plant were not this rigid. However, everyone in the plant, from the plant manager to team members on the line, used this way of thinking as a basis for professional discussions. It effectively gave everyone a common language to discuss problems, putting everyone on the same sheet of music and contributing to strengthening the feeling of teamwork in the plant.

2.6. Toyota Product Design Process

Prior to the production of a new car model, initial planning to design a new automobile must be completed. This process involves considerable work to research, design and develop a new vehicle. Market analysis must determine what attributes customers desire and then transfer this information to designers to develop new automobile model designs. Designers use this market research to develop new ideas.

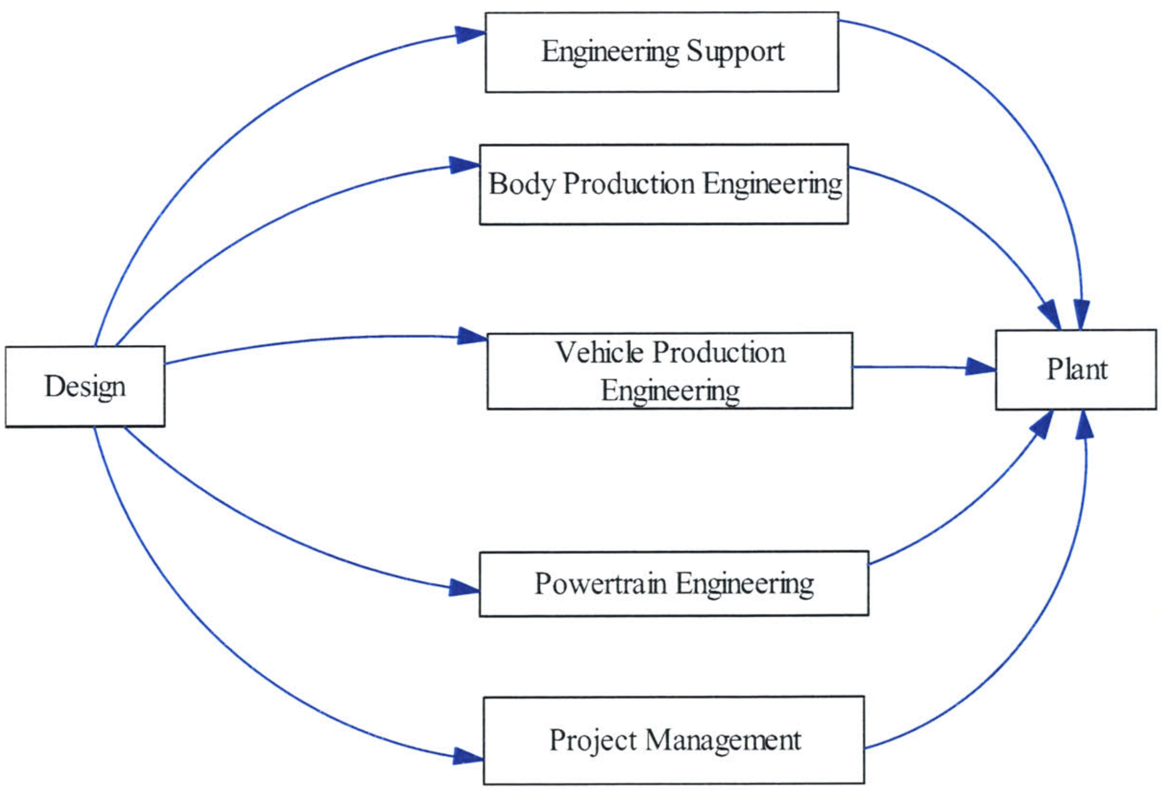
Like many other organizations in numerous industries, the basic product design process is relatively simple in the automobile industry. A design entity develops the new product and its characteristics. It then hands these plans over to a second group which further develops them to the point where production is ready to occur. Once the product is ready to be produced, the manufacturing plant takes the plans and carries out the day-to-day production of the new product. Figure 2-3 below outlines this very basic product development process.

Figure 2-3: Basic Product Design Process



During my experience at Toyota Motor Manufacturing North America, I was assigned to the middle entity above, Production Engineering. As you may suspect with a complicated product such as an automobile, there are several departments within Production Engineering which are responsible for developing the new model proposed by design. Among these departments are Engineering Support, Body Production Engineering, Vehicle Production Engineering, Powertrain Engineering, and Project Management. Figure 2-4 demonstrates these many departments.

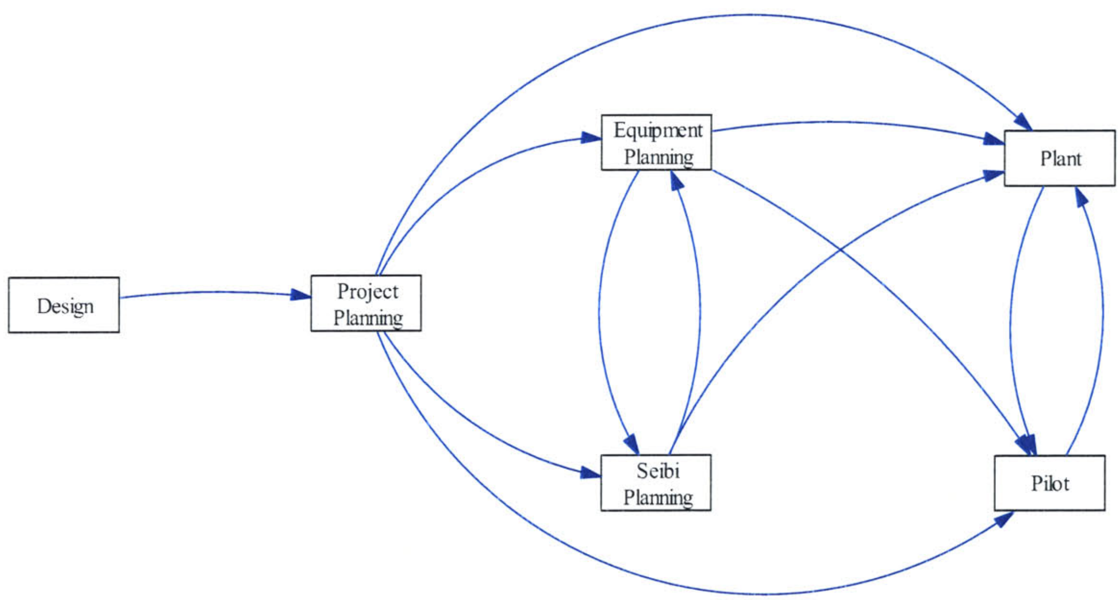
Figure 2-4: Production Engineering Departments



This project focused on group within the Vehicle Production Engineering (VPE) department. Vehicle Production Engineering is primarily concerned with assembly changes necessary to produce a new or modified automobile downstream of the design personnel. Vehicle Production Engineering plans and carries out all changes necessary to manufacturing equipment that must be completed prior to production of the new model. This involves modifying machines and patterns on the factory floor to produce both new and existing automobile models.

Breaking this process down even further, this project focused on a section within the Vehicle Production Engineering department called Assembly Equipment. This section included three groups, Project Planning, Equipment Planning, and Seibi Planning. Assembly Equipment is responsible for the selection and implementation of assembly line equipment to produce the new automobile model. Figure 2-5 outlines these three groups and their interaction with other stakeholders in the product design process.

Figure 2-5: Vehicle Production Engineering Assembly Groups



While the three groups interact with each other fairly closely, they each have specific responsibilities in the assembly line equipment selection and implementation process. Project planning is the first group to receive the new designs from the design team. They look at the design plans and study the proposed plant and assembly line where the new model is intended to be produced. This group studies the new models and determines if changes will be necessary to the assembly line in order to both make the new automobile and also any other automobile that is currently being produced on that assembly line. They determine if assembly line equipment will need to be moved in order to meet takt time requirements. They will work with the plant to implement any improvements recommended by plant kaizen teams into new assembly line equipment or processes. They will also look at existing equipment and determine if new equipment must be purchased to either replace existing equipment or to perform new processes.

Once project planning has completed their initial studies, the designs are then turned over to the two remaining groups, equipment planning and seibi planning, who work together to complete the rest of this process. The equipment planning group looks at the equipment plans and uses this information to prepare detailed specifications concerning the new equipment that needs to be developed. They work with suppliers to understand these specifications and aid them in developing the new equipment. Along with TMMNA Purchasing, they negotiate with the suppliers for equipment costs. They also work with suppliers to determine what specifications the equipment must meet and the testing plan to ensure that the equipment meets these requirements. Finally, they work with these suppliers to install and test the new equipment.

Seibi planning works very closely with equipment planning in this process. This group possesses very good trouble shooting skills. They are the group that can make certain the equipment will work in reality. Their technical skills are used to determine and correct any problems with the equipment. They also work very closely with suppliers during the equipment testing process. Perhaps most importantly, Seibi planning tracks and ensures all problems are resolved as the equipment is installed and tested prior to turnover to the plant.

Another stakeholder in the assembly equipment selection and implementation process is the plant pilot group. This group is made up of plant team members on usually a three year rotation. They are selected based on assembly line performance and are responsible to create and modify the standardized procedures that the plant will use for the new model. This group trains manufacturing team members who work on the assembly lines to assemble the automobiles. Pilot works very closely with all three groups within Assembly Equipment during the launch of a new vehicle model.

Once the assembly line equipment has been modified to accommodate the new automobile, initial testing is completed to ensure that both the new and existing models can indeed be produced on the assembly line. This is completed via the production of several series of trial vehicles. The production of the trial vehicles is closely monitored to determine any possible quality or production problems. Automobiles are monitored by representatives from throughout the product development process. This is important so that any problems can be documented and corrected in future model developments. This entire process is very time consuming but necessary to ensure that adequate quality and production metrics can be met.

2.7. Toyota Motor Manufacturing North America Overview and Summary

This chapter provided a basic overview of Toyota's operations in North America. This included a review of Toyota's history in North America, where specifically in North America it has developed its operations, and what automobiles it produces there. Toyota's focus on manufacturing and the unique language that has developed are also reviewed. This chapter also includes an overview of the product development process that Toyota carries out. This information is provided to help better understand the parameters under which this project was developed and conducted. This context is necessary when evaluating both the successes and failures of this project. The next chapter outlines the organizational structure and culture of Toyota in North America and provides further context for this project.

Chapter 3. The Organizational Structure and Culture of Toyota Motor Manufacturing North America

3.1. Formal Organizational Structure

Before discussing the culture at Toyota, it is helpful to look at the organizational structure the Vehicle Production Engineering Assembly operated in. Vehicle Production Engineering, as well as most other corporate functions, is located in Erlanger, Kentucky at Toyota Motor Manufacturing North America.[7] Toyota Motor Manufacturing North America performs these corporate functions for all of the North American factories. These corporate functions include divisions such as:

- Quality
- Production Control
- Supplier Commodity Engineering
- Corporate Strategy
- Corporate Affairs
- Human Resources
- Information Systems
- Accounting and Finance
- Purchasing
- Production Engineering

Vehicle Production Engineering is one of several departments in the Production Engineering division. Other departments included in Production Engineering include:

- Body Production Engineering
- Powertrain (Production) Engineering

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[7] TMMNA is located in Erlanger, Kentucky near the Cincinnati (Ohio)/Northern Kentucky International Airport. While the author was technically assigned to Vehicle Production Engineering Assembly which was technically based in Erlanger, the author spent the majority of his time researching at the various North American manufacturing plants. The vast majority of this time was spent at the Georgetown, Kentucky plant which is approximately 60 miles south of Erlanger.

Engineering Support

Project Management

These divisions and departments are managed in a hierarchical manner with linkages between various divisions occurring at senior management levels. Issues can generally be resolved at lower management levels if members of two different divisions or departments have a personal relationship with each other. Generally, this is much more likely to occur between different departments where personnel are often collocated and often working on common issues. Otherwise, issues are often resolved at higher management levels.

3.2. Historical Perspective

3.2.1. Strategic Design

Since a good deal of this project focuses on a strategic initiative to organize a central organizational group that works at separate production facilities, let us begin with an examination of the strategic lens.

From a strategic standpoint, Toyota faces significant challenges due to its strategic design. In the late 1980's and early 1990's, only two solely owned Toyota plants (TMMK and TMMC) were operating in North America. These two plants were the only plants in their respective countries and enjoyed great autonomy. When problems did arise, they each worked through their respective sister plants in Japan to get assistance and guidance. The two plants were heavily supported by Japanese team members who worked to transfer the principles of both the Toyota Production System and the Toyota Way to their new plants in North America.

These plants were fairly well established and "set in their ways" by the time that TMMNA was created. Both plants considered themselves "Toyota" in their respective countries.

"We were Toyota long before TMMNA was created, and we will continue to be the focal point of Toyota in North America"

TMMK team member

Both plants are somewhat cautious of the creation of TMMNA and the additional challenges it supplies to them. They miss the autonomy that they had enjoyed prior to the creation of TMMNA.

Toyota Corporation decided that the rapid development of new plants in North America necessitated the development of an entity to directly oversee these operations. TMMNA was created in 1996 as the manufacturing headquarters responsible for overseeing all manufacturing facilities. TMMNA consolidated many of the administrative functions that had previously been located at each of the individual plants (purchasing, production control, accounting, human resources, production engineering, etc.). All in all, TMMNA became a focal point for the control of Toyota's plants in North America.

The creation of TMMNA has caused many challenges for the plants that it manages, particularly TMMK. In the late 80's and early 90's, TMMK had a mission to bring the principles and processes of the Toyota Production System to one single plant in North America. Their success or failure would determine the direction that the Toyota Corporation would follow in North America from that point forward and likely determine if further plants would be built. This challenge created great stress but united the personnel at TMMK in an "us against the world" mentality. This greatly united the team members at the plant, a feeling that still exists to some extent today.

The creation of new plants in North America and TMMNA as a managing entity has taken away a great deal of TMMK's mission. No longer are they the only plant in North America. No longer is their success a focal point for Toyota's plans in North America. This loss of responsibility and opportunity has led to a relationship with the other plants and TMMNA that can difficult. Similar to individual plants in other large organizations, TMMK enjoys its level of independence and likely will resist any changes to their level of autonomy. The following table provides a timeline with the year each of these plants were built as well as the year that TMMNA was started:

Table 3-1: North American Toyota Production Levels for Selected Years

Name of Plant	Year Built
Toyota Motor Manufacturing Kentucky (TMMK) (USA)	1986
Toyota Motor Manufacturing Canada (TMMC) (Canada)	1986
Toyota Motor Manufacturing North America (TMMNA) (USA)	1996
Toyota Motor Manufacturing Indiana (TMMI) (USA)	1996
Toyota Motor Manufacturing Baja California (TMMBC) (Mexico)	2002
Toyota Motor Manufacturing Texas (TMMTX) (USA)	2003

In a way, the manner in which Toyota created TMMK has caused much of its feelings of independence. The plant was developed in Kentucky with personnel with little or no automotive industry experience. The Japanese advisors assigned there in large numbers spent tireless hours transferring what is now called the Toyota Way to the workers in Kentucky. This entire process led to a strong feeling of autonomy and loyalty to Toyota by TMMK and its workers. The creation of TMMNA and the new plants is perceived as taking away this autonomy and has resulted in TMMK resisting these changes to some degree.

3.2.2. Project Development and Fit with Strategic Design

In many ways, this project revolved around the tactical implementation of a strategic process. The group that I worked with primarily, Vehicle Production Engineering Assembly, was extremely busy throughout my time there with the implementation of the new Avalon model. While I originally believed that this was a temporary challenge, I soon learned that they are generally always busy with some model change. Due to the numerous models being produced in North America and the continual updating of at least one or more of these, this group was perpetually involved in working to launch a new vehicle.

