Lean Engineering Standard Work In the Product Development Process

by

Mario Alberto Rubio Monroy

B. S. Mechanical and Electrical Engineering, 1997
Instituto Tecnológico y de Estudios Superiores de Monterrey

SUBMITTED TO THE SYSTEM DESIGN AND MANAGEMENT PROGRAM
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Science in Engineering and Management

at the

Massachusetts Institute of Technology

February 2016

Signature redacted

Signature of Author____

Mario Alberto Rubio Monroy
System Design and Management Program

Signature redacted

Certified by____

Eric Rebentisch
Research Associate, Sociotechnical Systems Research Center, MIT

Signature redacted

Accepted by____

Patrick Hale
Director – System Design and Management Fellows Program
Senior Lecturer – Engineering Systems Division

This page intentionally left blank

Lean Engineering Standard Work In the Product Development Process

by
Mario Alberto Rubio Monroy

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

Master of Science in Engineering and Management

Abstract

This thesis proposes to use an adapted version of ESW (Engineering Standard Work) to develop an assessment that enables identification of opportunity areas for the implementation of ESW in an existing Product Development Organization, by integrating the consistency and quality of the work performed by the engineers, with the additional benefit of introducing lean engineering standardized processes that will help them to work in a more structured and efficient way. The standardization tools would add value to the organization by guiding the engineers throughout the product development process that are designed to minimize process variation introduced by the engineer and to eliminate unnecessary activities. The group of these standardized processes with the integrated Lean Engineering tools is named as LESW (Lean Engineering Standard Work), these would provide support defining crucial steps within a process or provide guidelines for specific characteristics of the product design using the current best practices to follow to complete their jobs. They would be based on firsthand experience and would be updated and validated regularly to incorporate any new data or technological developments. With LESW implemented, the engineers no longer have to work from memory. The process documentation provides a baseline, a standard, which would be referenced by any engineer whether experienced or not, and since the process is documented then it will also help to improve the learning curve of new hired engineers.

A gap analysis is performed in order to understand the organization's current status vs. desired status, and then, based on the findings, a new way of working is proposed with the implementation of the best suitable lean engineering techniques applied to a product development organization, including LESW as part of the improvement. All this is done keeping the main target of making the organization more efficient, the process friendlier to the engineer, having a more stable and reliable process that can be duplicated in the entire organization. The management would also be benefitted, by having a better control of the programs, avoid delays and reduce costs by reducing the amount of errors committed by the engineers.

Thesis Supervisor: Eric Rebentisch

Title: Research Associate, Sociotechnical Systems Research Center, MIT

Acknowledgements

To my son Mario, to whom I dedicate this thesis, thanking him for showing me his love and support all this time, he has enlightened me since he was born, giving a beautiful meaning to my own existence.

To my Father, who has been the torch leading my path, even now when he is only present as a guiding spirit.

To my mother, who taught me to never give up and to never feel defeated even defeated because there is always hope and because life is a continuous challenge whose journey we must enjoy.

To my sister Tere, who has always been there for me in both the good and bad times, always supporting me and demonstrating the meaning of honesty and trust in each of her actions.

To my sister Monica, a perseverant soul, a human phoenix, who shows me the possibility of being reborn from our own ashes in order to become a stronger human being.

To my brother Jorge, an entrepreneur making his dreams a reality, the best mixture of ambition and family values.

To Harumi, for her great support during all this time, my Buddhist guide and best friend in the USA.

To my friends Ferlo, Luigi, Thomas and Alex; my peers throughout my master's journey; they were a valuable source of learning opportunities that made this time truly enjoyable.

To my professor Eric Rebentisch, I will forever thank him for his infinite patience with me, leading me to my own discoveries, guiding me along the right path and helping me to enjoy doing this thesis.

Glossary of Acronyms and abbreviations

Acronym:
A word formed from the first letters of each one of the words in a phrase

Countermeasures:
All of the Lean tools, including the tools in this book, are countermeasures. A countermeasure is by definition an interim solution, which helps us remember to review it periodically to see if it's still working, and to improve it if we can. We always have the ability to replace it with a better countermeasure later.

CPDP:
Corporate Product Development Process

Escape:
According to the UTC jargon an "Escape" is any problem or inefficiency that reaches the internal or external customer. In other terms, a problem or inefficiency that leaves the engineering department or functional area.

EPDP
Engineering Proficiency Development Plan; this is a system developed for the NACC in order to assess the proficiency and development of the engineer's capabilities working for the product development organization.

Kaizen:
A Japanese word that literally means: To take apart and study, and then put back together better than it was.

LAI:
The MIT Lean Advancement Initiative (LAI) was a research consortium that was founded in 1993 and active through 2012. LAI's purpose was to enable enterprises to effectively, efficiently, and reliably create value in complex and rapidly changing environments.

LESAT:
The LAI-Enterprise-Self-Assessment-Tool (LESAT) is an enterprise level assessment tool designed to guide leadership through a transformation process leading to enterprise excellence.

LESW:
Lean Engineering Standard Work

MIT:
Massachusetts Institute of Technology

MUDA:
A Japanese word meaning "futility; uselessness; idleness; superfluity; waste; wastage; wastefulness", and is a key concept in the Toyota Production System (TPS) as one of the three types of variation (muda, mura, muri) [1].

MURA:
A Japanese word meaning "unevenness; irregularity; lack of uniformity; non-uniformity; inequality [2] [3] this term was simply defined by Womak as "unevenness in operations" [4]

MURI:
A Japanese word meaning "unreasonableness; impossible; beyond one's power; too difficult; by force; perforce; forcibly; compulsorily; excessiveness; immoderation" [3] And Womak defines it as "any activity that is waste because it doesn't add value for the consumer but does consume resources" [4]

NACC:
North American Car Company

Product Developer:
Any person that is part of the product development process [5]

SDM:
System Design and Management (MIT)

Standard Work:
Is the method by which work is simplified and structured to ensure maximum quality, productivity and repeatability over time.

Synergy:
From Greek "συνεργος"(synergos) meaning: working together, synergy is an abstract concept that refers to a result that arises from interacting processes; this interaction or cooperation of two or more organizations, substances, or other agents produce a combined effect greater than the sum of their separate effects. [1].

Takt Time:
Derived from the German word Taktzeit, translated best as meter or beat; in Lean Manufacturing Takt Time is a measure of the speed at which parts must be made (one at a time) to meet customer demand. It is calculated by taking the ratio of available time in a day, and dividing it by the number of units required per day. The result is known as the beat or pace of flow. In Product Development this calculation is more complex. [1].

Upper Management:
Upper Management is defined as the board of leaders starting at the vice-president level in the NACC. At other organizations it would be the hierarchical level that has enough power in the organization to drive deep changes in the strategy of the company and the way it works. According to Investopedia (http://www.investopedia.com), upper management is defined as "Individuals and teams that are responsible for making the primary decisions within a company. Personnel considered to be part of a company's upper management are at the top of the corporate ladder, and carry a degree of responsibility greater than lower level personnel. Upper management is imbued with powers given by the company's shareholders or board of directors. Examples of upper management personnel include CEOs, CFOs and COOs."

UTC:
United Technologies Corporation

Value-creating activities:
Value creating activities are the steps that must be taken for the product to reach the customer needs. [5]

Value streams:
A value stream is a group of processes that delivers value to its customers or sequences of value-creating activities, necessary waste, and unnecessary waste. [5]

List of Tables

Figures List

1 Table of Contents

1 Thesis Introduction

1.1 Motivation

> *"Today's standardization is the necessary foundation on which tomorrow's improvement will be based. If you think of standardization as the best you know today, but which is to be improved tomorrow you get somewhere. But if you think of standards as confining, then progress stops"*
>
> Henry Ford

The automotive industry has been evolving in order to react quicker to the customer demands and to respond to the fierce competition launching new appealing models in the shortest possible time. In order be competitive in the organization, engineers need to learn new ways to work in a lean way. As part of the Product Development Organization I have been looking for ways to make my job more efficient. Since I was hired by the NACC back in 2009 my learning in the organization was not as quick as I expected. There was a frustrating feeling due to the fact that we have access to an overwhelming amount of information through the Intranet and little amount of information and guidance to perform my daily job. In general the company operates in an interesting way in which your essential activities are learned by doing. Which I believe is the right philosophy in the sense that the retention of the information is higher when we experience things first hand. However the lack of documented information on guidance for developing a part leads to the need of consulting other engineers with more experience, but I noted that each engineer had their own particular way to execute their tasks. Most of the engineers I worked with have been in the company for years and are very reliable but the work was not consistent between them. Sometimes their knowledge is not transferred in the correct way and this leads to mistakes in the process of learning and even worse it leads to mistakes on the job performed. Currently there is not a detailed work standard for the engineers in the Product Development Organization that could quickly be accessed for our daily activities in order to complete higher milestones that are part of the product development process, in a quicker, more reliable and leaner way. Based on this scenario I was willing to find opportunities to improve these tasks, understand if the described scenario was only part of my own experience, or if it was a systemic issue in the organization. I also wanted to interweave my master's degree learning to my own organization by applying this knowledge to the automotive industry, which is one of the most complex sociotechnical organizations in the world.

1.2 Problem Formulation

There is a fierce competition in the Automotive Industry and if a company is willing to succeed it is necessary to operate in a lean way at every level of the company. One of the most important operations is performed by the Product Development Organization, which requires launching new products that satisfy and if possible exceed customer expectations. And the ongoing ability to deliver a quality product quicker than the competition yields to a sustainable competitive advantage, so through time the product lifecycles have shortened and continue to shrink; this leads to a zero chance to commit mistakes in the process.

The NACC (North American Car Company) has taken several steps in order to improve the required time to develop a new product, reaching the current state of the organization by creating the CPDP "Corporate Product Development Process", with the aim of having a rigorous system applied to all the different branches of this international organization. The Product Development (PD) organization follows the CPDP system, which establishes clear milestones required to develop a new vehicle; however sometimes engineers work on activities that do not add value and create waste in time and resources. If some activities are not requested or completed on time then later those activities would create big issues leading from delays in the program to recalls, even to the extent of compromising the safety of the customers and a possible irreparable damage to the reputation of the company. In general this does not occur and has never occurred, the quality of the product nevertheless accomplished, thanks to the professionalism of the engineers and managers involved and a conservative review and verification practices. This situation has, however, a high potential for process inefficiency. For this reason it is required to find ways to improve consistency in the different activities and tasks performed by the engineers across the product development organization.

The thesis is focused on the engineering center located in Mexico City; which is an engineering branch with around 900 engineers providing support to Global programs. This engineering center is relatively new, providing support mainly to the North American operations, but since most of the programs are now handled globally then our engineering center also has involvement in other regions.

At the moment the current Product Development organization gives the freedom to engineers to work in their own way as long as they meet the required program milestones, and of course meet the expected quality and engineering needs from individual parts, systems and up to the entire vehicle. This freedom creates a scenario that leads to inconsistencies in the work being done, plus the fact that non-value-added activities need to be found as sources of waste that need to disappear from the system.

In order to have an efficient system, it is needed to create a framework that allows the analysis of all the relevant single activities performed by the engineers, in order to ensure a consistent, predictable and reliable outcome from engineer to engineer. This understanding is absolutely needed by a company like ours that has engineering centers located in different regions of the world. Especially considering that entire programs move from region to region as needed by the company.

Besides the described issues it is needed to know how lean the operations of our organization are, and at the same time create a framework that implements the best lean tools applicable to the Mexican engineering center.

1.3 Thesis Objectives

In order to provide a structured proposal that addresses the situations previously exposed, the research integrated only on the automotive industry, but also other industries were I found interesting situations similar to the one we are currently facing in our engineering organization. Based on the findings the thesis main objectives are described in the following points:

1) Literature Review: Research the available literature looking for good examples of lean applied to Product Development Organizations.
2) Benchmark Model Based on the literature review; create a desired benchmark model that includes the best lean practices of a Product Development Organization.
3) Proposed future PD State Compare current status of the organization versus the desired model, in order to establish the gaps and opportunities. Based on the findings propose a framework that will help achieving the desired future state of the organization.
4) Recommendations Based on the findings propose recommendations for implementation
5) Reflections and Conclusions Based on all the provided information
6) Future Work: Additional recommended work not covered by this Thesis that would be valuable for the organization

It is expected that the desired outcomes of the LESW is to provide a framework with efficient lean methodologies in order to obtain the following desired outcomes:

- Increase productivity
- Increase Value creation
- Improve motivation of employees
- Improve Definition of Roles and responsibilities
- Reduce learning curve of new employees
- Establish clear policies for the work well done
- Continuous improvement of the standard

1.4 Research Questions

By comparing the results of the gap analysis between the current status of the NACC organization and the proposed Lean Engineering Standard Work (LESW) benchmark model the following research questions could be answered.

1) LESW: Does the system already have embedded in its system a similar and efficient process as the LESW?

2) Lean Tools: Does the organization currently consistently apply the lean engineering tools?

In order to respond these questions, a survey was created, which was used to assess the current status of the NACC organization vs the desired future model based on the proposed LESW model.

From the obtained responses several recommendations will be provided in order to improve the current system. The survey was separated in sections; the purpose of doing this is to better understand the whole system based on the elements of the LESW model. It is probable that some sections are performing a lot better than others, so this will serve to concentrate the efforts on the areas that are needed the most and avoid spending resources on areas that are not a priority because are performing in the proper way.

It could be also the case that the whole organization is already performing efficiently and this would mean that the LESW is not needed. But there is no way to know it without actual information from the engineers that are working using the system at the current performance. Here the need of the survey.

2 Literature Review

American companies have been pioneers in the automotive Industry since Henry Ford created the concept of the efficient assembly line and for a long time these companies prevailed as leaders of this industry. However in the 1980's Toyota swept the world developing products in much less time and less manufacturing resources by improving the production systems. In fact the products had few defects according to the quality reports. At that time it was a mystery for the western companies to understand the reasons of such a success.

In 1979 MIT founded the International Motor Vehicle Program [6] aimed to understand the challenges faced by the global automotive industry analyzing paradigms, management systems, and technological innovations. A team led by Jim Womak, Dan Jones and Dan Roos (all three senior managers of IMVP) worked on a 5 year project using a rigorous research program that started in 1985. This project received funding in equal amounts from North America, Western Europe and Japan in order to not be subject to national or regional pressures in the conclusions. One of the most important outcomes from this investigation was the publication of the renowned book "The Machine that Changed the World" [7], this book showed how Japanese companies and specially Toyota revolutionized the automotive industry by creating a system that uses less of everything, creating more value on their activities which in fact is a clear definition of "lean" a term coined by IMVP researcher John Krafcik.

After the release of "The Machine that Changed the World" a vast amount of other studies and books were published aiming the efforts to the Manufacturing side of the companies in order to allow them to become lean.

Figure 2-1 Snippet of MIT Lean History [8]

However little was done applying the lean philosophy in the Product Development System. For the Toyota case there was no documentation that provided a deeper understanding of the applicability of "lean" to the Product Development, it was until the research done by James Morgan and Jeffrey Liker that the world was able to fully understand the way Toyota applied the lean concepts in Product Development organization. Morgan and Liker had access to an incredible amount of restricted information that allowed them to compare American versus Toyota, regarding the developing of their products. The work published by Morgan and Liker was titled as "The Toyota Product Development System", their book served as a reference for most of the automotive industry regarding the applicability of "Lean" in the Product Development Organizations.

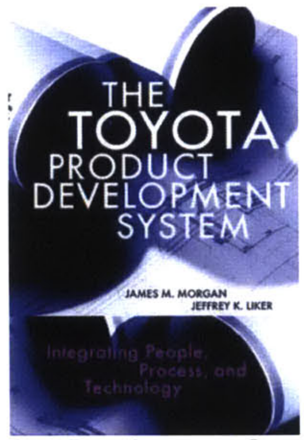


Figure 2-2 The Toyota Product Development System (Morgan & Liker, 2006)

James Morgan and Jeffrey Liker work were the most influential references that helped to develop the current stage at which the studied organization works. The lean philosophy was very well accepted in the organization and several aspects of the PD (Product Development) improved reducing the timing to develop new vehicles close to the ones only seen in the Asian companies.

Relative to the need to move faster in the automotive industry John Murphy, a research analyst at the financial firm Bank of America/Merrill Lynch has been presenting an annual proprietary study for the U.S. market showing that "replacement rate & showroom age are major determinants of market share, which drives capacity utilization, which in turn drives profitability and ultimately stock and bond prices" [9], since PD plays an important role in the cadence of events for improving the replacing rates it demonstrates importance of executing the engineering programs with excellence and zero waste as targets.

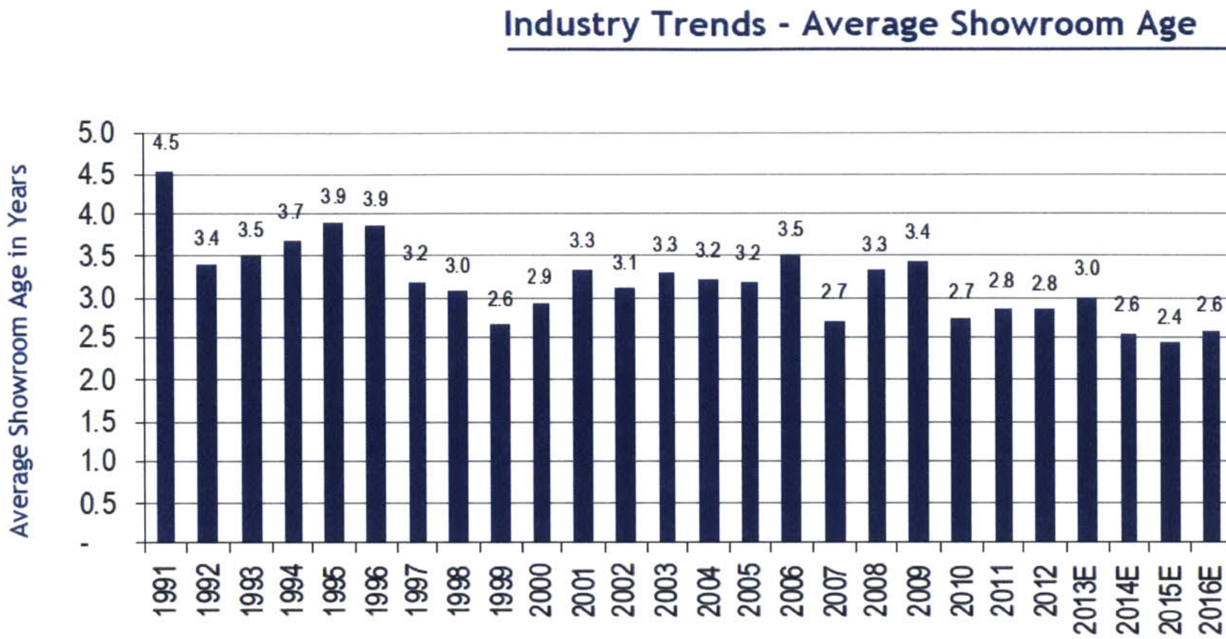


Figure 2-3 Avg. Showroom Age Trend (BoA-Merrill Lynch, 2012)

The graphic above shows the estimated average age for vehicles of model years 2013 to 2016 is about 2.6 years, down from 3.2 on average for the last decade. Competitive pressure and increasing utilization of common global platforms will continue to drive down product cycle times. [9]

One of the most efficient ways to improve the performance of Product Development is the utilization of lean engineering, and as it will be explained later, lean tools need to be adopted and adapted to the specific circumstances of each individual organization. This means that there is no silver bullet to optimize every system; it needs to be specifically designed considering the current status of the company in order to have an ever-evolving system always looking for a zero waste target. However there are lean engineering practices of product development common in diverse industries that have proven its value.

MIT-LAI consider the different activities in product development can be categorized as either, value creating (e.g. interacting with a customer to elicit his or her requirements), necessary but non-value creating (e.g. performing a necessary handover), or waste (e.g. over-engineering a component). [8] Other authors as Katherine Radeka define two types of waste, unnecessary waste: like defects, excess motion, and scrap, which obviously by removing them the system will perform better and "Necessary waste is all the non-value-creating work we do in order to keep the system working in its current state."

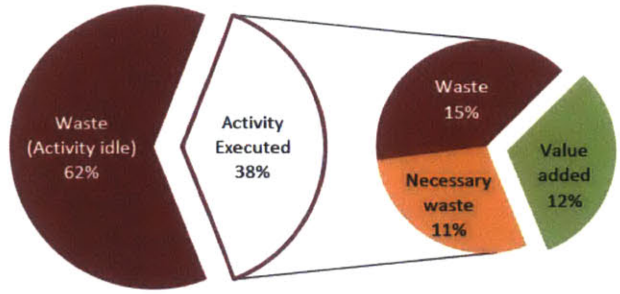


Figure 2-4 Time Share of Different types of activities in PD

Based on LAI's research and experience, the central value-creating engineering tasks are idle for most of the time (62%). If the tasks are active, engineers spend 40% of their time on pure waste, 29% necessary but non value adding activities, and only 31% on value adding activities (McManus, 2005, Oppenheim, 2004). Combining these two findings (Figure 2-4), on average only 12% of the time during the execution of a project are spend on value adding activities, 11% on necessary, but ultimately non value adding activities, and 77% of the time is wasted (the project either being idle, or the engineers working on waste).

According to a document published by the MIT-LAI, Lean Product Development "*can be understood as creating a product recipe or set of specifications that are then transformed into a physical product or service*" and comparing the lean initiatives from its predecessor "Lean Manufacturing" several processes the raw materials are transformed into products, similarly information is the required raw material for Lean Product Development. So Lean Product development focuses on the transformation of this information in order to create the most efficient recipe to create a product. From this document the MIT-LAI related the sources of waste from Lean Manufacturing to similar sources of waste found in a Product Development organization. When we focus the sources of waste in the transformation process of information the following 8 sources are described as the principal ones (Figure 2-5):

The Eight Sources of Waste in Product Development (MIT-LAI)

Figure 2-5 The Eight Types of Waste in Lean PD [8]

Product Development processes are very complex and the analysis and modeling of waste is even more complex because they interact in a vicious circle that concatenates dependencies in destructive synergetic ways. Despite its complexity it is always possible to map a value stream focusing and detecting the most important trouble spots.

According to the MIT-LAI the eight sources of waste [8] (Cited in the following list)

1) Overproduction of Information: Basically this occurs whenever either superfluous or unnecessary information is delivered, or if information is provided out of sync and therefore not useful. Examples: Two different groups creating the same deliverable or delivering information too early.

2) Overprocessing of Information: This is related to unnecessary information processing (while overproduction is related to the output of a process and delivery of information). Overprocessing can be divided into overengineering (generating information beyond the required specifications), data conversion (converting data between information systems or between people), reinvention (existing components or technical solutions are not reused) and processing defective information (defective information is used as process input). Examples

of this kind of waste can be described as the overengineering of components and systems, or that the organization is working using different IT systems, converting data back and forth during the transfer of information.

3) Miscommunication of Information: It occurs either through inefficient communication, or ineffective communication. Examples of *Inefficient* Communication: Use more resources than needed to conduct the communication (e.g. data format conversion instead of using unified IT systems, drafting of memos where phone calls would have sufficed). Examples of *Ineffective* communication: Large and long meetings, excessive email distribution lists. Unnecessary hand-offs instead of continuous responsibility assignments.

4) Stockpiling of Information: This waste leads to the build-up of information inventories, and, in the broader sense, inventories of product features and capabilities. Examples: Saving information due to frequent interruptions, or creating large information repositories due to large batch sizes.

5) Generating Defective Information: This waste is related to the quality of system components and architecture, the deliverables being up-to-date, and the defects that might occur during communication. It directly leads to three types of other waste: Processing defective information, rework and waiting. Examples: Making errors in component and architecture design or delivering obsolete information to following tasks.

6) Correcting Information: This waste is waste associated with the repairing or reworking of information. Examples: Optimization iterations late in the program, or reworking deliverables due to changing targets in the program.

7) Waiting of People: Waiting means that a person involved in the production of information is idle, so the value stream is not flowing. Examples: Waiting for long lead time activities to finish, or waiting due to unrealistic schedules. Or waiting for an authorization to perform or continue with the subsequent work process.

8) Unnecessary movement of People: can be typified as unnecessary human motion to obtain information due to insufficient information systems, disparate locations, and inefficient use of equipment, tools and techniques. Examples: Obtaining information by walking up and down from one point to another, traveling to meetings. A badly designed engineering center offices.

The 3 M's of Waste [10]

The Toyota Product Development System includes three types of interrelated waste: Muda, Mura, and Muri; Known as the Toyota Three M's.

1) Muda (Non-Value-Added): This is waste that includes any activities that lengthen lead times and add an extra cost to the product, for which the consumer is unwilling to pay. Is the best-known "M" as it includes the seven wastes of the Toyota Production System (Overproducing, Waiting, Conveyance, Processing, Inventory, Motion, and Correction) later compared to other sources of waste in Chapter 3.
2) Muri (Overburden): Muri is pushing a machine, process or person beyond natural limits. Overburdening people can lead to sloppy work resulting in quality issues breakdowns and defects. This situation leads to downstream errors and rework.
3) Mura (Unevenness): The basic nature of Product Development is unevenness; sometimes there is more work than people or machines can handle; at other times there is not enough work.

Common Sources of Waste in Product Development [5]

Another perspective of waste is offered by Katherine Radeka, according to her experience and after benchmarking different Product Development organizations has found the ones cited in the following paragraphs.

1) Design loopbacks: This is the most common and obvious source of waste in product development. This source of waste could be compared to the other authors as "Correcting Information" per MIT-LAI definition or simply "Correction" per Toyota and Morgan & Liker definition.

2) Reinvention: Reinvention is the need to redesign or rework something because previous solutions to a problem are not accessible to the problem solver or not generalized enough to be reusable. This is similar to the definitions of "Overprocessing of information" per MIT-LAI and "Processing" per Morgan & Liker.

3) Unproductive meetings: Any meeting that does not have a clear purpose or that result in no clear decisions or actions is waste. This includes all of the meetings we hold just to communicate status. This source of waste can be compared to "Miscommunication of information" per MIT-LAI or "Overproduction" per Morgan & Liker

4) Insufficient customer empathy: This type of waste cannot be related to the other ones listed before and refers to the capability of any organization to deliver customer value. According to Radeka the most wasteful thing a product development organization can do is to deliver the wrong product.

5) Excess requirements and specifications: Excess requirements and specifications create waste in three ways: By developing things the customer does not want, by building products to rigid specifications that rob all the ability to maximize value as knowledge increases and by maintaining the extra product complexity throughout the life of the product. This source of waste can be related to "Overproduction of information" per MIT-LAI, and "Overproduction" per Morgan & Liker.

6) Excess project management overhead: Product development is too complex to do without some way to track schedules and budgets, for this reason Project management is a necessary waste. At the same time, all the effort expended on project management contributes nothing to customer value and may in fact make it harder for developers to contribute value. It is difficult to relate this type of waste with other sources described by other authors; per my own experience it is important to consider it as a real source of waste in a PD organization.