This fact caused a great deal of difficulty with my project. Because the personnel involved were continually dealing with the tactical implementation of a new vehicle, they had little time to think strategically about how they operated. Because the performance of these personnel is graded and rewarded based on how well they bring a new vehicle to market, there was very little incentive for most personnel to make changes to the existing system. While many agreed that the shikumi may bring about improvements, most were unwilling to assist because they neither had time nor the incentive to work on this.

From a strategic lens perspective, this project fit very well with the needs of Toyota as a whole. Due to their rapid growth, maintaining knowledge and learning from different projects was becoming more and more important. Toyota had no formal mechanism to capture this knowledge and ensure that it was shared with everyone within the organization. However, due to the intense workload the Vehicle Production Engineering Assembly faced on a day to day basis, this project did not fit very well with their needs. While it did work to meet the primary goal (make our jobs easier on a day to day basis) it did not provide immediate benefits.

3.3. Stakeholder Analysis

The politics of the shikumi process are split across the three functional subgroups within VPE Assembly and the geographic subgroups of the different manufacturing facilities. I observed moderate political tension between the equipment planning group (the well established portion in North America) and the two newer functional sub-groups of VPE Assembly, Seibi Planning and Project Planning. Because of the relative size of these political subgroups[8], implementing a standardized shikumi procedure for all groups that consider themselves distinct and have different ways of doing business required significant energy and surfaced some tension between these groups. Employees generally had a strong allegiance to their respective functional sub-group. This allegiance is exacerbated by the fact that the three groups are evaluated on different metrics.

[8] During this project, the project planning group consisted of 10 employees, the equipment group 14 employees, and the seibi planning group 4 employees.

Although the following is a gross simplification, it is generally true that the project planning group is responsible for the initial planning and investigation of new or modified equipment and is evaluated on its ability to complete this information by a prescribed time (this requirement is currently not strictly enforced due to the recent establishment of this group as a North American entity and its inexperience working independently of TMC intervention). The equipment group is largely responsible of completing further investigation work into new equipment, determining viable suppliers, and working with TMMNA Purchasing to negotiate contracts that will allow completion of the installation of the new/modified equipment within budgetary constraints and time requirements. Finally, the Seibi Planning group is held responsible in many instances for the actual installation of new/modified equipment (the Equipment Group is sometimes responsible for this for equipment that is not assigned to the Seibi Planning group) and is evaluated by its ability to complete a project on time. These metrics are not always aligned and can lead to political tension between the groups. Generally, completing a project by the prescribed time requirements is the primary performance metric. However, cost is closely monitored and project managers (working in the Equipment Group) are strongly measured by their ability to bring projects in significantly under budgeted costs. These two strong competing metrics often lead to trade-offs between the three groups.

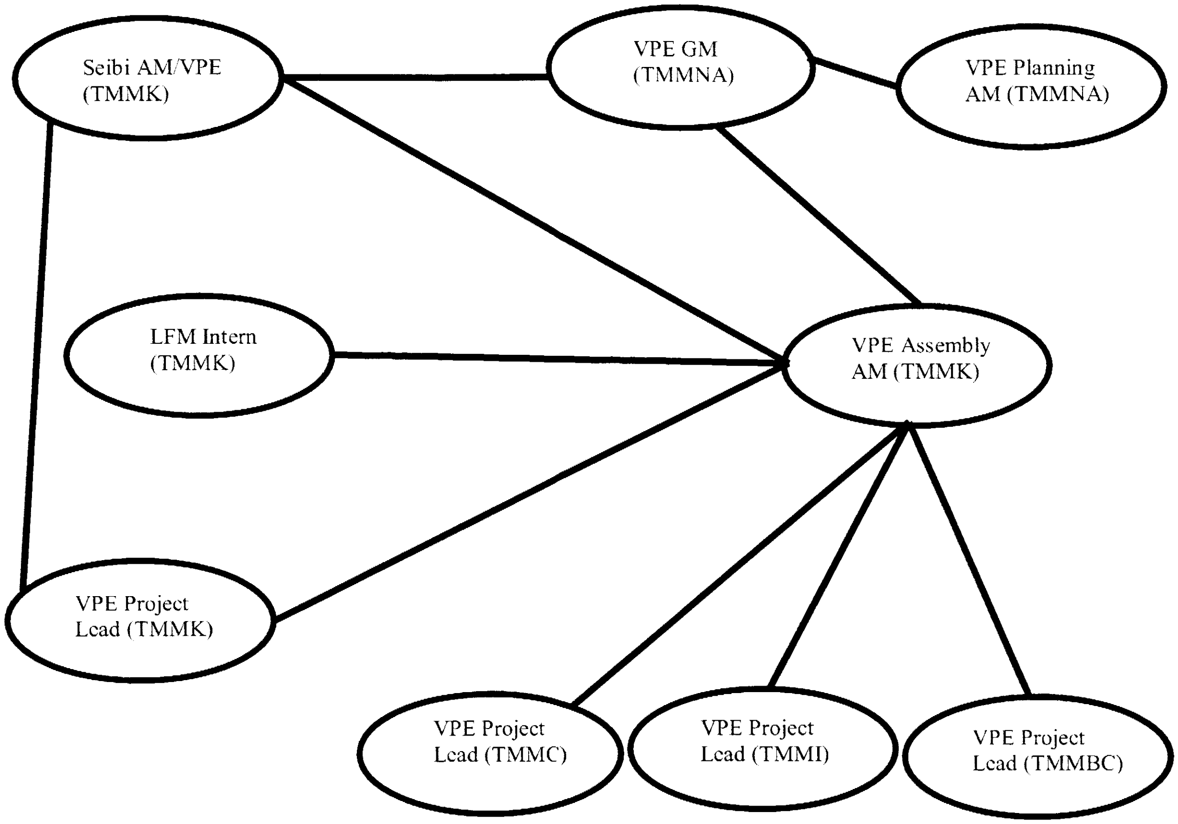
In addition to the functional subgroup distinctions, I also observed a strong geographical distinction at VPE Assembly. Specifically, employees tended to perceive important differences between the different manufacturing plants and to identify themselves as a member of the specific plant versus a member of TMMNA.

I also observed a strong use of personal networks within VPE Assembly. Specifically, some employees tended to be more powerful from a political perspective in relation to other employees. Generally, the more senior a person was the more power they wielded within the network. Toyota personnel respected personnel who had demonstrated proven performance over a period of years. Toyota's use of teams throughout the organization enhanced this network building. Team members grew to trust each other over time. As team members exhibited good team work and performance, they gradually took a more powerful position within the team.

In addition to experience, some employees gained political power due to their personal network skills. These personnel were better, for whatever reason, at gaining the respect and assistance of a large network. Often this included developing alliances with personnel on other teams or groups. They were able to draw upon this network to help them to get work accomplished. These often informal political networks were very present everywhere that I visited within Toyota. As a general rule, the best managers I observed were also the best capable of understanding the networks that they dealt with and used them to their advantage.

To assist my project, I developed a map of the key stakeholders at Vehicle Production Engineering Assembly. The development of this map was a learning process of its own; the map changed greatly over time as I observed more and more interactions within the group. This map was useful in assisting how to approach challenges to this project. It allowed me to understand who the key players were in the group. Using this information made it much easier to make recommendations and implement changes. Gaining approval or acceptance of key stakeholders in this greatly aided implementing changes. The final version of my stakeholder map is provided below.

Figure 3-1: Vehicle Production Engineering Assembly Stakeholder Map



There had been a history of other similar projects within Vehicle Production Engineering Assembly. This caused many members to be skeptical of this project and any improvements that it might provide. These previous projects generally were unsuccessful because they did not heavily involve the team members at each plant in the creation of the new documents. The fact that these previous projects had failed made developing a standardized shikumi that achieves TMMNA's best interests as well as the interests of each political group a significant challenge that required a great deal of time and persistence. More importantly, the present project would most likely have achieved greater success if team members were in charge of writing the shikumi vice bringing in an outsider to carry out the project.

3.4. Cultural Analysis

Toyota is perhaps best known for its development of the Toyota Production System. This lean production system stresses the use of standardized work and the development of best practices to complete production. In many ways, the development of a standardized shikumi fits very well with the principles of the Toyota Production System. A shikumi provides a method for standardizing the processes carried out by different teams and plants. It also provides a central point where improvements can be discussed and documented. In many ways, a shikumi is a natural migration of the Toyota Production System to more administrative and support functions.

It can be effectively argued that the culture of Toyota is the real key to its success in the automobile industry. This culture, termed the Toyota Way, is really more a way of thinking rather than a way of doing. It stresses problem solving and going to the source to find the facts of a problem. It greatly values experience. The Toyota Way "has its own vocabulary, and practitioners advance through formal gradations of enlightenment." (Chandler, 2005) As such, many of the leaders within the North American plants have worked their way up through the ranks, gaining experience and responsibility along the way.

Similar to the "Copy Exactly" method for plant construction and development utilized by Intel, Toyota has carried out a variant of this process. However, contrary to Intel's practice of creating a new plant that exactly mirrors existing plants, Toyota instead creates new plants in North America that are structured to mirror existing plants in Japan. These Japanese plants are considered sister plants to the new plants and serve as models for how to set up the new plant. This model is not used for equipment or manufacturing processes, rather it is a transfer of the culture or Toyota Way to the new plant. The sister plants are essentially guiding the new plants in how they should do things and not necessarily giving them the plans to their equipment or plant set-up.[9]

[9] Information in this section is the result of numerous interviews and discussions with a wide variety of individuals both within Toyota and outside the organization.

The interesting challenge that this creates is illustrated by the fact that standardization among Japanese plants generally does not occur formally. Each plant operates as a stand-alone organization responsible for optimizing operations within it field of influence. Sharing of best practices is not formally structured. Instead, this occurs through the transfer of personnel from one plant to other plants. This method of transferring best practices is made possible due the relatively short distance between each plant facilitating the movement of personnel between plants. Due to the sheer geographic distances between North American plants, this method of sharing information and best practices is not practical.

TMMK possessed a difficult culture to break into as an outsider. Relationships are very valuable here; it often matters more who you know than what you do. Effectiveness at TMMK is significantly improved if a person has a large social network across various functional groups. This greatly improves a person's ability to get work completed.

Finally TMMK team members were very tight with their work time. Consistently, I was told that workers were too busy to speak to me. A culture of "fire fighting" exudes throughout TMMK, as team members always seem to be tackling the problem of the day. Overall, they were not greatly interested in supporting any project that did not help them with the problems and challenges that they were facing on a daily basis today. This led to proportionally very little interaction with team members considering that this was the site where I spent the vast majority of my time at Toyota.

3.5. Cultural Evaluation and Recommendation

Given the observations provided concerning the culture at Toyota Motor Manufacturing North America, the only viable method for successful creation of a department shikumi is to leverage characteristics of the existing culture to push along the process. It can be argued that Toyota's culture is as much, or possibly even more, responsible for the success of the organization than the much more heralded Toyota Production System. Given this fact, it is not only impractical but also not prudent to attempt to alter the culture at Toyota in order to implement a shikumi. Rather, the focus should be on using the characteristics of Toyota's culture to assist the development and implementation of the shikumi. This can be done by outlining the necessity for finding best practices at other manufacturing sites. Once all team members understand that assistance from TMC will not be available as it has in the past, the necessity to seek out solutions among the North American manufacturing sites will be clear.

I believe that the challenge of creating standardized procedures for Toyota's North American operations is primarily cultural. Toyota's method of plant development has led to many of the cultural differences between the many plants. This method of transferring best practices via word of mouth between plants is not possible in North America due to the greater distances involved. The transfer of personnel between manufacturing sites does not occur as freely. While some middle and upper management personnel as well as some aspects of TMMNA departments will move to different facilities during their careers, the general work force, those most responsible for creating and implementing improvements to the manufacturing systems, does not transfer among the various sites. This fact creates a stagnation of best practices and facilitated the desire of Toyota to develop a method to document and transfer best practices among the various sites.

In many ways, the manner in which Toyota has developed has created "local perspective" throughout its North American operations. Personnel were initially hired into local plants and worked for many years created their own culture and operations. While this culture was heavily influenced by the Japanese advisors, the workers at the Kentucky plant knew each other well and developed a very effective working relationship over the years. At the same time, Toyota was experiencing great success in North America and the employees at TMMK rightly believed that they were directly responsible for this success. This has created a "local perspective" of the world and has resulted in TMMK "pushing back" to some extent against ideas and recommendations from TMMNA.

I think that it is very important for Toyota to create a more "global perspective" in its plants in North America. These plants need to learn to work more closely with each other to share best practices and methods. It is important for Toyota to identify personnel with this "global perspective" who also have the strategic, political, or cultural power to implement these changes. Most of the personnel within these plants have grown to look inside for solutions. Personnel with a global perspective are necessary to identify those best practices from outside and bring them in for implementation. The Toyota Corporation appears to recognize this and is making great strides to cultivate leaders with this global perspective within it North American operations.

Finally, when implementing any change at Toyota on a global scale, it is very important to take into account the cultural differences between the varied plants and the individual problems and challenges that they are facing. Many discussions with TMMK team members were worthwhile and provided insight. However, most team members commented that unless the project would help them with the daily jobs immediately, they likely would not support such projects. Indeed, while the development of the shikumi allows for improved sharing of best practices and further collaboration, it does not directly meet the individual needs of the plants. This will likely continue to lead to natural tension between global and local priorities (Klein and Barrett, 2001) as this and similar projects move forward.

3.6. Summary of the Organizational Structure and Culture of TMMNA and Its Impact on this Project

This chapter provided an overview of the organizational structure and culture at TMMNA and the challenges they presented. The analysis of the various stakeholders and their involvement in the project as well as the history of Toyota in North America provide an important backdrop for this project. Each of these topics had a direct effect on this project and provided unique and interesting insights into the inner workings of Toyota. Understanding how Toyota carries out its operations was perhaps the most difficult part of this project. At the same time, it also provided perhaps the most interesting topics that I studied. The next chapter outlines the books and academic works that were reviewed to provide a knowledge base for this project and important insights gathered from them.

Chapter 4. Automobile Product Development Academic Review and Observations at Toyota Motor Manufacturing North America

This project dealt greatly with improvement initiatives for a portion of Toyota's product development process. Steve Eppinger and Karl Ulrich define product development in their book Product Design and Development as "the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product." This definition provides interesting insight into the wide variety of tasks that go into the product development process. This definition served as a basis for my study of Toyota's product development process and provided a roadmap to the many stakeholders who should (and in most cases do) have an important role in this process. This chapter develops an academic review of the automobile product design process and provides a baseline for comparison of the observed process at Toyota.

4.1. Product Development at General Motors

One of the best descriptions of automobile industry in it early days was Alfred Sloan's book entitled My Years with General Motors written in 1963. In this book, Sloan gives an interesting overview of the automobile industry and General Motor's growth to an industry leading position. The book covers a wide array of automobile industry aspects but the portions concerning product development were most interesting for this project. According to Sloan, generally two years are required from the first decisions to build a new model to the time when the car shows up at the dealerships. The process of developing a new automobile model has three general phases. The first year revolves around basic engineering and styling while engineering design is carried out over the entire two year period. Finally, production and tooling dominates the final year as the processes required to produce the car are developed. Engineering work revolves around either the actual product or on the processes required to make it. Styling and engineering define the automobile and its characteristics while manufacturing is responsible for developing a process to actually make the product. This process involved a great deal of actual car models and prototypes. Until fairly recently, this process was the benchmark for automobile product development and has remained fairly intact over the years.

4.2. Product Development in the Automotive Industry

4.2.1. The Machine that Changed the World

For additional information of the automotive industry, The Machine that Changed the World written by Womack, Jones, and Roos offers an insightful comparison of the entire industry. This includes numerous comparisons of traditional mass production firms and modern lean production firms. While many areas of this book were useful for this project, perhaps the most interesting was the comparison of the product development processes. In general, the design process at a mass production firm is sequential. After a component is developed, a supplier is approached with the component drawings and asked to make a bid. Bids are generally compared most strongly on cost with the winning bid often being the lowest bid. With all suppliers constantly in a price based bidding competition, they are reluctant to share thoughts on how to improve a product.