7) Overloaded resources: If product developers have too many projects and do not have a prioritized list of projects to work from, then senior product development managers have delegated responsibility for making strategic decisions to the people least equipped to make those decisions. Overload in fact can provide exactly the opposite result as the original intent because its final result is program delays and the incapability of the organization to work in new projects. This source of waste defined by Radeka does not fit exactly in any of the other previous sources of waste cited by previously mentioned authors.

Most of the waste sources are detected and eliminated by several Lean Engineering tools, the ones that have demonstrated being valuable and that are used extensively in Product Development organizations are the following ones:

Value Streams [5]

Value streams are sequences of value-creating activities, necessary waste, and unnecessary waste.

Product Development Value Stream Mapping [11]

The PDVSM was developed by the MIT LAI (Lean Advancement Initiative) and consists of the following four steps:

1) A preparatory phase.
During the preparatory phase, relevant stakeholders are identified, and then the team that conducts the value stream analysis is defined and trained. The problem is then bounded, i.e. the scope of the analysis is delimited. Based on scope and stakeholders, the value is defined. Lastly, the processes that create value are analyzed.

2) The mapping of the current value stream
First the tasks and flows between the tasks are mapped. Then, the necessary data to describe the value stream are collected and the generated value evaluated. As iterations play an important role in PD, those are analyzed in detail in the last step.

3) The identification of the different types of waste in the current value stream
First, the different types of waste have to be discussed, understood and agreed upon by all team members, before they are identified along the value stream in the second step.

4) The improvement of the current process.
This step may include the establishment of "takt" time to synchronize processes. Other specific actions include assuring information availability, balancing of the workload and capacity of activities, and eliminating unnecessary or inefficient reviews. Other measures addressing more types of waste are also discussed in detail. Finally, the future state of the value stream is mapped to serve as guidance for the implementation of the improvement actions.

Systematic Problem Solving Methodologies

PDCA: (Plan Do Check Act) is also known as the Deming circle/cycle/wheel, Shewhart cycle, control circle/cycle, or plan–do–study–act (PDSA). The plan–do–check–act cycle (Figure 1) is a four–step model for carrying out change. Just as a circle has no end, the PDCA cycle should be repeated again and again for continuous improvement. [12]

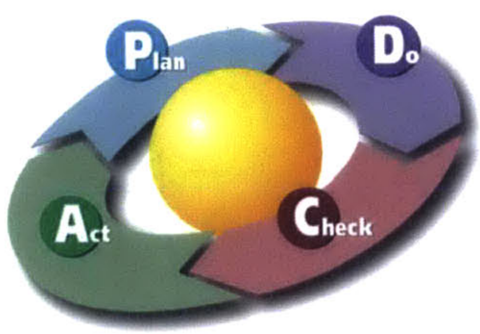


Figure 2-6PDCA Model [12]

LAMDA: (Look-Ask-Model-Discuss-Act). All LAMDA from [13]

This is the preferred systematic problem-solving method applied for product development. This method is very similar to PDCA tailored for engineers and scientists. The LAMDA Cycle consists of the following steps:

Look at the problem. The best is to have firsthand experience with the issue in order to best understand the entire environment.

Ask two questions: What do we already know? What is already known?, Who are the experts? Who has already solved this problem before? Why is this happening? And use the Five Whys (5W) tool that consists on a sequence of 5 consecutive Why's to find the root cause of an issue.

Model Create simple models to help articulate thinking; It could be physical models or visual models; the models are more useful than words helping to synthetize and transmit thoughts.

Discuss the problem and the proposed solution with a wide variety of people including identified experts, the people impacted by the problem (and the solution) and the person who will ultimately decide what to do.

Act Now, it is ready to act or put the implementation plan into place. And repeat the Cycle for continuous improvement.

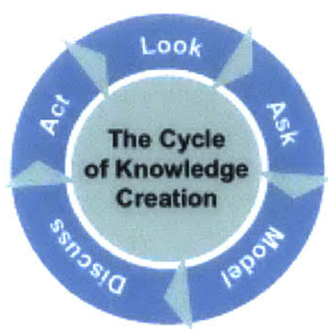


Figure 2-7 LAMDA Model [13]

A3 Reports: A3 is a communication tool supporting systematic problem solving, initially developed by Toyota. The A3 refers to the paper size: 11 × 17 inches in USA. Toyota developed three types: the Problem Solving A3, the proposal A3, and the Status Reporting A3. [5]

2.1.1 Benefits of Lean Product Development [5]:

According to Katherine Radeka the direct benefits of applying lean principles to a Product Development organization are the following ones:

1) Greater schedule predictability. It is easier to have control of the development time through the different milestones. By applying lean methodologies and system problem solving less design rework will be required reducing the overall time of the project.

2) Shorter development time. By applying lean methodologies and system problem solving less design rework will be required reducing the overall time of the project by at least 30% and once they implement and have more experience using the lean product development practices they can improve timing to deliver products by 50%.

3) Increased R & D capacity. Once the lean development practices are implemented through the organization the teams will require a lot less time on tasks that create no value, by doing this they will have more time on value creating activities such as innovation.

4) Lower costs throughout the product life cycle. Since manufacturing activities are integrated early in the development of the product and thorough analyses are carried out this is reflected in lower costs in both final manufacturing and service activities.

5) Less uncertainty. By taking advantage of the available knowledge it is easier to close the gap where required and have a better understanding of the overall knowledge level of the organization.

6) Products that meet customers' needs more completely. By integrating customer knowledge and use that knowledge to maximize value and develop products closer to customer desires.

Type of Processes

According to the MIT LAI (Lean Advancement Initiative) the three major areas or processes of Lean Product Development are:

Value-orientation

This type of process is focused on the creation of value and elimination of waste. [8]

Enterprise Integration

As its name self describes it "Enterprise Integration" aims to integrate all enterprise processes and is considered one of the main challenges in order to develop a Lean Enterprise. [8]

Efficient Execution

Efficient Execution finds ways to improve the PD processes within the PD organization and the overall enterprise. [8]

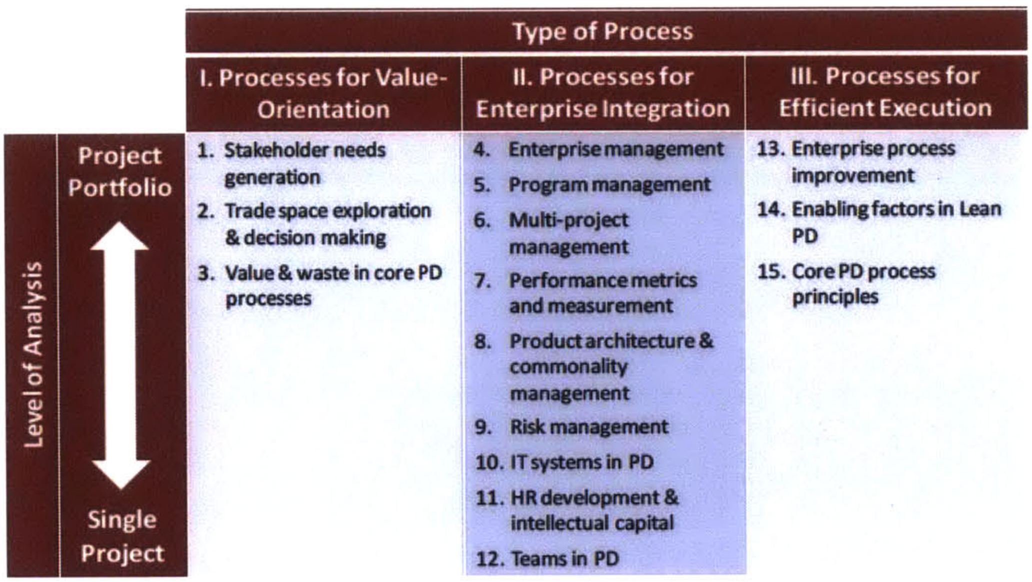


Figure 2-8 Three Main Areas of Lean Product Development [8]

The implementation of LESW focuses on improving the efficiency of Product development activities, for this reason it is considered as part of the "Processes for Efficient Execution." (Figure 2-8)

The following chapter provides valuable information about "knowledge management" which is an important part of the LESW model.

2.1.2 The Knowledge Creating Company [14] and [5]

The "Knowledge Creating Company" refers to a book originally released as an article back in 1991, this article later became a book published by Ikujiro Nonaka, which popularized the notion of "tacit-knowledge" (abstract knowledge and experience difficult to carry and share because it is embedded into the minds of the engineers) and "explicit knowledge" (knowledge that can be transferred into teachings and documents), these references are included in several chapters of this thesis. Managing both kinds of knowledge is vital for innovation; making efforts to convert tacit knowledge into explicit knowledge creates a strong corporate asset for the company, and once this knowledge is transferred then is converted again into tacit-knowledge by being disseminated throughout the organization, becoming even more valuable when is used again to innovate by taking the advantage of the experience, creativity and abstract thoughts of the engineers. In his book, Nonaka demonstrates that the companies that are capable of managing knowledge are being faster and more innovative which, at the end provides a strong advantage in order to beat the competition in terms of time, quality and execution.

2.2 Summary of basic concepts on Lean Engineering

The initial part of this literature review starts with a short history of the evolution of the concept of "lean" which was originally applied in the manufacturing world, and that later was applied to Product Development organizations. One of the most representative books mentioned in this field was "The Toyota Product Development System", written by Morgan & Liker.

Sources of waste were briefly described from different author perspectives, and a series of basic "Lean Engineering tools" were presented; since an essential part of lean principles is the detection and elimination of sources of waste. These tools have demonstrated its usefulness in both manufacturing and product development organizations.

Later, it was mentioned the concept of the "Knowledge Creating Company" developed by Nonaka which provides the basic concepts of knowledge management which mentions the importance of the cycle of knowledge management.

The next chapter provides a brief history of the origin of the proposed LESW model.

2.3 Origins of the "Lean Engineering Standard Work" model

The concept of the LESW.; Lean Engineering Standard Work evolved from a patent found through the investigation of standardized engineering processes and activities that could be used to address the issues previously presented on the thesis introduction. The investigation was originally centered in the automotive industry, but little information was found, for this reason the search fields were expanded in order to include other industries, such as the aeronautical industry, space industry and even the medical industry. Of course, the search was limited to organizations with a structured product development process, and it was desired that the discovered system was operating in synergy with other elements of the organization, providing at the same time knowledge management, engineering activities and reporting tools for program management control. After a thorough search the patent US-7496860-B2 "Engineering Standard Work Framework, Method and System" was found, this patent was framed on the management of complex engineering processes in product development organizations. The owner of the patent was UTC (United Technologies Corporation). Continuing with the search an interesting article was found based on the previously mentioned UTC-Patent; this article was published by Harvard Business School and written by H. Kent Bowen and Courtney Purrington. The article is about the aeronautical company Pratt & Whitney, which is the UTC division that implemented the patent and the article, contains a thorough analysis of the Engineering Standard Work (ESW) framework, providing details about the great benefits that UTC obtained from it. (More detailed information is presented on chapter 2.6)

Right after the discovery of the ESW patent the original intent was to adapt this model created by UTC to the NACC Product Development organization. Unfortunately, the UTC patent lacked the explicit integration of the lean engineering tools, which were an essential part the pursued system to be implemented in order to optimize to the maximum the operations at the Mexican PD organization.

Considering that each organization is different, and it is not possible to find a "silver bullet" to give solution to all the organization improvement needs, a specific model was needed for our PD organization. In this sense the objective was to integrate the Engineering Standard Work from the UTC patent as the fundamental base from which the LESW (Lean Engineering Standard Work) would emerge.

In order to create the LESW model, the thesis integrated three main sources of information; and a few papers to support the main ideas of the proposed model. The reasons of choosing these principal sources are described in the following bullet points:

1) "Toyota Product Development System" provides 13 lean principles unveiled by Morgan & Liker after a 5-year research at Toyota. These principles are summarized in chapter 2.4 in order to offer a background that later will be referenced in the LESW model. This book was selected since previous initial efforts to implement "lean" concepts in the NACC followed the principles described in Morgan & Liker work.

2) "The Mastery of Innovation: A Field Guide to Lean Product Development". Is a book written by Katherine Radeka, which provides a deep analysis of successful implementations of "lean" practices; Radeka focuses its work on "The Four Value-Streams of Lean Product development" looking for a continuous search to maximize value. This value stream concept is later integrated as part of the LESW model.

3) "UTC Engineering Standard Work" is a patented method and a system for managing complex projects created by UTC (United Technologies Corporation). This patent provides the most valuable information for this thesis by framing the needed structure for the purpose of establishing standardized activities in the NACC Product Development organization.

This thesis includes extracts from the above literature reviewed and used in order to later explain the proposed LESW benchmark model for the optimization of the studied Product Development Organization. The extracts are presented in the same sequence as the previous list in order to sustain the LESW model.

2.4 The Toyota Product Development System[1]

Jim Morgan already had a couple of decades of experience in the automotive industry when he decided to write "The Toyota Product development System", at that time he was a Ph.D. student at the University of Michigan collaborating with Professor Jeffrey Liker, who is widely known and praised for his book "The Toyota Way". This amazing project took several years and both of them counted with an unprecedented access to Toyota's Development Organization in the United States and Japan.

The result of this mix of experiences with Morgan in the automotive world, and Liker knowledge in the Toyota philosophy, created not only a theoretical but a practical analysis of the basic singularities of Toyota product development system, which, compared to the European and North American companies seems to be way more evolved.

The following paragraphs provide a review of the 13 principles, which were integrated in the proposed LESW (Lean Engineering Standard Work) model.

2.4.1.1 The lean Product Development System Model

Socio-technical system design is based on the premise that an organization or a work unit is a combination of social and technical parts and that it is open to its environment. [15] A sociotechnical system as its name self explains, does not consider machines only but also the policies and standard operating procedures of an organization. The term system, suggests multiple interdependent parts that interact to create a complex whole; we cannot understand a system simply by looking at its individual parts. Only by studying people and equipment working together we can see the way the whole system functions.

---

[1]J.M. Morgan, J.K. Liker "*The Toyota Product Development System, Integrating People, Process and Technology*" Productivity Press, New York. ISBN 1-56327-282-2

The Sociotechnical systems model used here to describe Toyota's PD System has three primary subsystems:

Figure 2-9 PD System Primary Subsystems (Morgan & Liker)

1) Process
2) People
3) Tools and Technology.

In a lean PD system model, these three subsystems are interrelated and interdependent and affect an organization's ability to achieve its external purpose.

"*Any organization can continue to exist only if it imports sufficient information and resources from the environment to sustain the system. In other words, there must be an intimate connection between the organization and its environment*".[2]

However the existence of an organization does not mean that is automatically capable of working in perfect harmony, both internally and with its environment; it is required a set of specific tools in order to make it work in the best possible way.

Applying only one or a few set of tools does not warranty that the system will improve, the important message here is that a system in order to operate in the best way needs to apply a diverse set of tools that supports each other mutually interacting with its processes and human systems; this way of working could be described as an holistic approach engaging the whole organization.

[2] J.M. Morgan, J.K. Liker "*The Toyota Product Development System*"

2.4.1.2 The Process Subsystem

This technical subsystem "*comprise all the tasks and the sequence of tasks required to bring a product from concept to start of production*" [10]. In Lean terms "this is what you look when you map the value stream" through the product development process, which in general contains all the information to engineer a product that will be built by the manufacturing area of the organization.

The objective of a lean product development system is to capture what is actually done in the organization and not what is documented; it is interested in the day-by-day activities that will lead to a final finished product.

<u>Principle 1: Establish Customer-Defined Value to separate Value-Added Activity from Waste</u>

This principle considers what the customer values; any activity that takes time and money but that does not add value from the customer's perspective is waste.

1- *Waste created by poor engineering that result in low levels of product or process performance is the most destructive waste.*

2- *Waste in the product development process itself.* This comes from the insights of queuing theory and Product Development Value Stream Mapping (PDVSM) that can help to combat these wastes.

<u>Principle 2: Front-Load the Product Development Process While There Is Maximum Design Space to Explore Alternative Solutions Thoroughly</u>

This principle establishes that by far the greatest opportunity to explore alternatives is during the Product Development phase of the design of a product, and Toyota has been able to effectively front-load its product development process with integrated cross functional engineering resources that help to evaluate all engineering options at the design stage.

<u>Principle 3: Create a Leveled Product Development Process Flow</u>

The purpose of this principle is to create a waste-free process based on lean product development initiatives. It is important to notice that although each project will have its own engineering challenges most of the engineering activities are common project to project and program to program. Toyota utilizes the powerful perspective of the "Knowledge work job shop" to level workload, create and shorten management event cadence to create a "Takt" time, minimize queues and synchronize processes across functional departments and reduce rework to a minimum.

Principle 4: Utilize Rigorous Standardization to Reduce Variation, and Create Flexibility and Predictable Outcomes

One of the biggest challenges of every Product Development organization is to reduce engineering variation without impacting the creativity of the engineers. Toyota has created higher-level system flexibility by standardizing lower level-tasks. The three most important categories of standardization at Toyota are:

1. Design Standardization: This standardization of product/component design and architecture. It includes the use of proven, standard components shared across vehicle models, building new model variation on common platforms, modularity, and design for (lean) manufacturing standards that creates robust, reusable design architecture.

2. Process Standardization: This involves standardizing tasks, work instructions, and the sequences of tasks in the development process itself. This category of standardization also includes the downstream processes that test and manufacture the product.

3. Engineering skill-standardization: This standardization of skills and capabilities across engineering and technical teams. It is based on a deep commitment to people development and growth through demonstrated competencies. It is quite powerful and often overlooked.

At Toyota the use of this standardizations allow them to apply already known and proved solutions to every cycle of the process and create highly stable and predictable outcomes both in quality and timing. The objective is also reducing uncertainty to a minimum by applying known solutions and focus on the most important challenges that required creativity and innovation.

2.4.1.3 The People Subsystem: LPDS

It is obvious that for a sociotechnical system its most important asset is the people that work for it, for this reason it is mandatory to have a common mindset across the organizational structure; This people system starts from the recruiting, selecting, and training the engineers, up to the higher organizational level. By creating this structure, the desired organizational culture is established and will be homogeneous by sharing the same language, symbols, beliefs and values. Of course all this is reached following the lean thinking philosophy.

Principle 5: Develop a Chief Engineer System to Integrate Development from Start to Finish

Toyota has developed the Chief Engineer position in order to have a program leader that is accountable for the performance of the project and knows exactly what the status of the project is, and is able to make the best decisions by having a complete background of the issues. He is not solely a project manager but an engineer that excels as a technical integrator. His position is vital to the extent that he orchestrates and architects the complete Product Development process in order to achieve maximum performance in time, quality and expected outcomes.

Principle 6: Organize to Balance Functional Expertise and Cross-Functional Integration

For the Toyota a Product Development system it is very important to integrate each of the functional experts to all the other different functional areas, this will create the required synergy within the organization in order to deliver maximum cross-functional performance to every project.

Principle 7: Develop Towering Technical Competence in All Engineers.

Today's vehicles need to operate in a reliable and safe way, there are no chances of mistakes, and a lot of the knowledge comes from the engineers working on every part, component, and system. This demands that each engineer excels in its technical capabilities in their own areas or functions. This Technical Knowledge is absolutely necessary for a lean organization in order to reduce waste in the design stage; this waste could be very expensive later during launch or worse once the product is on the hands of the clients. At Toyota, technical excellence is revered, spending a lot of time in the formation or their engineers, providing them with a career path that deeply emphasizes their respective technical knowledge development; they specially focus on the mentoring process known as *genchi genbutsu* (actual part, actual place) that helps them experience firsthand their learning process. This principle also provides the engineers with a common ground of skills in order to have consistency in their performance level across the organization.

Principle 8: Fully Integrate Suppliers into the Product Development System.

Interestingly at Toyota 75% of the vehicle content comes from their suppliers, this means that they also need to understand and follow Toyota lean product development process. In order to achieve this they incorporate their suppliers in the same way it is done internally valuing their technical expertise. Toyota requires having supplier's engineers at Toyota engineering offices involving them since the early stages of the product development. This creates a deep integration and involvement of the supplier to the program they are working for.

Principle 9: Build in Learning and Continuous Improvement.

Every experience provides knowledge that could later be capitalized to reduce uncertainty by applying the learning on new programs and projects. Experience is a continuous learning process that provides a valuable competitive advantage to Toyota by capturing and sharing all their knowledge across the company.

Principle 10: Build a Culture to Support Excellence and Relentless Improving.

Cultural values are part of the core principles at Toyota, these values are their embedded DNA that is transferred from one generation to the next providing solid values to all the levels, from the working level to the highest managers at the corporation. This culture to excellence is a result of a continuous effort to improve the way Toyota works throughout the organization.

2.4.1.4 The Tools and Technology Subsystem: LPDS

This is the third fundamental subsystem that takes special care to the needed tools and technologies required to produce a vehicle at Toyota using the most advanced CAD and CAE systems, machines, digital manufacturing pre-evaluations. The purpose is to understand all the manufacturing needs since the early stages of the program.

Principle 11: Adapt Technology to Fit Your People and Processes.

As it was explained before the highest opportunities lies during the Product Development of a vehicle, any improvement applied later during production will not have too much impact, especially it if a new technology was not understood and integrated early in the program. Manufacturing excellence will not help a bad designed product and will not offer any competitive advantage because other companies could rapidly copy any technology. It is the integration of both the technology capabilities and product development the one that brings the actual competitive advantage.

Principle 12: Align your organization through Simple, Visual Communication.

Toyota makes use of a concept known as *Hoshin Kanri* that basically means "policy deployment". Its purpose is to help conceptualize the most important objectives and goals set by the company from the highest level of the organization to the working level. These goals are then broken to every product and function down to very specific targets of weight, cost, and safety performances (Just to mention a few). In order to communicate these plans Toyota uses very simple visual methods that are often condensed in a single sheet of paper known as A3 (From the A3 paper size). This document contains the proposal, problem solving methodology, status updates, and competitive analysis.

Principle 13: Use Powerful Tools for Standardization and Organizational Learning.

The Toyota concept of "*kaizen*", which literally means, "change for the better" [16] refers to the well-known concept of continuous improvement. And according to kaizen principles "you cannot have continuous improvement without standardization" [10] and a second corollary says "learning should extend from program to program" [10]. Toyota has developed a series of checklists that are shared through all programs in order to standardize the design process. Besides the series of checklists Toyota engineers use "*hetaku-sekke*", which is the small booklet containing the failures experienced in the past"[3]. The purpose of standardization is not only to capture information somewhere, the target is to create a "learning organization" that embeds the capture and share of knowledge as an automatic process embedded in the current engineering processes being executed. Through the sharing of knowledge new generations are also immersed into this culture of learning, transferring the knowledge and learning from previous and more capable generations to the new ones.

The Toyota Product Development System in the NACC PD Organization

The importance of "The Toyota Product Development System" relies on the fact that several principles were previously adopted by the NACC in order to improve its performance as a PD organization. NACC wanted to make the Toyota principles to work in synergy with its current operations. The NACC was able to achieve several improvements in the organization after implementing these principles. Most of them are known in the engineering community. Since these elements are already part of the NACC organization the LESW could be easily integrated within the organization, adding value to the company by improving its activities and processes as it will be explained in later chapters.

The following chapter presents the second source of information; "The Mastery of Innovation" which comes from an outstanding book that provides very interesting insights of Lean Engineering Applied to Product Development; it contains actual cases (not cited here) from over 40 companies that shared their experiences with Katherine Radeka. She has become an authority regarding successful implementations of Lean Thinking initiatives in Product Development organizations. Her aim is to help companies deliver great products from great ideas in a consistent and predictable manner, which at the end leads to success.

---

[3] Kunihiko Masaki, former President of the Toyota Technical Center (Ann Arbor,MI) pp. 279 [10]

2.5 The Mastery of Innovation[4]

As it was previously mentioned at the beginning of the literature review, the term "lean" originated from the manufacturing principles focusing on "waste elimination" but in Product Development goes beyond waste elimination to the concept of value maximization, in Product Development what can be considered as waste in fact could be used to add value to the system; the secret is to document waste sources as part of a continuous learning process, sharing the learning after a thorough analysis, and searching for new innovative ideas to overcome those problems.

In several organizations problems are hidden or reported as on "track" or "green" especially when reporting to higher management levels, generally because teams do not want to be right on the spotlight reporting bad news; nevertheless the truth is that some of those problems are still there and will jump like a fierce beast in the least expected moment. As a result many managers will reward the ones controlling the untamable beast, and will consider and treat them as heroes. On the other hand, the teams that worked thoroughly avoiding mistakes are the ones unnoticed in the organization, and even penalized when they honestly report issues with actual delays or problems declared in "red". This culture leads to skyrocket costs due to the needed expenses to control the problems found late in development or even after launching the product.

As explained by Katherine Radeka (Figure 2-10):

"Managers put pressure on teams to be more creative and go faster, overloading them with more work than they can realistically do. In early product development, teams can go faster and alleviate overload by spending less time on problem analysis, testing, and supplier qualification and by making key design decisions without exploring alternatives. All of these shortcuts come back to haunt these managers in late development when one problem after another adds delay to the schedule. If the problem is bad enough or the teams continue to take shortcuts to relieve the pressure of overload, defects escape, customers find them, and the product is plagued by post-production engineering change requests that take time and energy away from future products. Since few product development groups can just hire more staff, their people get even more overburdened. Product development gets slower and more unpredictable." [5] *Regarding "The Vicious Cycle of Waste in Product Development"*

[4] K. Radeka "The Mastery of Innovation: A Field Guide to Lean Product Development"

Figure 2-10 Vicious Cycle of Waste (K. Radeka, 2012)

In order to eliminate this vicious cycle, it is important to focus on value creating activities by building customer or technical knowledge to create innovative or desired products. At the same time it is fundamental to concentrate on waste elimination. It is fundamental the elimination of "unnecessary wastes", as the ones described on previous chapters and reducing to a minimum all "necessary wastes"; the ones that add no value but are required in order to keep the organization operating. Necessary waste can be reduced by making processes more efficient, like documentation, verification and testing, just to mention a few examples. Immediate benefit of reducing unnecessary waste is freeing time to all engineers which can be used by engineers to innovate.

Since the value creating activities are those ones that help to reach the customer wants and needs, then, the purpose of the PD organization is to maximize this value by defining the most important value streams in the organization. Radeka proposes a model of four value streams that combined with the problem solving methodologies such as LAMDA provides a strong framework in which the organization operates in a virtuous cycle.