At a lean production firm, the lean producer selects all necessary suppliers at the beginning of the project. Suppliers are generally not selected strictly on bids but more so on past performance with the manufacturer. Because suppliers generally have expertise in one component and do not compete directly with other suppliers, they take a larger responsibility in designing and building components that meet performance and quality specifications and sharing best practices. Component pricing is set via a process of developing a target price. According to Womack, Jones, and Roos, "This target price is developed with the lean assembler who establishes a target price for the car or truck and then, with the suppliers, works backward, figuring how the vehicle can be made for this price, while allowing a reasonable profit for both the assembler and the suppliers. In other words, it is a "market price minus" system rather than a "supplier cost plus" system."

This process appeared to be especially true at Toyota based on my personal observation. Vehicle Production Engineering Assembly generally worked with a relatively small group of suppliers on all projects. This group's membership remains generally constant over several projects with few suppliers entering or exiting. By far the most important selection criterion is the supplier's ability to meet the design specifications and time requirements of the project. A supplier's performance on previous projects was often enough to ensure their selection for the current project. Suppliers are provided with design information very early in the process and challenged to come up with a design or process that will meet design specifications.

The process of bidding for projects is also very similar to the process outlined in The Machine that Changed the World. The project budget for assembly equipment development is provided to VPE Assembly by the project manager. Management in this group attempts to develop a detailed budget for the new equipment based on the amount of changes to equipment, the complexity of those changes, and finally the past bids provided by their suppliers. Throughout the bidding process, suppliers generally come forward with several different bid options. These generally include several options ranging from a high-priced option (exceeds design requirements) to a low-priced option (meets basic needs). Based on these bids and their associated price, VPE Assembly team members work with suppliers to select the appropriate option to build the new equipment. The process is a fairly free exchange of ideas and requirements. This would not likely be possible if not for the trust that the two sides have developed over several years of projects. To borrow from Economic Game Theory principles, both sides understand that their relationship is a repeated game and therefore do not try to take advantage of this process.

4.2.2. Product Development in the World Auto Industry

In their paper entitled "Product Development in the World Auto Industry," Clark, Chew, and Fujimoto provide an interesting study of the product development processes at Japanese, U.S., and European automakers. This paper found that there are significant productivity differences in the product development processes of these three geographic areas. Of significant interest, they found that Japanese companies generally completed their projects in two-thirds of the time and with much fewer engineering man-hours than non-Japanese projects. This advantage resulted in Japanese firms completing their projects as much as 18 months prior to their competitors. Clark, Chew, and Fujimoto's paper attempts to define the reasons for these differences and found two particular reasons which are of interest to this thesis:

1. The use of a "heavyweight project manager" to head up the entire project. "The project manager is not only a coordinator but a concept champion with direct responsibility for all aspects of the project." The research found that a management structure headed up by a heavyweight project manager had a significant advantage over other structures employed by U.S. and European automakers. In fact, their research found that "the heavyweight group had an advantage of 9 months over the lightweight group, which in turn was 8.5 months faster than the functional projects."
2. The dependence on the competency of trusted outside suppliers. "The Japanese firms appeared to draw on a set of suppliers whose capability created an advantage in both engineering hours and lead time." The Japanese automakers allowed their suppliers to become experts for the technology that they were supplying to the product development process. These suppliers better understand their technology and as such continue to develop improvements that can be brought into future projects. This results in further improvements in the product development process. The research completed by Clark, Chew, and Fujimoto indicated that this supplier relationship resulted in "about 30-40 percent of the Japanese advantage."

As demonstrated earlier, the advantage that Toyota realizes from their supplier relationships is definitely real and effective. During this project, I had the opportunity to work with an equipment supplier to Toyota. This company had worked with several of Toyota's North American plants on different projects. Throughout the observed interactions between the supplier and VPE Assembly, the mutual trust between the two parties was clearly evident. Both sides worked through multiple options for equipment and processes. Both sides were extremely forthcoming in their concerns and capabilities. This exchange was contrary to what I had expected to see and is likely unique in the automotive industry for the most part. The competency of the engineering supplier was certainly an advantage for Toyota that they take advantage of throughout their organization.

4.3. Product Development at Toyota

4.3.1. Principles from Toyota's Set-Based Concurrent Engineering Process

In their paper entitled "Principles from Toyota's Set-Based Concurrent Engineering Process," Sobek and Ward offer an insightful look at Toyota's product development process. This paper provides many interesting insights in this process. Among the most interesting are the following.

1. Set-Based Concurrent Engineering employs a process where multiple designs are explored in parallel. Eventually, the process gradually narrows the multiple solutions down to one best solution. In effect, this process works to identify and resolve issues early in the process avoiding rework and frustration later.
2. Engineering checklists are used to document lessons learned on previous projects and programs. These checklists are essentially a history of what can and has been done.
3. US automobile product design processes make decisions early in the process and employ "hard points" which are "essential to avoid confusion among styling, body engineering, and manufacturing engineering." On the contrary, Toyota employs a process where "minimum constraints" are employed to allow many degrees of freedom for the various groups working on a new model. By avoiding tight numerical specifications, Toyota allows each group great freedom to explore alternatives to come up with the model change that is deemed most attractive to the end customer.

4. Toyota "pursues a potentially high pay-off, but risky solution, along with a back-up solution it knows will work." Rather than selecting a radical change and then discovering late in the design process that it is unfeasible, Toyota ensures that it always has a design that can be produced to meet its quality and cost constraints.
5. Communication concerning the design process is extremely important. Different groups working at different sites must be aware of the work and decisions being made by other stakeholders in the process.

Sobek and Ward firmly believe that Toyota's Set-Based Concurrent Engineering offers great advantages to Toyota's product design process including robustness, reduced development cycles, and standardization that allow Toyota to bring products to the market more quickly.

This process appeared to be especially true at Toyota based on this research. The design process carried out by Vehicle Production Engineering Assembly often resulted in assembly equipment having to be able to accommodate different equipment characteristics or options. Specifications or definite characteristics were often hard to pin down early in the process. Where possible, Vehicle Production Engineering Assembly team members delayed portions of their process hoping that additional specifications or project granularity would appear. These decisions often were made very late in the equipment selection process. I believe that this was a direct result of Toyota's desire to pursue multiple design alternatives and defer their selection as late in the process as possible.

This process also had a significant effect on Toyota suppliers and required that they be extremely flexible. Indeed, the delay in definite specifications and characteristics placed pressure on Vehicle Production Engineering Assembly and also the suppliers that work with them. Those suppliers that understand that these delays are a part of the Toyota new vehicle development process and are able to adapt to this process are successful. Toyota ensures that communication with suppliers is good to ensure they understand the process.

Additionally, Toyota rewards suppliers that accept this system by working with them on future projects. Suppliers to Toyota need to be extremely flexible due to this new vehicle development process.

Vehicle Production Engineering Assembly team members made great use of checklists to document project or processes problems. These checklists were called punchlists and were extremely useful during the current process providing for a quick and easy reference to see what items are performing outside of standards or are delaying the project. These checklists provide a very easy-to-understand metric that management can quickly review to determine project status. These checklists allow management to determine what areas are potential problem areas and allow them to determine where management attention or manpower may be necessary.

These checklists are also very useful during the process of project reflection. At the completion of every project, all team members involved in the project are asked to reflect and document those aspects of the project that worked well and those that did not. These checklists provide an extremely useful document that team members can use to complete their reflection. These reflection documents combined with the checklists provide documentation of what has occurred during past projects that can be used during future projects.

Concerning the fifth point taken from Sobek and Ward above, I did not observe effective communication between the different personnel involved in the process. Generally, communication between Vehicle Production Engineering Assembly, the plant pilot teams, and plant manufacturing appeared to be very good. However, communication within portions of Vehicle Production Engineering Assembly and the upstream design entities appeared to be very poor. As mentioned earlier, project specifications often are extremely vague and not finalized until very late in the process. However, when either Vehicle Production Engineering Assembly or plant manufacturing needed to clarify a specification to ensure that the project could be completed on time, they often did not know who they should contact to get that information. Information often was pushed to them without them knowing where it came from. While Toyota is best known for its pull system used in the Toyota Production System, it appears to utilize a push system for information during the product design process.

Additionally, the lack of a standard process to be used by each project at each plant created communication problems. Individual teams did often discuss their project status but this did not generally go beyond an informal discussion without written documentation. While checklists and reflection reports existed, access to them by other plant teams was difficult. These checklists and reflection reports often existed on individuals' computers or in their files where access by others was not possible. One of the big goals of the shikumi development process was to provide a central area where these documents can be collected and reviewed by team members at each site. This would provide the greatest opportunity for learning from projects by all team members within Toyota.

4.3.2. Thoughts from "Clockspeed"

In his book entitled Clockspeed, Fine provides an interesting look at evolving business strategy based on his research of numerous companies worldwide. Of particular interest to this thesis are observations concerning Toyota. He presents one interesting story concerning the problems that Toyota experienced when starting up production of the Camry and Avalon at the Georgetown, Kentucky plant. Fine attributes many of these problems to the growth of Toyota and communication. "Because the Toyota system is built on dense communication links across the entire supply network, adding more nodes for each development step exponentially increased the number of communication channels used. This added complexity of global 3-DCE (Three-dimensional concurrent engineering) has led to a more complex overall process."

Also of interest is Fine's discussion of product development as a company evolves from a small to a large company and the problems this evolution presents.

> "In a small company, everyone on the product development team can meet regularly in the same room. "Can we manufacture this product?" is a question that team members could raise informally, and they could thrash through many of the production issues in an afternoon. As the company grows and expands its production lines, product and process developers move to different departments, different buildings, and even different continents. Geographical distance is one challenge to overcome, but more important is the need for more formal approaches to reconcile design-for-product performance with the realities of manufacturability."

Fine appears to attribute communication to be one of the biggest challenges that organizations face today. In the instance outlined above, communication challenges are possibly magnified by the global growth of an organization.

The thoughts presented by Fine in Clockspeed rang very true during my time at Toyota Motor Manufacturing North America. Employees at Toyota spoke often of how much easier many of their processes were when the Georgetown plant was the only Toyota manufacturing plant.[10] They often lamented that the expansion of more plants has made it much more difficult to carry out projects. Where in the past, all interested parties would either be located within the Georgetown plant or in Japan, now there are process stakeholders at numerous plants, technical centers, TMMNA, and in Japan. This growth has greatly complicated communication. Decisions take longer to be made and often team members are unsure who they should be working with or getting approval from. Communication continues to be stellar within the plant, but communication outside the plant is difficult at best. Knowledge management is also very good within the plant due to limited movement by personnel between plants. However, knowledge management between the many plants can be difficult. These communication and knowledge

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[10] Most Toyota employees did not refer to NUMMI as a "true" Toyota plant. Indeed, I observed that many personnel regarded NUMMI as a special case. It was rarely discussed and interaction was similar to an automotive market competitor.

management problems in North America can directly be associated with the rapid growth of Toyota facilities.

Many people within Toyota observed these problems and recognized that action is necessary to overcome them. Indeed, I believe that a significant driver behind the shikumi development projects at Toyota is desire to overcome increases in distance through improved processes and uses of new information technology. The shikumi format gives a standardized format and a system for information sharing. The use of video conferencing to link up different groups is becoming more commonplace. While still not as effective as a face to face meeting, the use of email to ask and respond to questions is becoming more common. Toyota's hope is that these improvements in processes and information technology can help them to overcome the challenges associated with geographic growth.

4.4. Academic Review Summary and Impact on this Project

The observations provided in each of these books and academic works provided much of the baseline knowledge for this project at Toyota. Each provided unique and interesting insights into both the automobile industry and its product design processes. This provided valuable insight into the automobile industry and allowed someone coming in from outside the organization to understand the industry quickly. These insights often provided the baseline to frame and analyze observations for this project. They also provided background information helpful in determining what areas should be tackled and possible methods for addressing them. In this chapter I have attempted to list the references that were used and important insights gathered from them. Where applicable, I have attempted to contrast or build on these insights based on my time at Toyota Motor Manufacturing North America. The next chapter outlines the process that I carried out in developing the Vehicle Production Engineering Assembly shikumi.

Chapter 5. The Shikumi Initiative

5.1. Overview of the Shikumi Initiative Project

The primary goal of this project was to find a way to standardize/streamline the project management process for the Vehicle Production Engineering Assembly group. The hope was that this process would aid the continued development of a centralized method to control assembly line equipment selection across all the Toyota plants in North America. Among the benefits of a centralized approach is "that the standardization of critical operating decisions may improve communication and coordination across the network." (Hayes, Pisano, Upton, and Wheelwright, 2005) Further, a centralized approach can: (Hayes, Pisano, Upton, and Wheelwright, 2005)

1. Achieve a critical mass of technical talent in order to stay on the cutting edge of process technology changes. This is likely to be particularly true when process technologies are complex systems requiring large, multidisciplinary teams.
2. Eliminate redundant development efforts across sites, and facilitate communication and coordination with outside suppliers of technology and equipment.
3. Extract the cumulative experiences of multiple operating units more efficiently. This may enable a company to exploit learning curve economies and improve process performance better than any one unit could have done on its own. A centralized group also can achieve economies in transferring the same technology across multiple sites.
4. Act as a conduit for ensuring the best practices are shared across dispersed operating units.
5. Enable the implementation of standardized process technologies across multiple units.

Vehicle Production Engineering Assembly, as a function of TMMNA, has continued to work toward being the central focal point for assembly equipment issues. Achieving this centralized control and finding ways to improve communication and knowledge management within the group became a primary focus of this project.

The desired outcome of this process was to develop a department shikumi and make recommendations to streamline the process. While it proved difficult to find a simple translation for the word shikumi, through a series of interviews with personnel throughout Toyota Motor Manufacturing North America I developed a working definition. Based on these interviews, a shikumi is essentially an operating procedure or methodology for completing projects or tasks. More simply, a shikumi is a way of doing things and is used to define/describe how this particular process is carried out. I was given great latitude in how I went about creating this shikumi. I started by looking at existing academic works concerning the automobile product development process in order to attempt to get an overview of the process (this research is outlined in chapter 4). Following this review, I developed a plan of action to develop the Vehicle Production Engineering Assembly group shikumi. This process included the following basic steps:

1. Internal Benchmarking
2. Process Mapping
3. Design Structure Matrix Modeling including stakeholder interviews
4. Nemiwashi (Consensus Building)
5. DSM Analysis and Process Simulation
6. Development of a Standardized Shikumi Document

An important issue to be examined is exactly what it means to have a standardized process. This is a challenging and difficult question to answer. Through my numerous discussions, many people told me what they thought a shikumi was, but generally they had great difficulty exactly describing what the shikumi should be. Numerous different people with VPE Assembly had differing views on what the shikumi should say, and more broadly if standardizing the process was a good idea. These differing views often focused on what level of detail the shikumi should go into, and how much value would be added if such a project were undertaken. Due to the self-reliance of each manufacturing plant, trying to achieve any significant level of consensus between the numerous plants was a daunting task.

Throughout this process, the goal was to better understand the entire process and then make recommendations that would allow Toyota to better utilize their product development system. The fact that Toyota's North American operations only recently began controlling a significant portion of the product development process required that background research be completed to understand the process before making recommendations. The goal of this process was to attempt to develop guiding principles or thoughts and not to develop a detailed procedure for carrying the product development process. The hope was to develop a basic overall map, allowing the individual team members to develop the finer details of the road map. The chapter outlines the process that I carried out in developing the Vehicle Production Engineering Shikumi and some lessons learned along the way.