2.5.1 The Four Value Streams of Lean Product Development

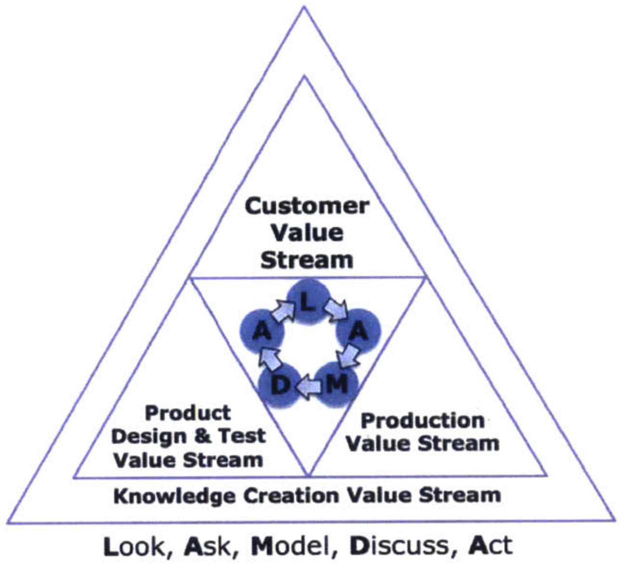


Figure 2-11 The Four Value Streams Of Lean Product Development (Radeka, 2012)

Each of the Value Streams is described in more detail in the following paragraphs:

2.5.1.1 The Customer Value Stream:

"*This value stream consists of the function that customers want to realize when they purchase a product*" [5], it is focused on what the customer values, which is not an easy task to clearly understand the voice of the customer, for this reason it is very important to be in touch with them in order to have a reliable customer knowledge, there is no magic formula to hit the precise target for which the customer is willing to select our product; however the basic proven rule to increase customer value is to innovate by decreasing cost, improving quality, and increasing ease of use. This activity has to work holistically with other areas, as marketing.

2.5.1.2 The Knowledge Creation Value Stream:

"The knowledge creation value stream is the process of building, capturing, and sharing technical and customer knowledge". [5] In the case of the NACC the technical knowledge includes design criteria, design standards, lessons learned, best practices, etc. regarding Customer knowledge is related to the translation of what the customer values including what the waste they find using the product.

Radeka provides three basic recommendations that could be resumed on the following bullet points.

1) The organization needs to explicitly allocate resources to create reusable knowledge in order to understand the fundamental science behind the product technology. This knowledge is broadly applicable to reduce trial and error during design and a significant source of competitive advantage, since it is not easily copied.

2) It is needed to build an infrastructure for sharing knowledge that facilitates knowledge reuse. Simple systems work better than complex systems, and people are more likely to reuse knowledge from trusted sources that is generalized and actionable.

3) Make it easier to reuse knowledge than it is to create something new: Part libraries, design templates, and simulation models can all embed the organization's best technical knowledge so that the path of least resistance is to use the organization's knowledge as much as possible.

This Value Stream operates in agreement with Nonaka's book "The Knowledge-Creating Company" [14] by supporting knowledge management in order to successfully maintain a strong competitive advantage. As Radeka describes: *"The ability to capitalize on an organization's knowledge supercharges a team's ability to innovate by helping them see the areas of opportunity where innovation will be the most valuable, and by ensuring that they don't have to waste a single brain cell on anything routine."* [5]

2.5.1.3 The Product Design and Test Value Stream:

"This is the value stream that integrates knowledge into product designs and then verifies that the products work as expected." [5] This value stream reflects the core activities being executed by our product development organization. By implementing lean tools each of the activities will deliver value by eliminating waste and maximizing what the customer values, in this process it is important to consider the following:

- Carefully develop a knowledge creation system with a deep understanding of the customer in order to minimize future risks and reworks.
- Use checklists and design guidelines with the latest available knowledge throughout the organization.
- Work exhaustively eliminating waste.
- Develop adaptive stage gate processes.

This powerful combination simultaneously accelerates product development, frees up capacity, improves quality, and lowers cost.

2.5.1.4 The Production Value Stream:

"The production value stream is the process of converting raw materials into finished goods, delivering those goods to customers, and then supporting the products throughout their life cycle." [5]

This value stream need to be carefully developed in order to provide to the "product developers" the needed customer and manufacturing knowledge capabilities. In order to find the right balance, between engineering design and manufacturing it is recommended to consider the following:

- Identify the waste that may come from the manufacturing issues and document lessons learned as part of design checklists.
- Understand early in the program the current manufacturing capabilities of the organization, both internally and externally (Suppliers)
- Knowledgeable manufacturing engineers need to be involved early in the development process; these engineers need to be the top representatives of advance engineering in the organization. This would allow the team to identify the risks and engage them in offering solutions and not blocking innovative ideas. Of course making good judgment of the business side of the organization.

From the model shown above (Figure 2-1) we can conclude that the first Value-Streams are continuously feeding the fourth one "Knowledge Creation Value Stream" in order to transfer tacit knowledge to explicit knowledge.

In order to interrupt and destroy the "vicious circle of waste" it is important to apply the "The Four Value Streams of Lean Product Development". Paradoxically sometimes it is required to add more necessary waste in order to have a better control of the processes, which is the case of the creation of systems like the one presented in the following chapter, the ESW (Engineering Standard Work).

The Pratt & Whitney Case is related to the previously mentioned UTC patent at the beginning of this thesis. Pratt & Whitney history and evolution is used as an example of a Product Development organization that was aware that standardization was a necessary part of improving the engineering operations. The following chapter provides more information regarding the UTC organization and the creation of the ESW model which is an essential part of the LESW model.

2.6 Pratt & Whitney Engineering Standard Work (A division of UTC)

2.6.1 History [5]

Pratt & Whitney origins date back from 1860; their founders Francis Pratt and Amos Whitney started it as a tool company whose reputation was renowned for making quality guns and gun machinery. Their dimensional control precision allowed the interchangeability of parts, a concept that was completely new at that time. Their machines were so precise that some of them started the establishment of the 'standard for inch' and in 1882 they created the famous device known as 'The Rogers-Bond Comparator' and from that time Pratt & Whitney participated in the development of standards in the USA, creating both precise measuring equipment, precise tools and gages.

Back in 1924 a talented American inventor of aviation equipment Frederick Rentschler used to work for the Wright-Martin Company during the Great War (World War I), when the war ended Rentschler became the President of Wright Aeronautical Corporation. Rentschler had his own visionary ideas, which were not understood by the board of directors, the board was composed mainly by investment bankers with almost no aviation knowledge. Rentschler wanted to convince them to fund the required research to develop air-cooled engines, unfortunately he was not successful in his attempt and since his ideas were not compatible with the main direction of the board of directors Rentschler had to resign from Wright in that same year.

Frederick Rentschler decided to continue his vision and in July 1925 he was able to strike a deal with the Pratt & Whitney Tool Company in order to develop a high-powered air-cooled engine for the Navy. Rentschler approached Pratt & Whitney because of their precision regarding the development and construction of high quality tools, which was a key element in order to produce aircraft engines.

Pratt & Whitney Company, Inc. loaned Rentschler $250,000, the use of the Pratt & Whitney name, and space in their building. This was the beginning of the Pratt & Whitney Aircraft Company.

Pratt & Whitney Aircraft Company's first engine was called the Wasp, completed on Christmas Eve 1925. The Wasp developed 425 horsepower on its third test run. It easily passed the Navy qualification test in March 1926, and by October the Navy had ordered 200 engines. The Wasp exhibited speed, climb, performance and reliability that revolutionized American aviation.

In 1929 Frederick Rentschler, ended his association with Pratt & Whitney Company, Inc. and formed United Aircraft and Transport Corporation, during this process they merged with Boeing and other companies, the predecessor to today's United

[5] This section is based on references [22] and [23]

Technologies Corporation. His agreement allowed Rentschler to carry the Pratt & Whitney name with him to his new corporation.

The notably history of Pratt & Whitney includes the development of revolutionary aircraft engines, including those used in the aircraft of Charles Lindbergh, Amelia Earhart and James Doolittle.

Later in 1934 United Aircraft and Transport Corporation was forced to split into three entities: Boeing, United Airlines, and United Aircraft, which was a precursor to UTC, and for a long time P&W controlled most of the passenger market, but they lost it when decided not to develop an engine for the B737.

Today Pratt & Whitney is a subsidiary of United Technologies Corporation (UTC) producing large commercial engines that power more than 25 percent of the world's mainline passenger fleet and the majority of the military market. The company continues to develop new engines and work with its partners in International Aero Engines and the Engine Alliance to meet airline customers' future needs. Pratt & Whitney is leader in the design, manufacture and service of aircraft engines for both military and civil industries, including auxiliary power units. P&W efforts to recover the mainline passenger fleet business are concentrated on the commercialization of the geared turbofan technology.

2.6.2 Engineering Standard Work[6]

As it is the case of every high-end technology company its success depends on the speed to react to the market needs or create new ones with innovative products. Those products need to be developed in time in order to beat the competition. In the case of Pratt and Whitney the complexity of the development of new innovative engines increased to an almost unbearable state.

Pratt & Whitney has always been an organization with highly capable engineers and resources that thoroughly designed their famous engines, and before the 1990's most of the validation was done through physical tests. Where research was required in order to verify a new design it was done by building prototypes and testing them. Part of the engineering quality assurance relied on supervisors reviewing engineering jobs in great detail in order to make sure it was done correctly several times. Young engineers were assigned a mentor and put in a rotational program of six to 12 months allowing them to be in contact with several experts.

Early in the 1990's Pratt & Whitney started to use the technological advancements of computer software, this allowed them to work more effectively, saving time and money by using computer models instead of testing prototypes. They also created a highly managed product development process known as "Integrated Program Development (IPD)" which incorporated the best management and engineering practices for the design, validation, manufacturing and support for all its products. Even with further

[6] UTC Patent: US 7496860 B2

restructuration Pratt & Whitney still needed to improve its development operations due to the fierce competition they were facing.

Pratt & Whitney reached a point in which they had the need to create a more efficient product development process to ensure consistent, predictable project execution to obtain high quality the first time the project is executed.

At the beginning of 1990 Pratt & Whitney initiated implementing Engineering Standard Work as part of the efforts in order to obtain the ISO-9000 certification. Unfortunately the upper management[7] did not support the system and it was ceased after the certification. According to the first ESW manager Sri Srinivasan: "*This initial effort was not really to comprehensively document the design process but geared more to capture the success criteria for designs, some work instructions, and procedures to do certain analysis steps.*"[8] However it was noticed that it served a very important role by documenting engineering activities. At that time knowledge was transferred from chiefs or experts to the engineering community, but all this information was lost when these experts leave the company for any reason.

In 2000 Joe Adams, was designated as the leader to implement ESW, he started to search for support and funding in order to implement ESW to Pratt's product development process. He interviewed organizational leaders to assess the status of Pratt's current engineering process and understand organizational dynamics that might create barriers to implementing ESW. The implementation of ESW moved faster after Paul Adams started leading the implementation of the system since he was a highly regarded Pratt & Whitney executive.

In most industries there is a lack of control if the product development process as a process itself; engineering and program management activities are not documented including the first time a process is being used. Because of this situation Product Development process produce huge amounts of scrap and rework, in general the flow of processes and responsibilities are not created in a harmonious and cohesive way.

Current techniques of workflow mapping rely on existing organizational structures, which become obsolete as the company or organization grows. Instead of relying on existing structures the best is to create an independent system that documents the workflows and is aligned with standard disciplines and/or functions.

The Standard Work Architecture of ESW relied in the fact that designing a complex system required the creation of a prescriptive process that made all work as foolproof as possible and caused learning to be automatic.

---

[7] Upper Management is defined as the board of leaders starting at the vice-president level in the NACC. (See glossary for more information)

[8] Bowen, H Kent and Purrington, C. "Pratt & Whitney: Engineering Standard Work". Harvard Business School. Reference 9-604-084

As it was declared by the 2002 ESW manager Vivek Saxena, the ESW is defined as "*a system to drive engineering quality and productivity through process control instead of inspection, but also as a learning process through controlled experimentation and improvement of ESW*" [17]

The basic nature of every engineer is to be creative and not just follow a cookbook, at the same time they hate to redo things over and over. For this reason instead of fighting fires it is better to use engineer's time being creative in the really important areas for the company that adds value to the product. So if the regular work is standardized, then the engineers will be more productive finishing known tasks and invest the time being creative.

With this in mind UTC worked to create a system that can improve workflow in a complex process by improving communication and coordination of activities within the process while at the same time providing details on how to execute the activities with templates on work instructions, tools and methods, design criteria and design standards.

2.6.2.1 The six elements of Engineering Standard Work[9]

In 2004 UTC (United Technologies Corporation) filed the patent US 7,496,860 B2 describing the created work management system that manage complex engineering processes. This management and framework provides a structure to drive a complex project via process control. It is important to note that the ESW operates independently from the functional areas; in fact it serves to join all the functional areas so they work in an orderly way helping to understand the relationship between them and their activities in the project.