5.2. Shikumi Benchmarking

5.2.1. Benchmarking at Toyota

As Toyota continues to foresee an increased management focus on newly developing markets such as China, India, Russia and Western Europe, they have realized that North American operations will need to be more self-sufficient. Prior to the creation of TMMNA, the desire to benchmark other operations at Toyota in North America was relatively new and is not well practiced throughout Toyota. Toyota middle management was (and continues to be) extremely busy with day-to-day operations and did not have time to sit back and review those practices that have been successful or unsuccessful at other manufacturing sites.

The creation of TMMNA combined with the desire for more self-reliance led to a push for increased benchmarking of not only North American sites but also organizations in other manufacturing sectors. A great deal of the benchmarking activities and documenting is assigned to designated personnel not actively involved in daily operations. While this is a reasonable method in that these personnel become very effective at identifying best practices of both internal and external subjects, much information is lost by not having the personnel who would actually carry out any recommendations (project leaders) actually doing the benchmarking studies. Indeed, Toyota's principle of Genchi Genbutsu (go to the source to find the facts to make correct decisions) seems to imply that the project leaders should be the personnel involved in the benchmarking studies.

As mentioned earlier in this paper, Toyota uses a language based very heavily on the scientific method. They do not believe in solutions, which indicate that a problem is completely solved. Rather, they look for countermeasures that can be implemented to overcome a problem but also can be reviewed and improved if conditions dictate. This thinking was also prevalent in the manner in which Toyota carried out benchmarking. They stressed that they never were looking for absolute best practice. Rather, they were looking for the best methods, practices, etc. that currently existed. They also stressed that these best practices may not always be the best way of carrying out operations and would constantly need to be reviewed and kaizened.

5.2.2. Internal Shikumi Benchmarking

The process of developing departmental shikumis has existed in North America for a few years. Several other departments within Vehicle Production Engineering, including Power Train and Body Weld, have been working on shikumis for their respective departments. These departments have made great progress towards developing their respective shikumis and documenting how they do things.

I started my research by speaking to team members, including management and individuals actually responsible for shikumi development, in both Power Train and Body Weld. These personnel were given responsibility for developing their department shikumi as a collateral duty in addition to their normal roles carrying out the very processes that they were improving. During these interviews, we discussed the process through which both groups were approaching shikumi development. This included a discussion of the baseline templates that both were using and how they were going about the drafting of the physical documents. We discussed how they were tracking their completion. These discussions provided great insight into the scope of this process as well as a good baseline template that Vehicle Production Engineering Assembly could further modify to meet our desires for our shikumi. An added and unexpected benefit of these discussions was an initial exposure into how team members made decisions and worked within Toyota.

5.3. Initial Process Mapping

In order to streamline the assembly equipment selection and development process, it became clear early on that a through understanding of the entire process was necessary. I started by looking at the existing group descriptions that existed on the Vehicle Production Engineering Assembly website. These descriptions outlined all the processes that VPE Assembly and its associated groups were required to carry out for every model change. Although these steps were not thoroughly detailed or complete, they did outline the general steps that each individual group was required to carry out. To aid in the study and understanding of the responsibilities of each group, I worked to graphically demonstrate these. Based on the group descriptions that currently existed, three separate linear processes, one for each group, were created. These diagrams (figures 5-1, 5-2, and 5-3) are presented on the following pages.

-1: Vehicle Production Engineering Assembly Process Planning

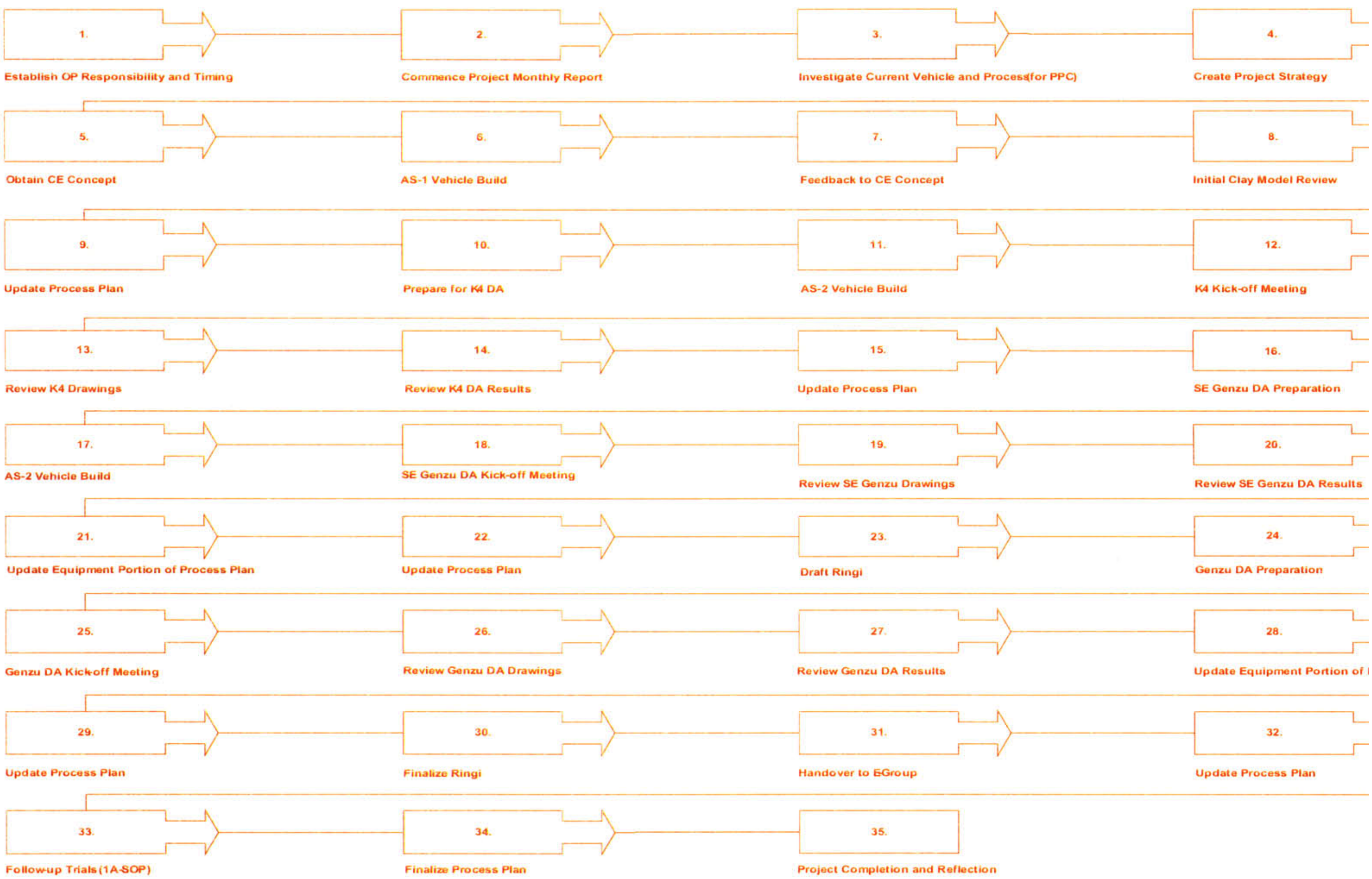


Figure 5-2: Vehicle Production Engineering Equipment Planning Steps

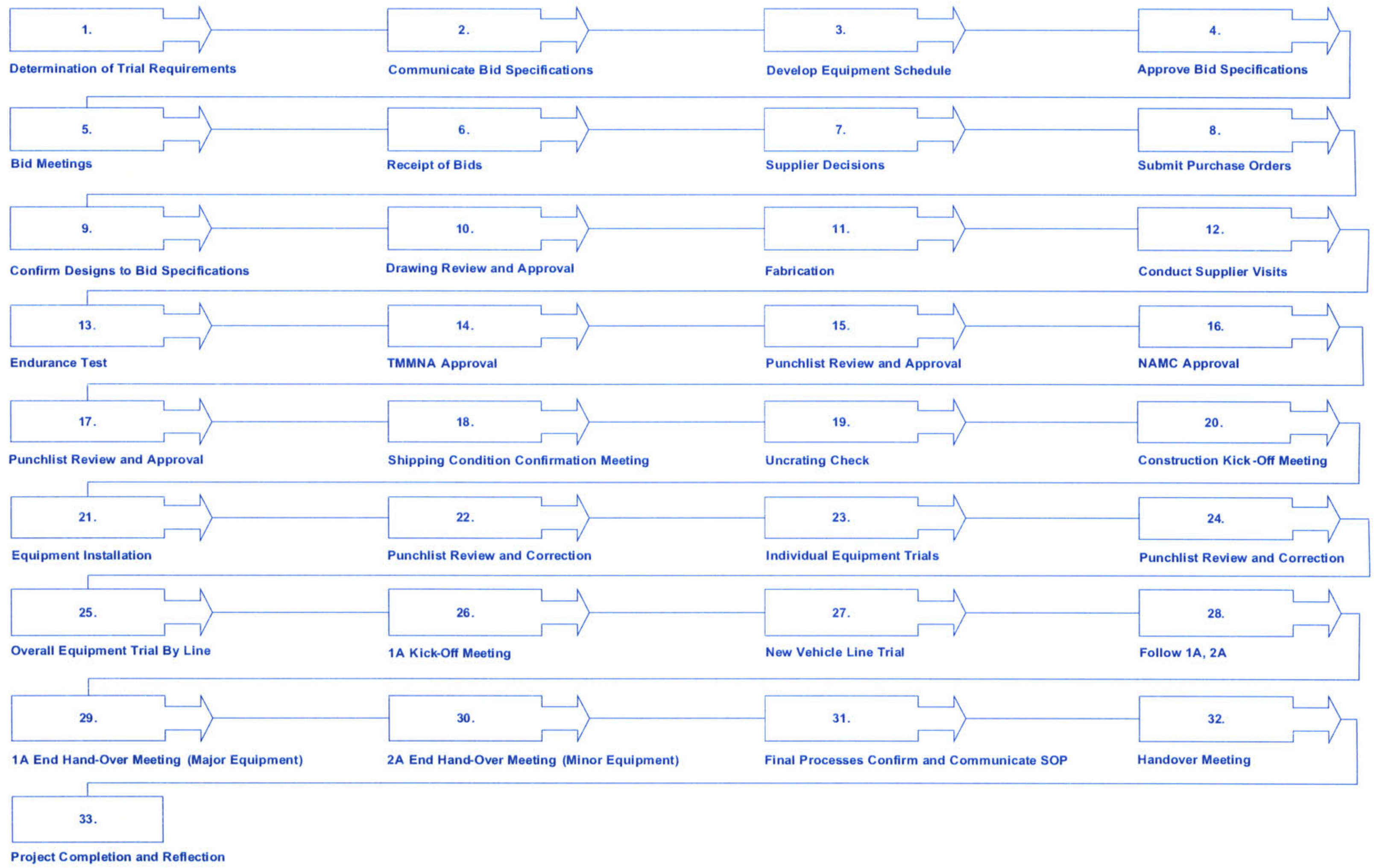
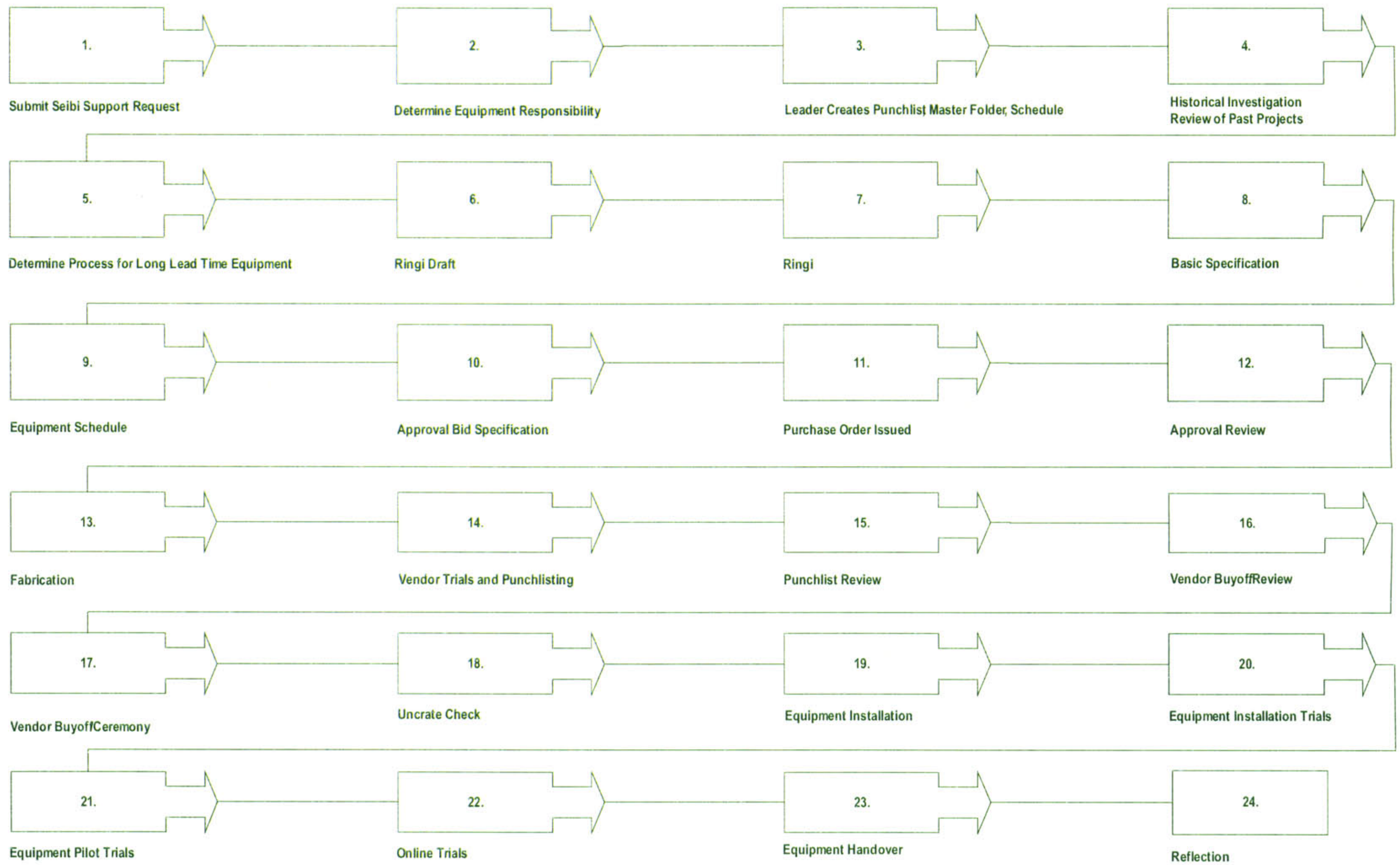


Figure 5-3: Vehicle Production Engineering Seibi Planning Steps



Even though figures 5-1 through 5-3 show a linear process, I quickly understood through conversations with Vehicle Production Engineering Assembly team members that the equipment selection process was not linear but actually quite complicated. It involves interactions between all the different groups as well as with external groups such as suppliers, design teams, and the plant. As they currently existed, the models were insufficient to characterize the process. Using this information as a baseline, I moved forward with a Design Structure Matrix analysis of the process to better understand and attempt to characterize the process.

5.4. The Design Structure Matrix Analysis

Any time an automobile manufacturer decides to bring a new or modified automobile to market, the entire process involves an amazing amount of coordination and support from personnel throughout the organization. The sheer numbers of individuals and functional units within an organization cause this process to be extremely complex. When first approaching the problem of how to streamline and standardize the implementation and selection of assembly line equipment, I quickly realized that this process would be extremely difficult to easily characterize. After discussion with my thesis advisors, I decided that utilizing Design Structure Matrix (DSM) analysis would be an effective tool for characterizing this complex process.[11]

5.4.1. Design Structure Matrix Analysis

The Design Structure Matrix is a system analysis tool that allows for a simple method to characterize complex systems. In fact, the Design Structure Matrix Website (http://www.dsmweb.org/) describes the Design Structure Matrix as a "system analysis tool that provides a compact and clear representation of a complex system and a capture

[11] For more information concerning the Design Structure Matrix, I strongly recommend referring to the Design Structure Matrix website (www.dsmweb.org). This website provides the latest in tools and techniques to utilize the Design Structure Matrix. This website provided invaluable information for the completion of this research project.

method for the interactions/interdependencies/interfaces between system elements (i.e. sub-systems and modules)." DSM analysis employs a process of interviews and questionnaires to study a process. It focuses on the flow of information throughout the process, including interaction with internal and external process stakeholders. The result of the DSM is a determination if process steps are properly ordered and identifies key process steps or areas requiring increased managerial focus. It aids management in mapping out their process and understanding how this process works in reality and how it could work if improved. Finally, the DSM identifies opportunities to streamline a process to make it most efficient and effective.

5.4.2. Interviews with Process Stakeholders

The first and perhaps most important step in the DSM process involves a series of interviews with personnel involved in the process. Interviews were scheduled to attempt to sample personnel throughout the process as well as key external groups which interacted during the equipment selection and implementation process. Internal stakeholders interviewed included:

1. Specialists (Engineers) at TMMC, TMMI, TMMNA, and TMMK
2. Assistant Managers (Project Managers) at TMMNA, TMMC, TMMK, TMMBC, and TMMI
3. Assembly Line Team Members at TMMK

Gaining access to external stakeholders was much more difficult. These external stakeholders could include suppliers to Toyota, design personnel, and Toyota Motor Sales personnel. I was unable to make a viable connection to either the design or sales groups, but was successful in speaking with a few suppliers to Toyota for this particular process.

A great deal of preparation was required prior to conducting any interviews. This involved studying the process and becoming conversant in how it worked. Based on the process mapping described earlier, I spent a great deal of time determining the list of tasks or parameters involved in this process. This list greatly evolved throughout this process as progress was made.

After a great deal of preparation, the actual interviews were carried out. In most cases, I attempted to schedule one hour blocks to carry out these interviews when I believed that the interviewee would be available. I attempted to schedule these interviews at a neutral site where neither the interviewee nor myself would be distracted by phone calls or other interruptions. While this was possible most of the time, on several instances interviews were conducted "on the fly." This particularly occurred with some individuals who were especially busy. In these cases, I took the opportunity to discuss the process with these individuals whenever and wherever possible. For example, an "on the fly" interview may occur on the plant floor or during the trip to another schedule meeting. Generally, it required many more "on the fly" interviews with individuals to compose a satisfactory interview. Regardless of the location where an interview occurred, the process yielded satisfactory information to characterize the process.

The actual interviews were generally loosely structured. I generally would begin the interview with a question asking them about the process. This general question would allow the interviewee great latitude in describing the process. As the discussion proceeded, often comments by the interviewee would lead to follow on questions to clarify points or dig deeper into varying aspects of the process. Generally interviewees would grow tired after about one hour of conversation. Based on this, I would often end the interview at that point and schedule a follow-up interview to further discuss the process. This ensured that responses were accurate and not just made to attempt to finish the interview.

The follow-up interviews were more structured in nature. These interviews were generally based on the previous interaction with the interviewee and his or her responses. These interviews focused on particular inputs and outputs (information needs, deliverables, etc.) as well as who they interact with during the progression of the equipment selection process. Additionally, the strengths of these information interactions were characterized.

5.4.3. Developing the Matrix

After several months of conducting interviews, the actual process of inputting information into the matrix began. Rather than construct an excel macro to input this data and analyze it, I took advantage of several macros available on the Design Structure Matrix Website (http://www.dsmweb.org/). After attempting to use several of the macros with varying levels of success, I finally decided to use a macro developed by Soo-Haeng Cho as a part of the M.S. thesis, "An Integrated Method for Managing Complex Engineering Projects Using the Design Structure Matrix and Advanced Simulation."[12] This model proved to be very robust and effective at analyzing the information that had been collected in the interviews.

The initial matrix was based on the existing process maps which included 92 process steps.[13] The interview process revealed a great deal of repetition in the existing process. In several cases, each group (Seibi Planning, Project Planning, and/or Equipment Planning) had an individual step in their process that was the exact same step for another group. A good example of this was the punchlist. The punchlist is a constantly evolving list which documents and tracks every discrepancy with a new automobile model. This can include process problems (how the car is physically made), quality problems, or

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[12] I want to personally thank Soo-Haeng Cho for discussing his model with me and providing it for use by researchers like me on the Design Structure Matrix (DSM) Home Page (http://www.dsmweb.org/). The model is available at http://www.dsmweb.org/macros.htm and proved to be very robust. It greatly contributed to the research that I carried out.

[13] Initial Design Structure Matrices were not provided due to the rapid nature that they were developed and changed based on the interview process. In many cases, several models were constructed over a short time period and often were obsolete based on new information gained during the interviews.

physical modifications to the assembly line equipment. Generally, the problem is characterized, the root cause is identified, and a responsible group is assigned. The responsible group is often VPE assembly but can be a supplier, plant team members, etc. They are required to resolve these punchlist problems prior to turning the new assembly equipment and processes over to the plant. Each group had a separate process for creating, tracking, and resolving a punchlist. While in reality there were several different punchlists maintained by the different groups, there was only a need for one "master" punchlist that VPE assembly created and tracked. There was no need for each group to have an individual punchlist procedure. One consolidated and standardized punchlist procedure would simplify the process a great deal.

Based on the series of interviews and an improved personal understanding, I began the process of simplifying the equipment selection process. This generally occurred through the consolidation of repetitive steps (similar to the punchlist example above) where two or more groups had procedures for the same process step. This process was fairly slow in evolving and the process and associated Design Structure Matrix changed almost daily. As I made changes to the entire process, I went back to the process stakeholders that I had interviewed and got their feedback on the changes. Based on their comments and feedback, the process evolved slowly over time until we reached the final process that was used in the Design Structure Matrix analysis.

Of particular interest was the initial partitioning process of the early Design Structure Matrices. According to the Design Structure Matrix home page (www.dsmweb.org) "partitioning is the process of manipulating (i.e. reordering) the DSM rows and columns such that the new DSM arrangement does not contain any feedback marks." Partitioning was carried out using tools in Cho's model (Cho, 2001) and essentially results in the process that is best ordered to prevent feedback and time delays. As mentioned earlier, the initial matrices were based on the existing documented processes. As the interviews progressed and the process was simplified, newer versions of the Design Structure Matrix were created. As a general rule, any time that the process was partitioned, the resulting process was nearly identical to the process existing before partitioning. This was very interesting result which basically indicated that the process that Vehicle Production Engineering Assembly was employing was very good in terms of preventing and overcoming feedback. A likely reason for this result was the fact that Toyota had carried out this process many times before, albeit many more times in Japan than in North America. Toyota has likely learned and reordered their process over the years based on the many projects that they had completed.

After several iterations based on the interview process, a final Design Structure Matrix evolved. This matrix presented how the various process steps interacted with each other. Process steps were input into the matrix. Interactions between steps were characterized with either a number 1 or 2 depending on the interaction. The following describes how the information flow interactions were modeled:

> "The tool receives two types of information flows between tasks. The first type represents the case that a downstream task requires final output information from an upstream task to begin its work. The second type represents the case that a downstream task uses final output information in the middle of its process and/or begins with preliminary information but also receives a final update from an upstream task. When there is the first type of information flow from task a to task b, enter '1' into (i, j) of the square matrix where i and j are the unique indices representing tasks b and a, respectively. For the second type of information flow, enter '2'. Reading across a row reveals the tasks where the inputs of the task corresponding to the row come from. Reading down a specific column reveals the tasks receiving outputs from the task corresponding to the column." (Cho, 2001)

The interview process revealed that very few specific process steps required complete information from preceding steps. In fact, the vast majority of process steps were started using preliminary and incomplete information from other steps. Figure 5-4 is provided on the next page and presents the final Design Structure Matrix. The table following Figure 5-4 provides individual step names referred to in figure 5-4.

Figure 5-4: Final Vehicle Production Engineering Design Structure Matrix

Level	Step	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
1	1																																									1
2	2	2		2		2		2																																		2
2	3	2	2		2																																					3
2	4	2		2																																						4
2	5		2	2	2																																					5
2	6				2	2																																				6
2	7		2			2	2																																			7
2	8	1																																								8
3	9								1																																	9
3	10	2	2																																							10
3	11						2	2																																		11
3	12	2	2	2		2		2																																		12
3	13	2	2	2		2		2																																		13
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7	38	2	2	2	2	2	2	2	2	2	2	2	2	2								2														2				2	2	38
7	39														2		2	2	2	2	2		2	2		2	2				2	2					2	2	2		2	39
7	40															2									2			2	2	2			2	2	2			2	2	2		40
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	

Block1

Block2

Block3

Table 5-1: Assembly Line Equipment Selection Process Step Names and Numbers

Step Name	Step Number
CE Concept	1
Investigations	2
K4 DA	3
Update Process Plan (post K4 DA)	4
SE Genzu DA	5
Update Process Plan (post SE Genzu DA)	6
Genzu DA	7
Establish OP Responsibility and Timing	8
Commence Project Monthly Report	9
Create Project Strategy	10
Update Process Plan (post Genzu DA)	11
Ringi	12
Basic Specification Development	13
Investigate Equipment	14
Submit Seibi Support Request	15
Determine Trial Requirements	16
Communicate Bid Specifications	17
Develop Equipment Schedule (post steps 16 and 17)	18
Select Equipment Supplier and Issue Requisition	19
Develop Equipment Schedule (post Issue Rec)	20
Update Process Plan (post Basic Spec Dev)	21
Design/ Drawing Review and Approval	22
Develop Equipment Schedule (post Design)	23
Punchlist Review and Correction (post Design)	24
Fabrication	25
Develop Equipment Schedule (post Fabrication)	26
Punchlist Review and Correction (post Fabrication)	27
Equipment Trials (post Fabrication)	28
Punchlist Review and Correction (post step 28)	29

Ship/ Shipping Condition Confirmation Meeting (SCCM)	30
Develop Equipment Schedule (post SCCM)	31
Equipment Installation	32
Equipment Trials (post Installation)	33
Punchlist Review and Correction (post step 33)	34
Follow-Up Trials (1A-SOP)	35
Develop Equipment Schedule (post Installation)	36
Equipment Handover/ Communicate SOP	37
Project Completion and Reflection	38
Project Reflection	39
Reflection	40[14]

Similar to the earlier models, partitioning of the final Design Structure Matrix provided in Figure 5-4 also resulted in an overall process that was identical to the "pre-partitioning" Design Structure Matrix. Again, this indicates that Toyota has likely learned from previous projects and modified their process to be more efficient.

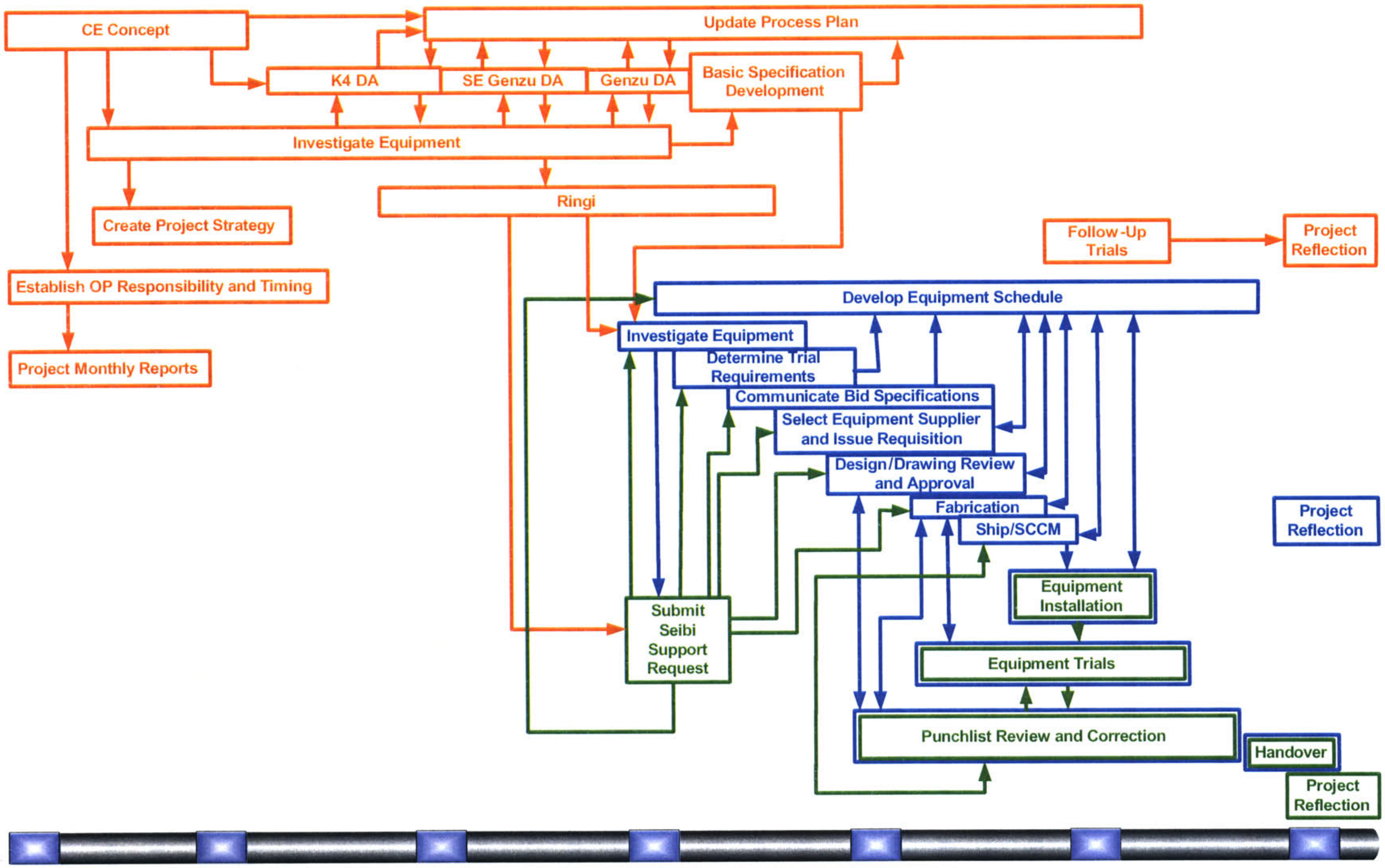
Figure 5-4 also represents the result of the clustering process on the final Design Structure Matrix. According to the Design Structure Matrix home page (www.dsmweb.org), clustering involves the process of "finding subsets of DSM elements (i.e. clusters or modules) that are mutually exclusive or minimally interacting subsets. In other words, clusters absorb most, if not all, of the interactions (i.e. DSM marks) internally and the interactions or links between separate clusters is eliminated or at least minimized."

[14] While 40 steps appear in the final Design Structure Matrix model, the final process only included 28 steps. Several steps took place over a long period of time based on several other process steps. These steps were demonstrated in the DSM as essentially sub-steps to allow for the simulation described in section 5.5.

Clustering was carried out using tools in Cho's model (Cho, 2001) and resulted in four clusters. The first cluster, labeled Block 1 in light blue in Figure 5-4, essentially represents the initial planning, investigations, and digital drawing reviews carried out by the Project Planning group early in the project. The second cluster, labeled Block 2 in yellow in Figure 5-4, essentially represents the investigations and development of bid specifications and trial requirements carried out by the Equipment Planning group. The third and largest cluster, labeled Block 3 in green in Figure 5-4, essentially represents the development, installation, and testing of assembly line equipment carried out by both the Equipment Planning and Seibi Planning groups. Finally, the fourth cluster, grey font in Figure 5-4, represents the development and sharing of reflection reports by all three Vehicle Production Engineering Assembly groups. The clustering tool resulted in four large blocks that comprised a majority of the steps in the overall process.