The fundamental objective of the Standard Work Process Framework is to have a solid execution in order to achieve a Repeatable, Capable and Efficient Process:

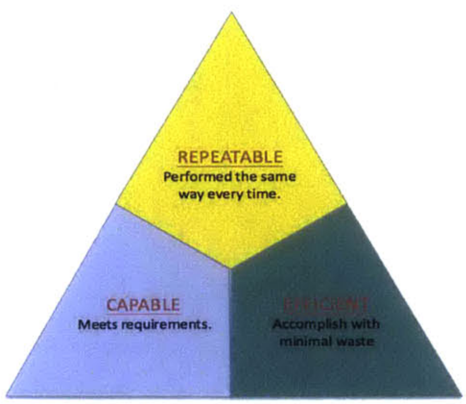


Figure 2-12 Standard Work Fundamental Objectives[10]

[9] UTC Patent: US 7496860 B2

[10] http://www-prod.utc.com/StaticFiles/UTC/StaticFiles/Standard_Work.pdf

The six elements of Engineering Standard Work:
The fundamental structure of the ESW is described in the following graphic; described by a block diagram illustrating elements in a standard work framework using functional Swimlanes. [18]

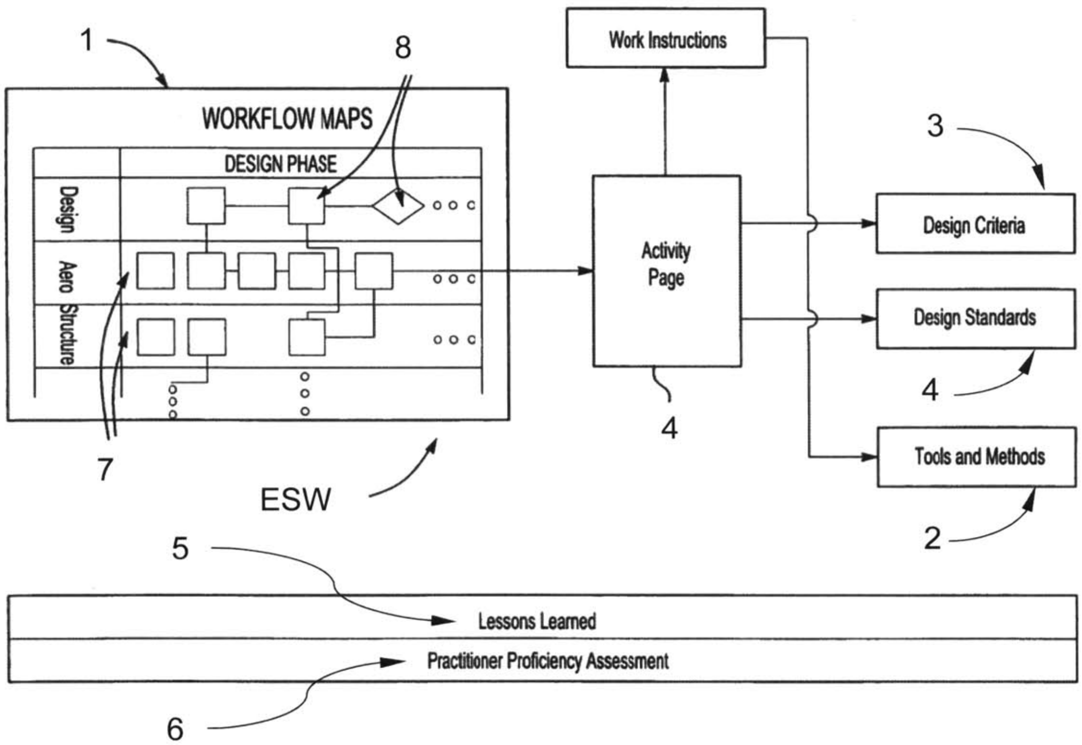


Figure 2-13 ESW Framework (UTC Patent: US 7496860 B2)

Description:

1) Workflow Maps
2) Tools and Methods
3) Design Criteria
4) Design Standards
5) Lessons Learned
6) Practitioner proficiency assessments

And additional resources:

7) Swimlanes
8) Activity Page

Swimlanes (Figure 2-13)
Swimlanes represent each of the functional areas of the organization, and their purpose is to represent the sequence of its activities, as well as the interrelation with other functional areas and its activities.

2.6.2.1.1 Workflow Maps

A Workflow Map is a graphical map depicting information flow and dependencies between activities in a clear way. [18]

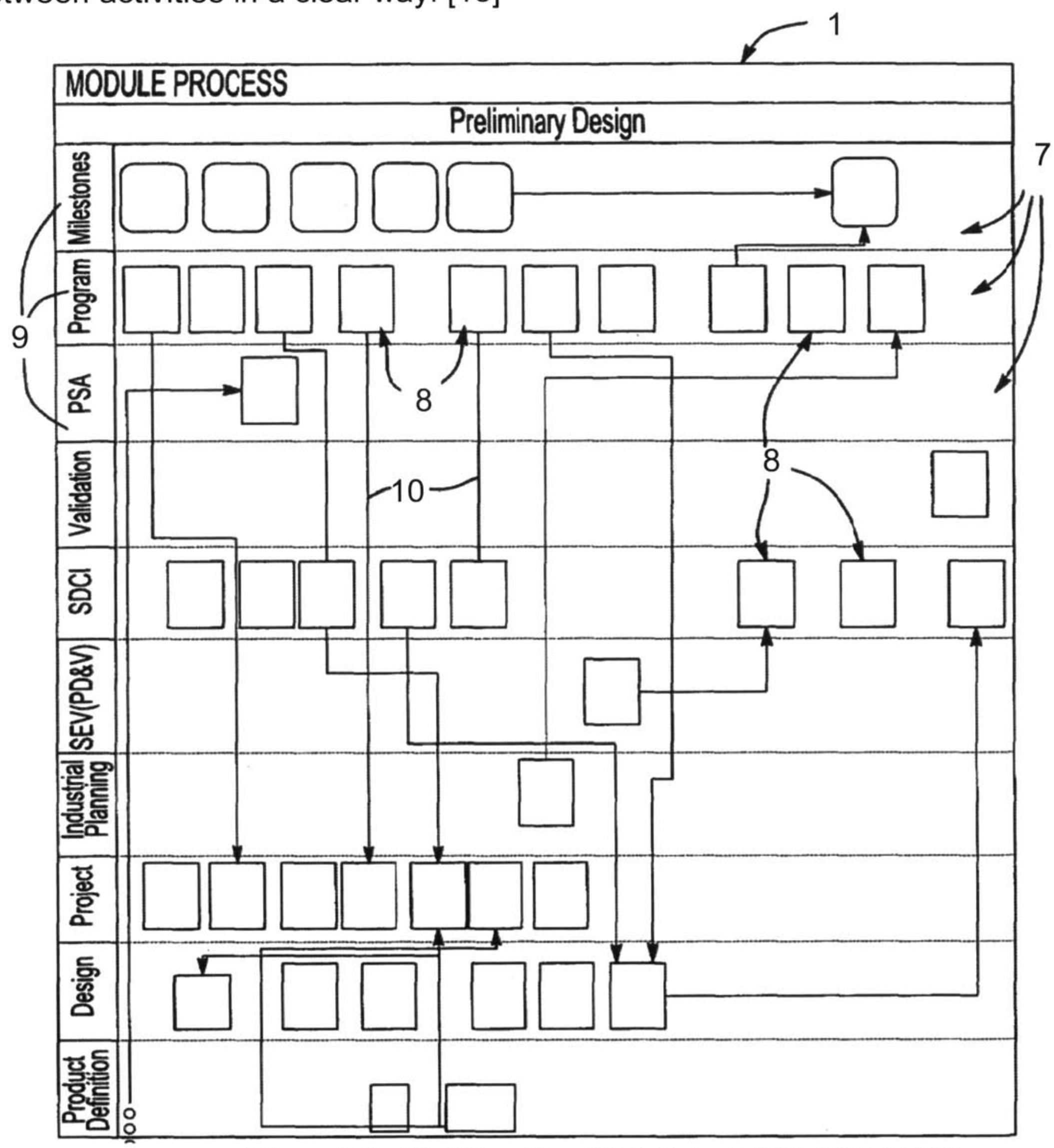


Figure 2-14 Workflow Map (UTC Patent: US 7496860 B2)

<u>Description of Workflow Map elements</u> (Figure 2-14)

1) Workflow Maps
7) Swimlanes
8) Activity Page
9) Functional Group
10) Connectors (Indicate flow between activities and/or external organizations)

2.6.2.1.1.1 *The Activity Page*

The activity Page (Figure 2-15) describes in detail each individual task on the map. This is the basic construction block of the Engineering Standard Work. [18]

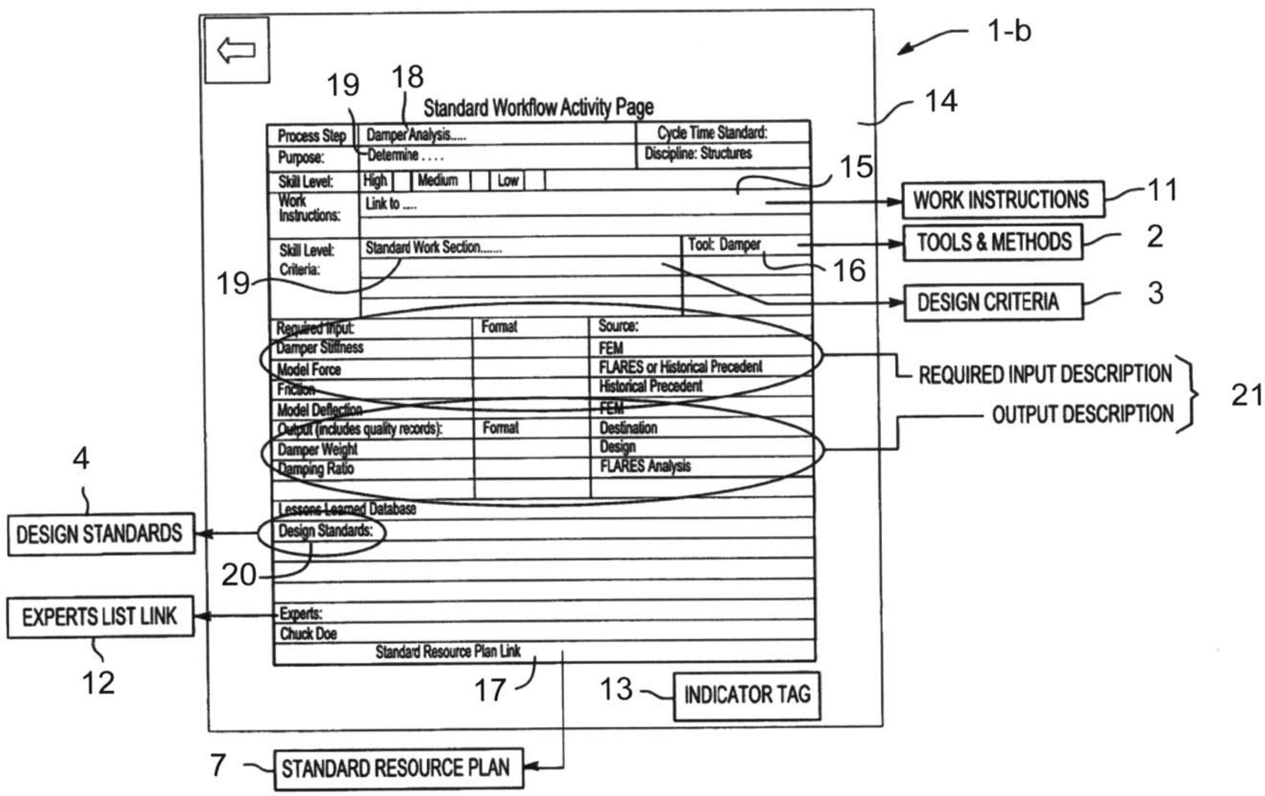


Figure 2-15 ESW Activity Page (UTC Patent: US 7496860 B2)

<u>Description of The Activity Page elements</u> (Figure 2-15)

2) Tools & Methods (Range of applicability of each tool and method)
3) Design Criteria
4) Design Standards
7) Standard Resource Plans needed to execute the activity (e.g. cycle time, labor, hardware, consumables, etc.)
11) Work Instructions
12) Experts List (Could be a Web link to the expert's site)
13) Indicator Tag (Changes Color when acceptable inputs are entered with respect to the design criteria, depending on the proficiency of the engineer entering the results, approved to indicate the successful completion of the activity.)
14) Activity Index Page
15) Web Links to the Work Instructions
16) Web Links to the Tools & Methods

17) Web Links to Standard Resource Plans
18) Name of the activity/process step
19) Activity Description
20) Web Links to Design Standards
21) Required Inputs and Outputs (From Whom and to Whom)

Note: The numbers were assigned in order to keep the nomenclature used on the previous figures of this section.

In order to insure in-process quality, each activity is color coded with a tag (10) that serves to control the readiness of the activity. It is required to have a successful completion of the activity in order to change the activity from Incomplete (Red) to Complete (Green). Also depending on the proficiency of the executor the system required higher-level approvals to allow completion. (Summary: Red=Incomplete, Yellow=Activity Completed and Waiting for Approval, Green=Activity Successfully completed) The system also controls deviations; the web-based system does not allow turning green the activity if unacceptable results are entered. This information can be fed to other link or web page in order to indicate status of the activity.

2.6.2.1.1.2 3-D connectivity

Based on the previous descriptions of Workflow Map and Activity Page the framework offers a 3-D connectivity by linking framework components in the horizontal, vertical, and depth directions. [18]

- Horizontal:
  Activities are connected "horizontally" as they move through various development phases (e.g. concept initiation, concept optimization, preliminary design, detailed design, validation, and service and field support)

- Vertical:
  Modularity from System to Module to Part

- Depth:
  Connectivity is provided by the elements as work instructions, tools and methods etc.

2.6.2.1.1.3 Technology Readiness

Technology readiness is a valuable tool that helps to define the maturity of a technology that is planned to be used on the desired project. The maturity is ranked using a numeric value known as the TRL (Technology Readiness Level). This approach boosts innovation within the organization because the latest technologies are incorporated. In the case that the technology is not ready for the planned milestone, then an alternative known and approved technology is used instead.

It is important to note that certain degree of uncertainty needs to be allowed since it is a new technology. The benefit is that its development occurs outside of the product development and could be incorporated to any project or product once it reaches certain maturity level. [18]

2.6.2.1.1.4 Standard Resource Plans

This is a vital process that provides information about the available resources, and current status of the project. Provides information regarding staffing levels, standard cycle times, standard materials, hardware and consumables costs for engineering work done at the system, module and part levels. Each part type had a separate resource plan with milestones. [18]

2.6.2.1.2 Tools and Methods

This portion of the framework describes the detailed work instructions, range of applicability, modeling standards, and validation. The tools needed to be certified and verified. This allows a uniform expectation of the level of analysis required. [18]

2.6.2.1.3 Design Criteria

The design criteria state, through standard work documentation, the intent of each criterion (i.e. the logic and underlying physics of the design) and the basis of each criterion (i.e. the reasoning for the specified numeric value). [18]

2.6.2.1.4 Design Standards

Are preferred configurations, which incorporate manufacturing processes (manufacturability) that had been followed previously and also took into account parts procurement, environmental, and technical issues. [18]

2.6.2.1.5 Lessons Learned

As part of the philosophy of continuous improvement, the lessons learned brings up to date the tools and methodologies by finding root causes of previous errors, finding new solutions and incorporating them as part of the ESW in order to keep it usable. [18]

2.6.2.1.6 Practitioner Proficiency Assessments

This portion of the framework provides a way to determine which engineers were skilled in what engineering practices. This test is administered to all engineers for the engineering tasks they are to work. Ratings are given to the engineers and based on the resultant category the engineers were classified on different competency levels. [18]

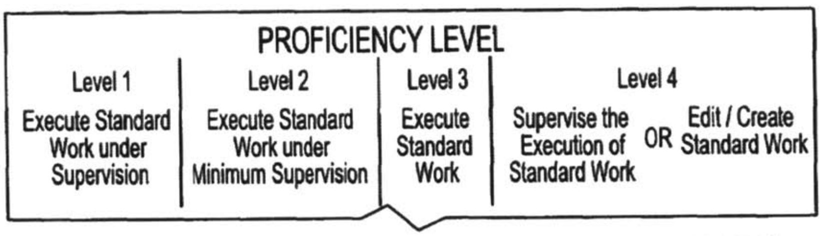
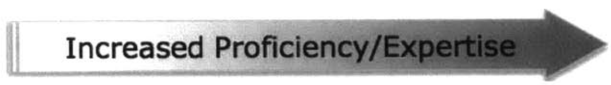


Figure 2-16 Proficiency Level (UTC Patent: US 7496860 B2)



<u>Competency Level</u>

1) Level 1: Full supervision
2) Level 2: Minimal supervision
3) Level 3: No supervision required.
4) Level 4: Could supervise execution

This allows management to assess whether the teams have capable engineers to complete the work of a project. At the same time it helps Human Resources to plan the required training in order to improve the skills of the engineers.

2.6.3 ESW benefits after its implementation[11]

By using the entire ESW framework the following benefits could be obtained:

- <u>Overall perspective</u>: The framework provides an overall perspective on the project for all involved personnel.
- <u>Documenting successful projects:</u> Provides a structure for documenting designs that have worked before to provide a base for further experimentation with improvements.

[11] Adapted summary based on the information from the UTC Patent: US 7496860-B2 and the article "Pratt & Whitney: Engineering Standard Work" Bowen, H Kent and Purrington, C.

- Continuous Improvement: Documenting the projects provides a way of capturing the experience, the ones that were successful could be used to provide a way to conduct controlled experimentation and improvement on future projects and understand the reasons to failure on the unsuccessful ones.

- Milestones Control: It may include periodic gated reviews during the process in addition to inspection of an end result.

- Consistency: By providing clear, prescriptive details on the engineering tasks within a process (e.g., content, sequence, timing, information, flow, dependences between activities, quality checks, etc.) the framework makes it difficult to conceal shortcomings in engineering problems and outcome within unaccounted variations in the design process

- Repeatability: By incorporating processes for all aspects of a planning, use, sustaining, and compliance with standard work, the framework ensures repeatable and flawless execution of the process.

- Efficient: All significant variables that could impact resource requirements are documented in order to guide task-specific plans and data is collected as tasks are completed. This provides reliable data and concrete method to do capacity planning allowing an efficient use of the resources.

- Quality Control It becomes straightforward and easy to complete regular process audits, following up by reinstructing engineers on the proper and desired techniques or perhaps institutionalizing the improvements developed by the best knowledgeable engineers.

The framework defined by UTC was conceptualized in block diagrams, later on UTC created a Web-based system in order to support all aspects of ESW in a faster way. The processes were linked in such an easy way that its usage was ubiquitous in the engineering process.

The ESW initiative was implemented on two of the most important engineering programs of P&W at that time, and despite the additional burden of creating and implementing the standard both projects was executed within budget and scheduled targets. The engineering organization created over 450 workflow maps, 9,000 activity pages, 17,000 documents overall.

Highlights[12]:

- A mid-year assessment performed in 2002 (The year after ESW implementation) found that for every $1 spent on ESW, P&W achieved a cost savings of nearly $4. [17]
- Engineering change orders (ECO's) most of which resulted from failures in the design process and required rework, had been a major cause of delays and cost. As ESW was implemented ECO's were reduced by 50% from 2001 to 2002. By mid-2003, they were further reduced by another 15%. [17]
- Savings from avoided or eliminated rework were estimated at %50 million for 2002, not including potential savings from fewer escapes, many of which might become evident years later. [17]
- A P&W study estimated that a lack of ESW and a failure to execute ESW were responsible for about 70% off all design-quality escapes (problems found on the field) at a cost of more than $46 million. Moreover, ESW improved customer satisfaction. [17]

According to Joe Addams (ESW Leader):

"*In 2000-2001, we had significant variances in terms of our budgetary performance within the organization and significant shortfalls in achievement of customer requirements associated with the programs. In 2002, we fundamentally closed within a few percent of our budgetary commitments and at the same time made significant progress relative to meeting product and customer requirements. It was a stunning realization.*" [17]

This Chapter provided important aspects and elements of the Engineering Standard Work from the UTC Patent US 7496860-B2 [18] and the paper written by Kent Bowen and Courtney Purrington, "Pratt & Whitney: Engineering Standard Work" [17] and shows the real benefits derived from its implementation.

The UTC patent provides fundamental information in order to elaborate the proposed "Lean Engineering Standard Work" model, described in more detail in the following chapter "Benchmark Model".

[12] Adapted from Bowen, H. Kent and Purrington, C. "Pratt & Whitney: Engineering Standard Work" Harvard Business School. Reference 9-604-084

3 Lean Engineering Standard Work (Benchmark Model)

This chapter provides details of the proposed LESW model (Lean Engineering Standard Work), which can be used to assess the state of LESW in a PD organization.

The proposed model is created in order to improve the way engineers operate in the NACC PD organization, which has gone through several changes in order to improve its performance. Back in 2007 the NACC PD organization followed what was internally known as the PDS (Product Development System), this process was not operating in a holistic way and had a lot of deficiencies. For this reason an enormous interdisciplinary effort was placed in order to better control the vehicle programs by introducing the principles of the "Toyota Product Development System". These principles were adapted and adopted in the organization, making profound changes in the performance of product development process, based on these changes a new product development system was created and branded as CPDS (Corporate Product Development System). This system was initiated in North America and later propagated to the other PD organizations in Europe, Asia, and South America. The PD organization in Mexico supports North America operations and has involvement in global programs and regions since 2007. For this reason most of the 13 principles provided by Morgan & Liker are already operating in the organization. However it was important to understand how efficiently the principles are currently operating in order to support the establishment of the proposed LESW model.

The model is based on the following three previously mentioned literature sources:

1) Toyota Product Development System [10]
2) The Mastery of Innovation [5]
3) Engineering Standard Work-UTC Patent [18]

The most important recommended elements for the improvement of the NACC Product Development organization are integrated in the benchmark model, which represents the desired future state of the organization. These elements are listed below; and shown in a block diagram, (Figure 3-1) each of them will be described in detail later in the document:

- Sources of Waste Detection (First mentioned on Chapter 2)
- Systematic Problem Solving Culture (First mentioned on Chapter 2)
- Application of the "The Four Value Streams of Lean Product Development" (Described on Chapter 2.5.1)
- Engineering Knowledge (Creation & Reuse) – (Based on "The Knowledge Creating Company mentioned on Chapter 2.1.2)
- The Six Elements of Engineering Standard Work (From ESW, Chapter 2.6.2.1)

The integration of these five elements result in what is defined as LESW (Lean Engineering Standard Work), this model incorporates the most important lean engineering principles and the six elements of the UTC patent of ESW US 7496860-B2.

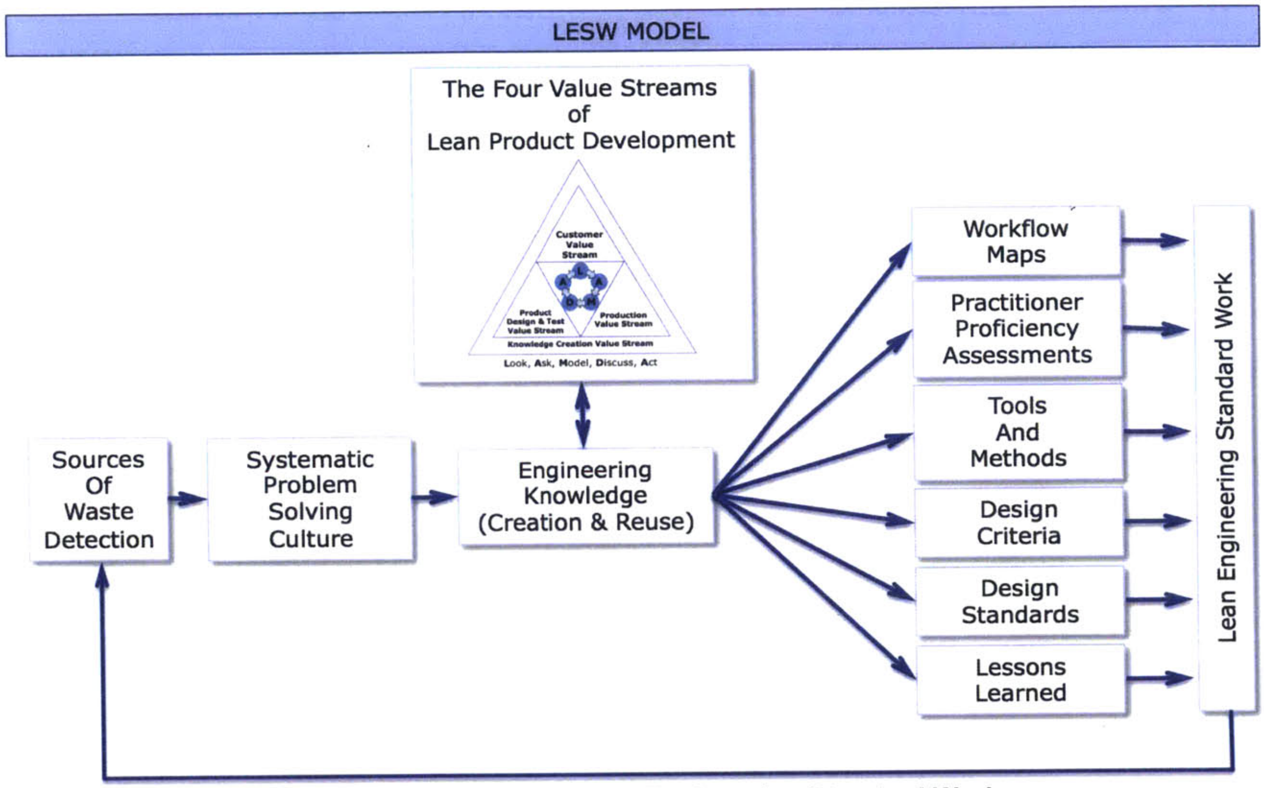


Figure 3-1 Elements of Lean Engineering Standard Work

The above block diagram (Figure 3-1) shows the knowledge management cycle handled by the Lean Engineering Standard Work system. The purpose of the Lean Engineering Standard Work is to incorporate the best elements of the 3 referenced sources of information by combining them in a synergetic way. The six elements of ESW are incorporated in a virtuous cycle of continuous improvement by detecting improvement opportunities in the model through Sources of Waste detection; and the created activity document becomes in fact a best practice that incorporates the highest level of knowledge related to the activity. These detected sources of waste are then processed by "The Four Elements of Lean Product Development" in order to verify that the outcome is producing value to each of the elements. This value, in the form of engineering knowledge, is incorporated into the activity in order to include the best processes known at the moment, thus operating in a continuous improvement cycle for the six elements of Lean Engineering Standard Work. This simple block diagram helps to visualize the interactions of the blocks in a simple form of communication, as recommended by Morgan & Liker in the principle 12.

3.1 Sources of Waste Detection

There are different ways of viewing the sources of waste in Product Development, and all of them are valid, since they all serve to the same purpose of detecting systemic waste in any organization. The MIT-LAI made an enormous effort by searching the different points of view of the sources of waste and they enriched them and added its own findings, making them very easy to apply to any institution.

The table shown in the following page makes a comparison of the sources of waste from selected authors. This table is an adaptation from the one created by MIT-LAI with an added column at the far right including Katherine Radeka's work on this matter. As it can be seen the authors, although with different points of view, coincide with almost all these categories as sources of waste in a Product Development organization.

The ones considered on this benchmark model are considering the most evident elements for this particular Product Development organization; these are listed in the following 4 points:

1) Overall Waste Awareness: This will serve to measure the level of awareness regarding waste perceived by the Product Development organization.

2) Unproductive meetings: Taken from Katherine's Radeka model and the application of the concept of Muda from the 3 M's since this waste takes valuable time from the participants, and if the meeting does not have a clear purpose or structure then no actual outcomes or clear decisions are obtained. In this category of waste it is also included the status-report-only meetings.

3) Design Rework: This is one of the most obvious waste sources, since design issues are generally discovered late in the design process and even once the product was launched. This waste creates the highest stress in the system because sometimes the cost of the changes are extremely high, compared to the incurred costs in the case the issue was detected early in the program. It could jeopardize the planned timing to hit the market; especially if the rework impacts a long lead component or system, and additional time would be required for re-validating the product.