A corresponding final process map is provided in Figure 5-5 on the following page for reference. This figure essentially demonstrates how the three groups interact with each other throughout the equipment selection and implementation process. The red boxes outline steps carried out by the Project Planning group. These steps essentially involve digital reviews of the proposed new model, reviews of existing plant assembly line equipment, and determination of what equipment likely needs to be replaced. The blue boxes show steps carried out by the Equipment Planning group. These steps essentially involve further studies of the actual assembly line equipment, development of equipment specifications and potential suppliers, and interactions with suppliers to build and test equipment. The green boxes show steps carried out by the Seibi Planning group. These steps essentially involve the testing and troubleshooting of equipment once it is installed to ensure its proper operation. Using this modified process map as a basis, the matrix was constructed. Due to the relative inexperience by anyone within Vehicle Production Engineering Assembly looking at the interactions between the various groups, the process of identifying the interactions between the three groups was a significant learning experience for all involved.

Figure 5-5: Final Vehicle Production Engineering Process Map



5.4.4. Nemiwashi (Consensus Building)

Throughout the Design Structure Matrix process, I returned periodically to those personnel that I had conducted interviews with to review the DSM. This process ensured that the interviewees agreed with the matrix representation of the process. These follow-up interviews were extremely valuable to both parties. The interviewees found interactions that they had overlooked or not considered before. The interviewees also pointed out areas where the matrix was not completely accurate and needed to be resolved to better represent the actual process. Finally, the interviews served to allow the interviewees to review the entire project and slowly begin to buy-in into my research project. This process resulted in the final Design Structure Matrix (Figure 5-4) for the equipment selection process.

5.5. Design Structure Matrix Modeling

5.5.1. Determining Process Timing

Following the nemiwashi or consensus building process and the completion of the Design Structure Matrix model, the final steps in this process were to create a model that represented actual model changes and determine what effect changes to individual steps within the process had on the overall process. To begin this process, I polled many of the stakeholders that were involved in the DSM interviews to determine the time requirements for each step in the process. During this process, each person was asked to determine three time parameters for each step in the process. These estimates included a best case duration (the shortest amount of time that a step could take), a worst case duration (the longest amount of time that a step could take), and finally a most likely case (the most likely amount of time that a step should take). An example portion of this questionnaire (figure 5-6) follows.

Figure 5-6: Design Structure Matrix Process Timing Questionnaire

Date:	
Interviewee:	
VPE Group:	

Time Requirements

	Step	**Minimum**	**Most Likely**	**Maximum**
1	CE Concept			
2	Establish OP Responsibility and Timing			
3	Commence Project Monthly Report			
4	Investigations			
5	Create Project Strategy			
6	K4 DA			
7	Update Process Plan (post K4 DA)			
8	SE Genzu DA			
9	Update Process Plan (post SE Genzu DA)			
10	Genzu DA			
11	Update Process Plan (post Genzu DA)			
12	Ringi			
13	Basic Specification Development			
14	Update Process Plan (post Basic Spec Dev)			

The results of these timing questionnaires were very interesting. The time duration responses varied greatly depending on who was answering the questionnaire. Generally, those personnel making estimates for those steps that they were familiar with generally produced results fairly close to those approximations that were eventually used in the simulations. However, personnel who were making approximations for steps outside their group generally gave responses that were either very long or short in duration. Generally, those personnel did not have a great understanding of the process outside their group or how that group's actions affected their group. Generally, the more experienced that a team member was, the closer their responses were to the approximations that were eventually used in the simulations. In the end, I took all the results of the process timing questionnaires and met with individuals in each of the three groups who had experienced several model changes. Working with these individuals, we were able to determine the most realistic timing results which best represented reality. Similar to the DSM process, I ran these approximations by a group of process stakeholders and through the Nemiwashi process arrived at a result that I believe accurately represented real life major model changes.

The results of the timing questionnaires were included in the DSM simulation. The probability of completing a particular step in the most likely case was set at 80%. The probabilities of both the minimum and maximum cases were each set at 10%. These numbers were fairly arbitrary and selected based on a review of the Avalon project. Toyota managers were very focused on the timing of projects. This generally resulted in individual process steps being completed as scheduled.

5.5.2. Running the DSM Simulation

Using the results of the timing questionnaires, the design structure matrix data was input and the simulation model was constructed using tools provided in Cho's model (Cho, 2001). The following assumptions were made when using the model:

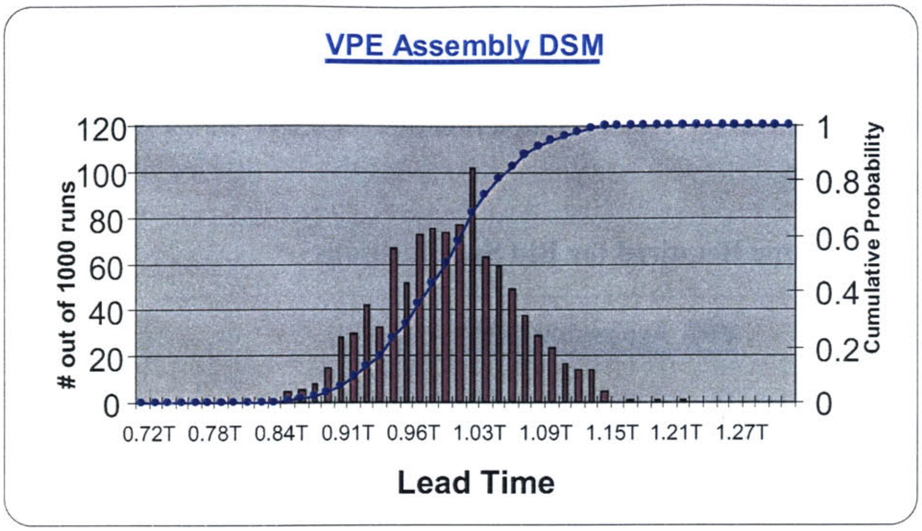
1. Overlap amount was set to 0.7. "The overlap amount represents the planned overlap amount between tasks." (Cho 2001) It is a fraction of the expected duration of the first task that must be completed before the downstream task can begin (Cho, 2001). It also implies that the downstream task cannot be completed before the upstream task finishes (Cho, 2001). The value of 0.7 was selected due to the make-up of the Toyota product design process where many different design alternatives are considered at any one time. Specific specifications are not provided early in the process and personnel work within a band of possible values. This ambiguity allows individuals to work ahead on downstream steps without knowing exactly what specifications they will have to achieve. Due to this process, the amount of overlapping appears to be very beneficial to Toyota to allow it to complete projects rapidly.
2. The overlap impact was set to 0.1. The overlap impact represents the expected overlap impact when one task is overlapped with a downstream task by the given

maximum overlap amount (Cho, 2001). It is a fraction of the maximum overlap amount (Cho, 2001). If it is equal to 1, it implies no benefit from overlapping (Cho, 2001). Similar to the selection of the overlap amount above, the value of 0.1 was selected due to the make-up of the Toyota product design process where many different design alternatives are considered at any one time. Specific specifications are not provided early in the process and personnel work within a band of possible values. Due to this process, the impact of overlapping appears to be very beneficial to Toyota to allow it to complete projects quickly.

3. Rework probability and rework impact were set to 0. This essentially ignored the possibility and impact of rework occurring in the overall process. The process that was modeled here encompassed steps that were overarching or macro in nature (made up of numerous processes for individual pieces of assembly line equipment). While individual "micro" equipment process steps were affected by rework, the larger macro steps were not. The impact of rework could be accurately modeled by setting both the rework probability and rework impact values to 0.
4. Resource constraints were ignored. Due to the short duration of this research project, Vehicle Production Engineering Assembly was assumed to have unlimited resources (personnel, equipment, tools, model computing capability, etc.) to complete projects. While this assumption is not accurate in terms of reality, modeling it accurately would have required extensive additional research. This additional research would prove valuable information as Toyota faces increasing levels of new model projects in the future.

As a part of this process, a baseline model was run to determine if the existing matrix combined with the timing approximations was an accurate representation of the actual process. The simulation involved running 1000 simulated projects using the assumptions to determine the durations of these projects. The initial simulation using the information collected and the final Design Structure Matrix resulted in the following results provided in Figure 5-7 below.

Figure 5-7: Time Duration to Complete an Average Major Model Change



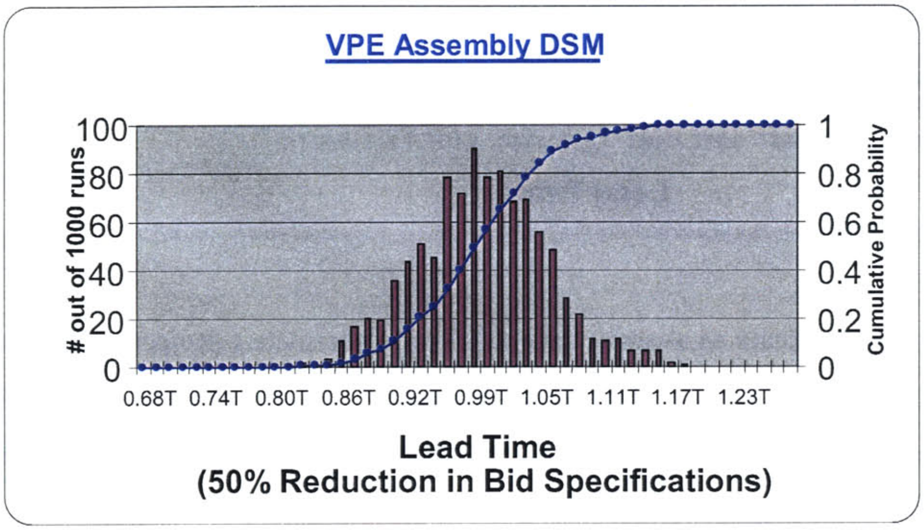
The results above indicate an average time required to complete a project, represented by T, that was very similar to most major model changes.[15] As a comparison, I reviewed the current major model change in progress at the time, the 2005 Avalon. The simulation model yielded an average total time duration, T, and a standard deviation of 0.07T. The total time duration yielded results very similar to the Avalon project. It appeared that the time durations and assumptions made resulted in a model that represents reality fairly well.

Based on this result, further simulations were run where improvements were made to the process and their effects on the overall process were determined. These improvements were determined based on frustrations that were communicated during the Design Structure Matrix interview process and generally involved decreasing the amount of time that individual steps required for completion. Additional improvements were based on my thoughts on the process and areas where I thought improvements could be made to the process. The improvements that were simulated included the following:

[15] Actual time durations are disguised for confidentiality. All times indicated here are provided in relation to the average time required to complete a major model change. The value T is used to indicate this average value.

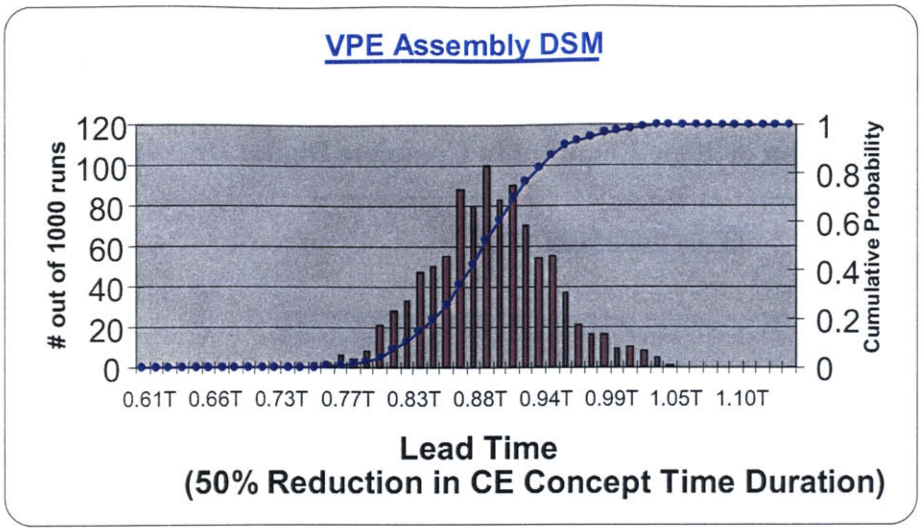
1. Reduction in the amount of time required to develop, communicate, and finalize bid specifications is provided in Figure 5-8 below. This resulted in a small reduction in average project completion time of 0.99T with a standard deviation of 0.09T.

Figure 5-8: Reduction in Time Required for Bid Specifications



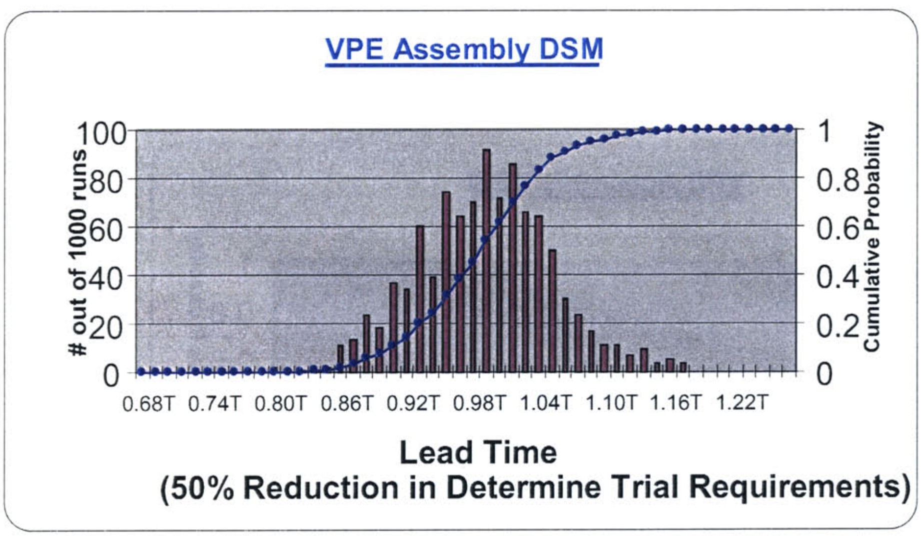
2. Reduction in the amount of time required to develop CE concepts (basic design information and drawings from either TMC, TTC, or Calty Design Research) is provided in Figure 5-9 below. This resulted in a large reduction in the average completion time of 0.89T with a standard deviation of 0.07T.

Figure 5-9: Reduction in Time Required Developing CE Concepts



3. Reduction in the time required to determine trial requirements for the acceptance of assembly line equipment is provided in Figure 5-10 below. This resulted in a small reduction in the average completion time of 0.99T with a standard deviation of 0.09T.

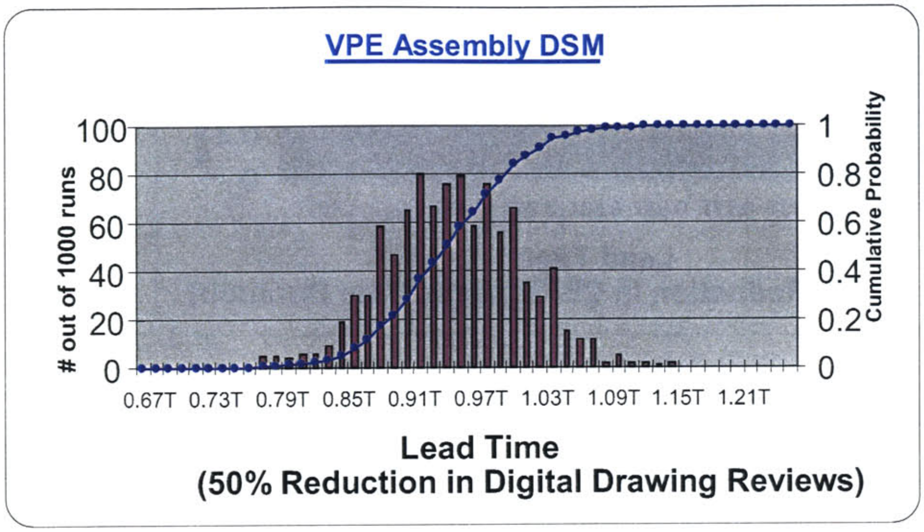
Figure 5-10: Reduction in Time Required to Determine Trial Requirements



4. Reduction in the amount of time required to complete digital reviews of the proposed model changes and proposed changes to the assembly line. This reduces the duration of K4 DA, SE Genzu DA, and Genzu DA digital review process steps. The result of this improvement is provided in Figure 5-11

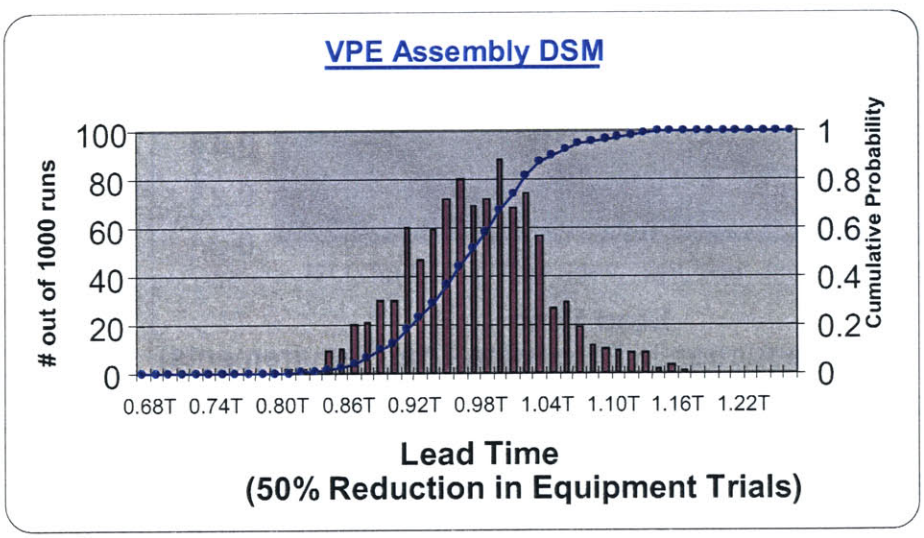
below. This resulted in an average completion time of 0.95T with a standard deviation of 0.09T.

Figure 5-11: Reduction in Time Required to Complete Digital Drawing Reviews



5. Reduction in the amount of time required to carry out equipment trials at both the supplier's site as well as after the equipment is installed in the plant. The result of this improvement is provided in Figure 5-12 below. This resulted in an average completion time of 0.98T with a standard deviation of 0.07T.

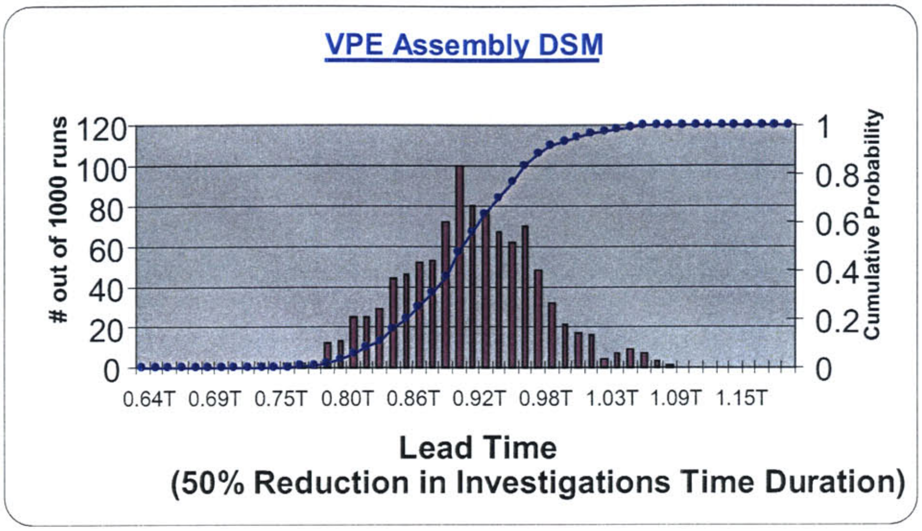
Figure 5-12: Reduction in Time Duration to Carry Out Equipment Trials



6. Reduction in the amount of time required to carry out equipment investigations (review of existing equipment and/or processes and determination of what physical changes are necessary). The result of this

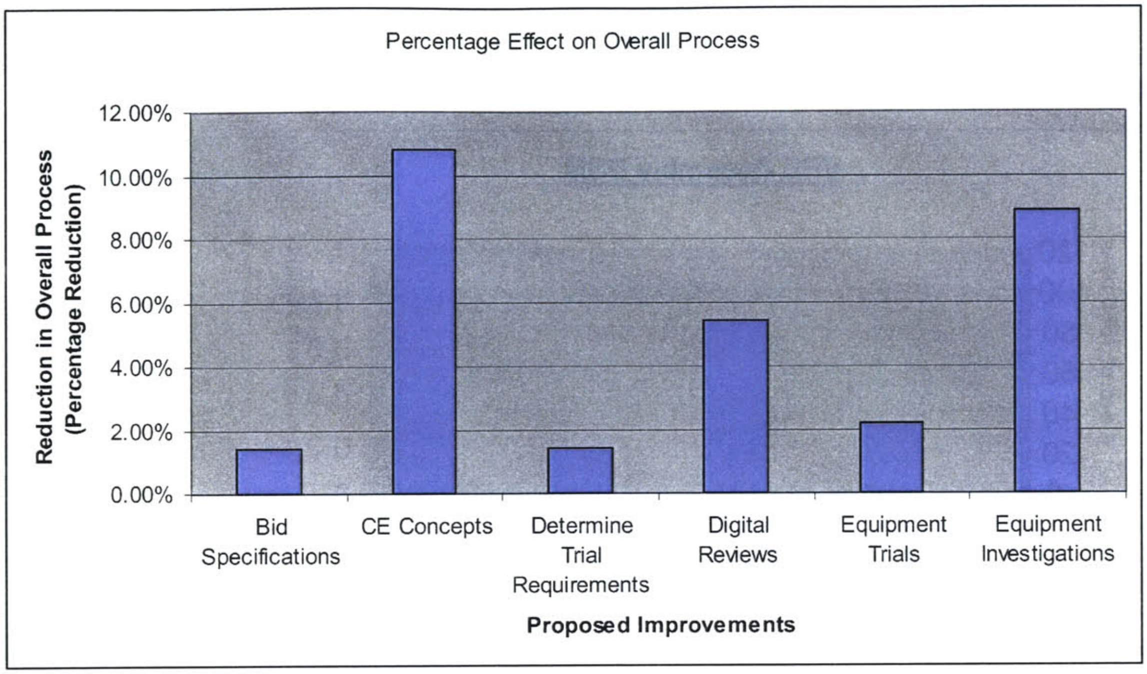
improvement is provided in Figure 5-13 below. This resulted in a large reduction in the average completion time of 0.91T with a standard deviation of 0.07T.

Figure 5-13: Reduction in Time Duration to Carry Out Equipment Investigations



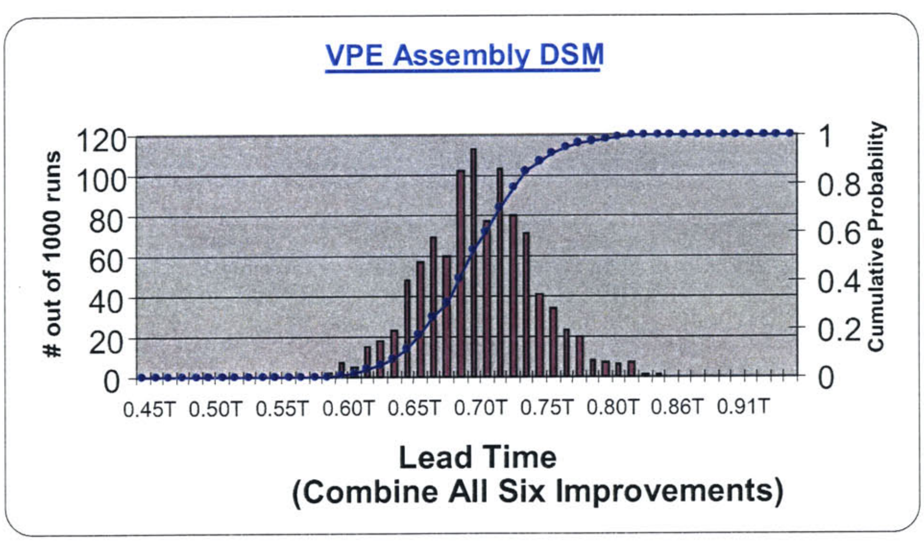
The results of these simulation runs revealed different results for each of the proposed improvements. While each of the proposed improvements had some effect on the entire process, two improvements had significant effects. A 50% reduction in the amount of time to develop CE concepts resulted in the largest overall process time reduction of approximately 11% percent (reduction to 0.89T). A 50% reduction in the amount of time required to complete equipment investigations also yielded a significant overall process time reduction of approximately 9% (reduction to 0.91T). The overall effects of a 50% reduction in each of the proposed improvements are summarized in Figure 5-14 below:

Figure 5-14: Assembly Line Equipment Selection Process Improvements and Effect on the Overall Process



Finally, if one is to combine all the improvements above, the results would be a significant reduction in the time required to complete the overall process. The result of completing all six improvements outlined above is provided in Figure 5-15 below. This resulted in an average completion time of 0.70T with a standard deviation of 0.07T.

Figure 5-15: Time Reduction When Implementing All Six Improvements



The results of all these simulations and their impact on Vehicle Production Engineering Assembly equipment selection process are discussed in further detail in chapter six.

5.6. Development of a Standardized Shikumi Document Format

5.6.1. Reviewing the Existing Vehicle Production Engineering Assembly Documents

The process of developing the Vehicle Production Engineering Assembly shikumi started with a careful review of the existing documents that were in use. These documents had been developed over the past several years by a long line of team members. As such, the documents were fairly inconsistent and inaccurate. The existing documents were fairly difficult to understand and were not complete. The format did not promote a basic understanding of the details of that step in the process. The example documents were PDF files that had been planned to be implemented with web links to example documents. However, the links in the documents did not work or referenced the wrong examples. The PDF format did not easily allow for updates to be made. In many cases, these documents had been developed by contractors or temporary employees. While in many cases this was a useful (and perhaps necessary) assignment of work based on the operational levels being faced by Vehicle Production Engineering Assembly, it did not lead to documentation that was accepted or utilized by the lion's share of team members in Vehicle Production Engineering Assembly.

5.6.2. Benchmarking Existing Shikumi Document Formats

I began the process of developing a shikumi format by first investigating other shikumi development formats in progress at Toyota. While several departments and groups within Toyota had worked to develop their own shikumi processes, two were very advanced. Two departments, Powertrain Engineering and Body Production Engineering, were actively developing departmental shikumis and had experienced both success and failure along the way.

Discussions with these two groups greatly aided the shikumi development process. The two groups were able to communicate where they were in the current process and how they had proceeded to that point. They passed on things that had either worked well or not so well and why they believed that they had turned out that way. Finally, each provided the physical documents and the process they had used for their development. This discussion was especially fruitful in that it provided a working example for the development of the Vehicle Production Engineering Assembly shikumi. Additionally, these physical documents provided evidence to the Vehicle Production Engineering Assembly personnel that the shikumi processes can be developed and can be useful.

5.6.3. Developing the Vehicle Production Engineering Assembly Shikumi Document

The process of developing the Vehicle Production Engineering assembly shikumi commenced with a transfer of all existing documentation to the new format. This proved fairly difficult due to the limited amount of information that was in place. After a great deal of time transferring this information, the interview process with process stakeholders (section 5.4.2.) yielded additional information that was implemented into the process documentation.

In conjunction with this interview process, the collection and development of example process documents took place. For many of the shikumi process steps, there were process documents necessary to carry out that step. These documents could include standard meeting minutes, a bid specification sheet, or an outline for an equipment test. In order to carry out the equipment selection process, these documents existed but were not contained in a centralized location. In many cases, each individual team member used their own version of a document that they had developed. These documents often existed on individuals' computers or in their files where access by others was not possible. This effectively precluded the sharing of best practices for documentation. The wide variety of documentation led to a degree of confusion for management as they reviewed project status reported on numerous different documentation styles. Collecting all this documentation into a centralized location (the Vehicle Production Engineering Assembly shikumi) was a daunting and challenging task achieved during interviews with the process stakeholders.

Once the initial draft of the shikumi document had been developed, I returned to those personnel that I conducting interviews with to review the documents. This nemiwashi process ensured that the process stakeholders were satisfied with the documents and make recommendations for their improvement. The interviews served to allow the interviewees to review the documents and slowly begin to buy-in into their use. This process helped ensure that the new shikumi documents would actually be used in the future. An example of the new standardized shikumi format is provided in figure 5-16 on the following page.

Figure 5-16: Vehicle Production Engineering Standardized Shikumi Format

TMMNA
North American Manufacturing

VEHICLE PRODUCTION ENGINEERING OPERATING PROCEDURE

Subject: Develop Equipment Schedule — **Shikumi Process # 2**

Page 1 of 1

Original Document Approvals						Revision Approvals				
GM	AGM	Mgr.	Advisor	AM	Originator	Rev.	Date	Change Content	Prepared	Approved
						1.0		Initial		

PURPOSE: 1. To generate an Equipment Schedule that clearly defines the timing of major project milestones (Bsc Spec, Bid Spec, P.O., Fabrication...).

IMPORTANCE: To clarify timing for bid specification
To communicate strategy to NAMC and NA team
Develop tracking tool to use throughout development

TIMING: N-18 to N-15

ROLES AND RESPONSIBILITIES:
Equipment Group: Develop schedule.
Project Planning: Provide input if required.
Seibi: Review and comment. Make support plans.
NAMC: Review and approve.
Equipment Supplier: Determine feasibility and use as basis for quote and delivery plans.

KEY TERMS:

STEPS:
1. Review basic specification and estimated time to install as starting point for schedule development
2. Use standardized equipment schedules and adjust for unique requirement
3. Document schedule using Microsoft Project
4. Incorporate schedule into bid specification document
5. Incorporate schedule into overall program schedules

PROCESS INPUTS:
1. Standardized equipment schedules
2. Unique requirements
 -Long lead time parts
 -Trials and investigations
 -Weekend and shutdown schedules
3. NAAMS

PROCESS OUTPUTS:
1. Microsoft Project schedule

EXAMPLES:
Blank forms:
None

Completed form:
1. Example Project Schedule

5.7. The Shikumi Initiative Process Summary

This chapter provides an overview of the shikumi intitive and the process carried out to implement it. This process included internal benchmarking, process mapping, and design structure matrix modeling and simulation. The chapter also outlines the process carried out to gain consensus (nemiwashi) and approval for the shikumi. Finally, an overview of the standardized shikumi documents is provided. Essentially, this chapter provides an overview of the entire research project and the processes carried out. The next chapter outlines the important advantages that can be gained through implementing a shikumi and some of the challenges encountered while doing so.

Chapter 6. Implications of the Shikumi Process

6.1. Potential Advantages of a Standardized Equipment Selection Process

6.1.1. Documentation of the Process Allows for Improvement Process to Occur

One of the greatest advantages of standardizing any process is that the process becomes more easily repeatable. This repetition makes it possible to identify the root causes both when a process is working well and also when it is underperforming. Without a standardized process in place, it becomes extremely difficult to determine the root causes of problems when they arise.

Under their present system, where each plant is fairly unique and based on their Japanese sister plant, standardized, and perhaps more importantly documented, processes did not exist. Toyota Motor Manufacturing North America recognized a few years ago that for them to truly become self-reliant, they needed to learn from the best practices of each of their plants. In keeping with their Scientific Method of problem solving (Spears and Bowen, 1999) Toyota began the push for standardization of all processes. Documenting and standardizing every process is necessary so that it can be kaizened and improved.

An added benefit of standardizing and documenting the process is that current experienced employees continue to learn as they work. This process allows existing team members to review the documented processes and compare them to their experience. As differences appear, the experienced employees have been trained to determine the root cause and propose improvements. This process will create continuing learning opportunities for experienced employees.

6.1.2. Standardization Results in Quicker Assimilation and Increased Productivity of New Employees

A variety of factors make it difficult for new employees to assimilate to the way Toyota carries out processes. The Toyota Production System, while fairly easy to understand on paper, is much harder to understand and implement in reality. The culture of Toyota is very different than other corporate cultures. Perhaps most difficult is the strong relationship based culture where having a strong personal network is vital to success. New personnel do not have this network in place when they begin work and consequently endure a long process of building this network in order to become effective contributors to the company.

As a general practice, Toyota typically counts on its personnel to learn skills on the job. This creates significant problems for Vehicle Production Engineering Assembly due to the limited amount of documentation that exists for their processes. With this limited documentation and without a strong personal network, these new employees often flounder and are under-productive in their new jobs. This leads to great levels of frustration with the system. Currently, Toyota is able to overcome this personal frustration due to positive characteristics of the company (good compensation, job security, etc.). How long they can continue to overcome these frustrations in the future in the face of new competition is unsure. Ultimately this frustration can be more directly overcome through documentation and standardization of the process.

Documenting and standardizing the equipment selection process will lead to a much quicker learning process for new personnel coming into Vehicle Production Engineering Assembly. This will allow new personnel to begin work and spend less time slowly learning the process and more time actually carrying out the process. This is where the best type of learning is accomplished. Documenting the equipment selections process through a department shikumi will result in less work and frustration training new personnel to learn the process for all involved.

6.1.3. Defining and Standardizing the Equipment Selection Process Results in a Reduction in the Time Required to Complete a Project

Perhaps the most exciting benefit of defining and standardizing the equipment selection process is the benefit it provides in terms of reduced time to bring a new model to market. It can be argued that Toyota is very efficient at using simultaneous engineering to bring products to market. Their product focus appears to be very sound. However, there are also benefits to be captured through the streamlining of processes necessary to manufacture this new product. (Hayes, Pisano, Upton, and Wheelwright, 2005) By also focusing on the processes necessary to bring a new automobile model to market, Toyota can further reduce this time.

The development of a group shikumi provides a method whereby process improvement can occur. The shikumi process provides a stand-alone product that personnel can refer to determine project status. This proves particularly valuable during the training of new personnel and allows them to become a high performing member of the organization much earlier in their career. This process also ensures that everyone, both new and experienced personnel, are "on the same page" and better understand where a project stands and more importantly what their role is in that process. Finally, the standardization of the equipment selection process into a shikumi format provides an easy tool for management review. By standardizing all projects to use the same development process and reporting documentation, it is much easier for management to quickly understand the status of a particular project.

A reduction in the amount of time required to complete a product development project allows an organization to gain a significant competitive advantage over other competitors in its industry. There are several advantages that can be gained through a quicker product development process. "A company that can develop new products twice as fast as its competitors has the luxury of using that advantage in one of two ways. It either can wait longer before initiating the development of a new product, or thereby begin the project with a clearer understanding of where markets and technologies are moving, or it can flood the market with wave after wave of new products." (Hayes, Pisano, Upton, and Wheelwright, 2005) Throughout Toyota's history, it has been exceptionally good at determining what items that customers feel are important and are willing to purchase. By giving themselves the opportunity to delay decisions until later in the product development process, they can ensure that they are better able to meet customer requirements. This ability would give Toyota a significant competitive advantage in regards to their competitors in the automobile market and allow it to continue to gain market share.

6.2. Implementation Challenges

The greatest challenge in implementing the shikumi is the basic pace and workload faced by Toyota. Due to its strong growth in North America over the last two decades, Toyota Motor Manufacturing North America has been in a constant race to keep up this pace and capture market share. Similar to many other organizations in similar situations, many things that most people would consider basic practices that a company would undertake have been neglected. The example discussed here is the documentation of the equipment selection process procedures. While having these procedures will lead to long term gains (less work for employees, quicker development of new models from design to production, etc.) in the short term they are difficult to justify based on the rapid growth.

"We have lots of things that we should be doing to make our lives easier. However, making cars and money always seems to get in the way."

TMMNA team member

Trying to make changes to any process is challenging. It was particularly challenging in the case of the shikumi for Vehicle Production Engineering Assembly in that the work load never relents. New car model changes are constantly coming. Once one project completes, another one is appearing. Toyota personnel are given incentives to complete projects on time and under budget. At present, Toyota personnel, especially at the specialist level, neither have the time nor incentives to develop change initiatives similar to the shikumi process.

Compounding this challenge is the fact that Toyota attempts to keep its manpower lean like many other areas in their company. The number of vehicles produced in North America has increased greatly over the past 20 years. While this number of vehicles and subsequent workload has increased, manpower has not grown as rapidly. Essentially

Toyota has always tried to do more with less. They believe that process improvements can allow fewer people or assets to continue to do the same amount of work. In reality, this was possible until recently due to the small footprint of Toyota in North America. While only a few plants existed, it was relatively easy to share best practices within the plant and keep pace with increased workloads. However, as the number of vehicles produced continued to increase, more plants were required. This greatly complicated the sharing of best practices as illustrated in this thesis. Toyota will have difficulty developing best practices and standardizing processes across their different plants until they assign personnel and create incentives for them to do this.

6.3. Summary of the Implications of the Shikumi Project

This chapter provides an overview of the implications of the shikumi project. It outlines the potential advantages that a shikumi provides to Toyota or other organizations. Further, this chapter outlines some of the challenges faced when implementing a change like this. The final chapter of this thesis outlines conclusions and recommendations based on the research carried out for this project.

Chapter 7. Conclusions and Recommendations

In this thesis I have discussed the automotive product design process and more specifically the assembly line equipment selection process at Toyota. While overall Toyota does many things very well, there are still specific areas where they can improve to continue to compete effectively in the automobile market. This project attempted to provide specific improvements to the assembly line equipment selection process and other observations of problems that I foresee Toyota facing in the future.

The first contribution of this thesis was a model for a coherent VPE assembly line equipment development process and a method for experimenting with process improvements. The associated Design Structure Matrix Model provides several simulated improvements, which, if implemented, could result in a 30% reduction in the lead time for assembly line equipment selection process. While many of these improvements may be difficult to implement in reality, this Design Structure Matrix and associated simulation model provides a capable method for Toyota to experiment with process improvements.

The second contribution to Toyota Motor Manufacturing North America was the opportunity to thoroughly study the VPE Assembly process. This study reveals several weaknesses and strengths in TMMNA's approach to organization and capability development. While several key managers and engineers thoroughly understood their portions of the process, few understood their individual impact on the overall process. Most VPE personnel understood that the push for greater self-reliance meant that changes were likely to occur but few understood the impact on communication and knowledge management that this change caused. Several managers knew that they needed to change to standardize and improve their processes to continue to improve productivity but didn't know how to do it. This study has laid the foundation for a possible way that VPE Assembly could approach this change initiative as they proceed with the continued evolution of their department shikumi. This thesis also provides several suggestions for how to improve the process in the future. The following sections outline potential challenges that I see Toyota facing based on my experiences there.

7.1. Toyota's Current Knowledge Management Procedures Have Resulted in the Loss of Some Knowledge

I would argue that Toyota's current knowledge management procedures, in the face of rapid growth in North America, are inadequate and leading to a loss of knowledge. As demonstrated, the current process provides limited ability to share information. Procedures and processes are unique to each facility or plant. Information sharing, feedback, and learning from projects are often informal. While this is certainly possible in other areas of Toyota where personnel are co-located or plants are closely located, it is not as easy in North America. The sheer geographical size of North American operations makes the current system extremely difficult.

The shikumi process is a good countermeasure for the communication problem that Toyota is facing in North America. The process allows for a standardized method for documenting processes. It is easily developed and can be updated as necessary based on future learning. The mere process of developing the shikumi also requires close interaction with numerous process stakeholders and thus sparks more collaboration and knowledge sharing. This development is probably best carried out by internal Toyota team members who are intimately involved in the processes that they are developing. The shikumi provides a viable countermeasure for the knowledge management problems that Toyota is facing in North America.

7.2. Improved Communication in the Automobile Product Development Process

Toyota has proven to be very successful at meeting customer requirements for both high quality and reliability at a low cost. In many ways their product development process is optimized to ensure that decisions and improvements can be made well into the process in order to meet changing customer needs. However, this latitude does come at a cost to portions of the product development process. Communication improvements throughout the design process can overcome these frustrations.

Late and often incomplete information from the design teams often leads to great frustration for the Vehicle Production Engineering Assembly group. Often they were given very vague product descriptions and were asked to make modifications to assembly line equipment to allow the production of the modified vehicle. These descriptions often greatly changed as final decisions were made concerning the new vehicle. These changes often led to budget and time challenges for Vehicle Production Engineering assembly as suppliers struggled to account for these new changes. It also led to equipment that did not function as well as possible if more definitive specifications had been communicated earlier. However, based on Toyota's new vehicle introduction processes and their success over the years, these problems are likely to remain.

Better communication in the product development process would alleviate these challenges. Toyota needs to work to break down the wall that apparently exists between the manufacturing portion of the company and the design side. The recent announcement of the merging of TTC and TMMNA under one operational heading is a strong move in this direction. North American manufacturing personnel need to be more involved and aware of the design process. Final specifications, or at least the band of possible specifications, need to be provided earlier when known. Where long leg equipment changes are necessary, design needs to be made aware and specifications finalized earlier in the process to prevent project overruns. Finally, design needs to understand that manufacturing is a key customer in the product development process and understand their desires. Once this happens, Toyota will be able to make significant reductions in the time required to bring an automobile to market.

7.3. Personnel Levels as the Toyota Family of Brands Expands

Throughout much of the 20th century, General Motors was the most powerful automotive company in the world. General Motors used its power to create many different types and brands of automobiles that essentially appealed to nearly every consumer group (size, cost, quality, etc.). General Motors used its various brands to segment the market. However, at the end of the 20^{th} century, General Motors has experienced increased competition from foreign automakers, most notably Toyota and Honda, for many of the markets that it traditionally dominated. With so many brands and different variations of automobiles, General Motors is experiencing challenges maintaining all the various brands. Advertising, engineering demands, and production costs are much higher trying to maintain such a broad product line. What once was a strategic advantage has now seemingly become a disadvantage.

As Toyota continues to capture greater market share, it has also commenced creating a brand family to segment its market. With the first sales of the Lexus brand in 1990 and the Scion brand in 2004, Toyota has greatly expanded its brand family. While many of the parts and subsystems of the three automobiles are similar or based on existing car models in other geographic areas, this brand expansion will create problems for Toyota manufacturing in North America. As the number of car models increases, the number of products that will be periodically modified will also increase. Additionally, the process will become much harder to control and additional problems will arise. Toyota, in its effort to remain as lean as possible, will likely not increase product design manpower levels as quickly as the number of car model modifications increases. This fact greatly supports the need for Toyota to optimize its processes and share best practices more effectively among all it manufacturing facilities. If Toyota is unable to do this effectively, the positive aspects of a more broad brand and product line will not be realized.

7.4. Vehicle Production Engineering Assembly Equipment Process Improvements

As mentioned above, the demands on Toyota product development and manufacturing are not likely to diminish over the coming years. Consequently, Toyota needs to continue to push projects which work to simplify their processes as much as possible. These projects will optimize their work force and allow them to continue to produce at a high level without adding significant manpower. While these process improvements alone will not be able to keep pace with the future increased demands (increases in manpower will most assuredly be needed), they will allow Toyota to better meet these challenges.

This process of improvement is underway in many areas at Toyota. During my time there, I saw many differing levels of progress. Many groups were well on their way, having devoted manpower and time to study their future demands and how they were working today to meet those demands. Conversely, many groups were not planning for the challenges ahead. Vehicle Production Engineering Assembly certainly knows of the challenges ahead and management is looking at how to meet these challenges. However, due to the numerous short term challenges that they are facing, long term planning is not as far along as one might hope. Adequate planning and manpower to address these long term challenges is needed.

Toyota also must ensure that it is working on areas and tools where the maximum overall process improvement can be achieved. The Design Structure Matrix analysis carried out in this project identified three areas where small improvements to an individual step or process resulted in a significant reduction time reduction in the overall process. Those areas included the transfer of information from design to Vehicle Production Engineering Assembly (CE Concept), the time required to investigate equipment (Equipment Investigations), and the time to complete digital reviews of new models and changes to the assembly line (Digital Reviews). Of the three, improved communication from design to assembly results in the greatest overall process improvement. In addition to other areas where it is working on improvements, Toyota should consider changes to better link design to assembly and manufacturing.

7.5. Thoughts on the Toyota Product Development Process

While this project has pointed out many of the problems that Toyota Motor Manufacturing North America and Vehicle Production Engineering Assembly face during the product design process, I believe that this process is still very good overall. The process is very customer focused and consistently provides automobiles that consumers value. The process consistently develops product features that customers are willing to pay for. Suppliers have a vested stake in the process and are encouraged to develop new product features. This process enables both Toyota and its suppliers to share both the risks and rewards of innovation. All in all, the Toyota product development process has greatly contributed to Toyota's current industry leader position and will likely continue to do so in the future.

While this process has greatly strengthened Toyota overall, it has come at a price. The process promotes the delay of important product decisions until late in the design process in order to better meet perceived customer needs. This process creates a great of deal problems for plant manufacturing and Vehicle Production Engineering Assembly. They often are required to develop equipment that is capable of accommodating several different design specifications. This often created additional stress on these groups to meet time and budget constraints. In order to meet these challenges, it is my belief that Vehicle Production Engineering Assembly needs to improve both its internal communication (via a group shikumi) as well as its communication with upstream design groups.

Perhaps the most refreshing part of this project was the fact that Toyota understands these problems. Rather than choosing to ignore these problems in the hopes that they may go away or correct themselves, Toyota is facing them and attempting to determine a method to overcome them. While Toyota may not completely understand what strategy they will employ, they do believe that the challenges can be overcome. This knowledge of the problem was apparent throughout the organization, from the hourly employees through upper levels of management. Communication of these problems was very good and provided a focal point for all team members' efforts. This common understanding of problems facing Toyota is a unique and key feature of its corporate culture.

7.6. Recommendations for Follow-on Research

There exist many opportunities for follow-on research concerning the Toyota product development process. Due to the set-up of the internship in Kentucky, direct access to design functions was extremely difficult to achieve. As such, the scope of my research was somewhat limited to only those organizations that I had access to, greatly limiting the breadth of this research. As such, the possibility exists for follow-on research opportunities. Of particular interest would be a similar internship project with a portion of the design organization. This research could be conducted similarly to outline, define, and streamline the design process. Due to the concentration of the design function, Japan would be a great location for this project. Similarly, research at the Toyota Technical Center would also prove a valuable study of Toyota's operations in North America.

Additionally, a complete Design Structure Matrix analysis of the entire product development process would be of interest. Due to the enormous size of Toyota, both in sheer process/personnel numbers and geographic distance, this project would likely require increased levels of research manpower and time. This thesis combined with the design-focused project described above could serve as a basis for this complete product development process DSM project. By having access to the complete process, this project could provide a unique perspective of the entire process and significant improvement opportunities.

7.7. Final Comments

Throughout my Leaders for Manufacturing internship at Toyota, I have observed many challenges and opportunities as Toyota pushes towards a standardized assembly line equipment selection process. This thesis pointed out many challenges that Toyota faces during this process. However, I was very excited to observe that Toyota's leadership understood that these challenges existed and that they needed to face them. While they did not always understand how they were going to overcome these challenges, the fact that they acknowledged their existence and understood their potential impact speaks volumes about the Toyota organization.

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