4) Overloaded resources: This kind of waste is taken from Katherine Radeka's sources of waste, and the Japanese concept of Muri (Overburden) from the Toyota Product Development System. If engineers are working in too many projects at the same time, or are overloaded with work, then the people is going beyond their natural limits and this leads to inconsistencies and unreliability in the executed work. This poor quality work will be later transformed into actual quality problems and potential safety risks. The actual outcome of the overload is to reduce the reaction capacity of the company to have new products hitting the market.

The Different Types of Waste in Lean Product Development (Selected Authors)

MIT-LAI (Oehmen and Rebentisch,	(Pessôa, 2008)	(Bauch, 2004)	(Kato, 2005)	(McManus, 2005)	Millard (2001) [cited from (Oppenheim,	Morgan (2002) [cited from (Oppenheim,	(Morgan and Liker, 2006)	(Anand and Kodali, 2008)	(Ohno, 1998)	(Radeka, 2012)
Overproduction of information	Overproduction	Overproduction Unsynchronized processes	Overproduction of information	Overproduction	Overproduction: Creating Unnecessary information	External quality enforcement	Overproduction	Overproduction or early production	Overproduction	Excess requirements and specifications
Overprocessing of information	Overprocessing	Overprocessing Re-invention	Overprocessing Re-invention	Overprocessing	Overprocessing: Working more than necessary to produce the outcome	Re-invention waste	Processing	Inappropriate processing or poor process design	Processing itself	Reinvention
Miscommunicatio n of information	Transportation	Transport Handoff	Transportation of information Hand-offs	Transportation	Transportation: Inefficient transmittal of information	Hand off: Transfer of process between parties Transaction waste Ineffective communication	Conveyance	Transportation or movement	Transportation	Unproductive meetings
Stockpiling of information	Inventory	Inventory	Inventory of Information	Inventory	Inventory: Keeping more information than needed.		Inventory	Unnecessary inventory	Stock on hand	
Generating defective information	Defects	Defects	Defective information	Defective product	Defects: Insufficient quality of information, requiring rework	High process and arrival variation		Defects	Making defective products	
Correcting information	Correction		Rework		Waiting: For information, data, inputs, approvals, releases etc		Correction		Time on hand	Design loopbacks
Waiting of people	Waiting	Waiting	Waiting of people	Waiting	Unnecessary movement: People having to move to gain access to information	Waiting Large batch sizes System overutilization and expediting Unsynchronized concurrent processes	Waiting	Waiting or delays	Movement	
Unnecessary movement of people	Motion	Movement	Motion of people				Motion	Unnecessary motion or inefficient performance of design		
						Lack of system discipline				
										Insufficient customer empathy
										Excess project management overhead
										Overloaded resources

Table 1 Adapted from "The Different Types of Waste In Lean Product Development (Selected Authors)" [8]

This block of "Sources of waste detection" works in harmony with Morgan & Liker's Principle 1, "Establish Customer-Defined Value to Separate Value-Added Activity from Waste", in order to separate value-added activities from waste-activities is necessary to detect waste and later find ways to eliminate it.

3.2 Systematic Problem Solving Culture

The importance of this block lays on the ubiquitous need of integrating a Problem Solving Culture into the whole organization by using the best-known lean tools to all of the performed activities. The systematic problem solving culture serves at the same time as a "purification" knowledge process by applying continuous improvement to the already documented knowledge. The best known systematic problem solving methodologies are PDCA, LAMDA, A3 Reports, and Product Development Value Stream Mapping; however, this does not mean that these are the only ones; new practices, methodologies or ideas may be integrated in order to keep it in the vanguard.

This block element works also in harmony with Morgan & Liker's Principle 1 "Establish Customer-Defined Value to Separate Value-Added Activity from Waste" and Principle 9 "Build in Learning and Continuous Improvement", at Toyota a problem solving methodology that is widely applied is the 5 why's, which consist on asking "why" five times in order to find the root cause and focus solutions once this root cause was found. However PDCA, LAMDA are also good practices to embed in the organizational culture of the PD organization. This block also supports Principle 10: "Build a culture to support Excellence and Relentless Improvement", since the purpose of this block is to embed into the DNA of the organization the problem solving culture.

3.3 Application of the "The Four Value Streams of Lean Product Development"

The "Four Value Streams" model shown in Figure 2-11: integrates Customer Value Stream, Product Design and Test Value Stream, and Production value Stream in a continuous improvement system by applying one of the most valuable tools in Lean Engineering known as LAMDA (Look-Ask-Model-Discuss-Act) and all the learning is integrated into the Knowledge Creation Value Stream, that is why is surrounding the other three and at the same time is using the LAMDA process for continuous improvement of the captured knowledge itself.

The "Four Value Streams of Lean Product Development" play a very important role in the model since the focus of every organization is to maximize value to the final client. The breakthrough of this model is that it gives value to "waste", since the model is integrated as both knowledge creation and as knowledge improvement. The system is continuously improving and taking advantage of that knowledge, which serves as a repository when documented. This knowledge provides learning and improvement by continuously feeding the system with lessons learned to the Lean Engineering Standard Work activities. The model also allows space for creativity and innovation since it transfers tacit knowledge to explicit knowledge by documenting by freeing time for engineers. The great benefit from this system is that it includes the PD engineers as active participants in the learning process; if they find new processes that prove to be better than the previous ones then this knowledge is incorporated as the actual process. If a new proposal or idea is created and at that specific moment is not adding value to the organization then it will be documented as a lesson learned too.

The "Four Value Streams of Lean Product Development" are also related to the Principle 1 of Morgan & Liker "Establish Customer-Defined Value to Separate Value-Added Activity from Waste" since it makes extensive use of Product Development Value Stream Mapping (PDVSM) tool to maximize value in the organization. Additionally it is related to Morgan & Liker Principle 11: "Adapt Technology to fit your people and process", as part of the "Production Value Stream". Since the LAMDA process in involved as a tool for continuous improvement, then Principle 9 "Build in Learning and Continuous Improvement" is also working in harmony with Morgan & Liker ideas.

3.4 Engineering Knowledge (Creation & Reuse)

The Knowledge Creation Value Stream plays a very important role in the transfer of tacit knowledge coming from all the other Value Streams to explicit knowledge described in the block model as the "Engineering Knowledge (Creation and Reuse)", this knowledge is then distributed and incorporated into the "Six Lean Engineering Standard Work" elements or activities. This block is also deeply related to the principle 13 from the "Toyota Product Development System" regarding the "use Powerful Tools for Standardization and Organizational Learning." since the target is to share and capture knowledge within the NACC, this process has not been very successful in the .Several attempts have been made in the NACC in order to create a learning organization by transferring tacit knowledge to explicit knowledge of seasoned engineers to the new generations, however the system is not constantly reinforced and this leads to inconsistencies in the organization. Most of the knowledge is still concentrated in the heads of experienced engineers and checklists kept on each engineer's computer instead sharing the information among the engineering communities.

By managing the engineering knowledge the LESW is incorporating the recommendations made by Morgan & Liker in the Principle 13:"Use Powerful Tools for Standardization and Organizational Learning".

3.5 Lean Engineering Standard Work

This is the heart of the proposed system; it contains all the vital documented information for the engineers' activities. Its attempt is to transfer all tacit valuable knowledge to explicit knowledge translated into the regular activities performed by the engineers. The LESW is composed of living documents that helps the engineers to develop the parts they are responsible for. All the knowledge captured by the Knowledge Value Stream and filtered through the "Systematic Problem Culture" and "Engineering Knowledge (Creation & Reuse)" blocks are documented here. These are divided into the Six Elements of Lean Engineering Standard Work.

The six elements of LESW:

1) Tools and Methods
2) Design Criteria
3) Design Standards
4) Lessons Learned
5) Workflow Maps
6) Practitioner Proficiency assessments

These elements are described in more detail in the following paragraphs.

3.5.1 Tools and Methods

This section calls for the related tools and methods applied to the part, subsystem or system being evaluated. By doing this the organization will be capable of having a standard set of requirements and a uniform expectation of the level of analysis required. Different links to web pages (e.g. Recommended Validation Processes, CAE Benchmark Information, Quality Information, Field Issues, Part Drawings, Regulatory Information, Test Procedures, Requirements, Regulations, Homologation, Methods, Durability, Six Sigma Projects, FMA, DFMA, Mode Analysis, Engineering Specifications, etc.)

3.5.2 Design Criteria

This portion of the framework will provide the intent of each criterion (i.e. the logic and underlying physics of the design) and the basis of each criterion (i.e. the reasoning for the specified numeric value). This could include recommended tolerances, radii, links to typical sections, design rules (Normally linked to Engineering Requirements), Material Selection, etc.

3.5.3 Design Standards

The purpose of this area is to reference the current design standards available in the PD organization, needed to manufacture a part (e.g. welding specifications, die specifications, etc.)

3.5.4 Lessons Learned

This area will link the lessons learned regarding the activity or the system, subsystem or part in order to provide the engineers with a valuable record of the learning captured by previous engineers. Even if the organization already has a system to document the lessons learned, its usage can be improved by integrating this knowledge into the current activity avoiding the hassle of having to search for all this information through thousands of web pages across the system. In general the purpose of the lessons learned methodology is to have a continuous improvement system where the lesson learned is documented and reflected on the Engineering Requirements, Design Standards or Design Criteria parts, but sometimes it takes time until those are reflected and do not contain the background of why those specifications were implemented. This area could also contain additional already documented Best Practices part of the entire organization.

3.5.5 Workflow Maps

As it was previously explained each activity page will be linked to the program milestones, Swimlanes (Related Engineering Functional Areas), and will have a way to mark if the activity was completed or not in order to have an automatic status report needed by the program management.

3.5.6 Practitioner Proficiency Assessments

The practitioner Proficiency Assessments will provide the information of the support required depending on the Proficiency Level of the engineer. This could be adapted to the Proficiency Level currently being used by the organization.

Depending on the level of maturity of the organization the performance of the team could be assessed by this tool, since engineers with little or no experience will take generally more time to complete the activity, compared to a senior engineer who is capable of executing the activity faster. The level of experience can be linked to the actual time it took to complete the activity, and after going through several programs it would be easier to forecast the time, and required experience to complete a program.

This portion of the framework provides a way to determine which engineers were skilled in what engineering practices. This test is administered to all engineers for the engineering tasks they are to work. Ratings are given to the engineers and based on the resultant category the engineers were classified on different competency levels. It would also serve to assess the headcount required by the organization depending on the number of programs the organization is working.

This practitioner proficiency assessment also applies "Engineering skill set standardization" as part of the Principle 4: "Utilize Rigorous Standardization to Reduce Variation, and Create Flexibility and Predictable Outcomes"

The following chapter offers an operational scenario for the LESW model; this scenario provides a suggested survey to be applied to a PD organization in order to assess its status relative to the desired LESW model.

4 Methodology

4.1 Thesis Approach

The primary methods for acquiring data and knowledge for this thesis were executed by performing literature reviews and gathering data from journals, books and international research institutions.

The second method was the usage of a survey (this survey is included in Chapter 6.3.1) in order to evaluate the current performance of the organization.

The third method was an interview that was obtained from a high rank manager from a Japanese company. His information was hidden in order to protect the identity of both the company and the person that provided this valuable information. This interview is included in Chapter 6.3.1.

4.2 Benchmark Survey

Based on the elements of the benchmark model developed in Chapter 3, a survey was designed in order to understand the state of the PD organization relative to this desired model. Some of the questions were adapted from the Katherine's Radeka book "The Mastery of Innovation" located in the Appendix 1; those questions are marked with a legend and the related question number from the assessment. The rest of the questions were created based on the LESW model and my personal experience as a Product Development Engineer.

4.2.1 Sources of Waste

Previous chapters have showed the importance of the sources of waste detection, in this case the survey helped to understand the perception of waste within the PD organization, starting from a very general perception to a more detailed perception. The questions were grouped in 1) General Perception of waste, 2) Waste caused by meetings, 3) Waste caused by design rework, 4) Waste caused by overload of the engineers and 4) General perception of the management organization.

4.2.1.1 Waste (General Perception)

1. I understand the sources of waste in Product Development.
2. The programs in which I have participated have consistently met their respective schedules. [5] (Adapted from Appendix 1:Q6)

4.2.1.2 Waste (Meetings)

3. All the meetings I attend lead to valuable outcomes for the project I work for.
4. Most of the meetings I attend are just for status report.

5. Issues or proposals have to be presented to forums that add no value for resolution. [5] (Adapted from Appendix 1:Q1)
6. I know exactly what path to follow in order to obtain final decisions for my issues/proposals. [5] (Adapted from Appendix 1:Q22)

4.2.1.3 *Waste (Design Rework)*

7. There are few design loopbacks late in development for general parts in my area. [5] (Adapted from Appendix 1:Q8)
8. There are few design loopbacks originated by program late changes.
9. In general there are few design loopbacks (rework) after final CAD release.
10. For the parts I am responsible for I have experienced few design loopbacks (rework) after final CAD release.

4.2.1.4 *Waste (Overload)*

11. Workload distribution is equitable for all engineers.
12. I have more tasks assign to me than I can realistically complete in the scheduled time and at the required quality
13. I am overloaded with non-engineering work related activities

4.2.2 Systematic Problem Solving Culture and "The Four Value Streams of Lean Product Development"

This set of questions were grouped to understand the level of permeation of the Problem Solving culture in the organization, in this section is also integrated the block of "The Four Value Streams of Lean Product Development" since these are based on the Value Stream Mapping Methodology.

14. I systematically apply PDCA Philosophy in the programs I work for (PDCA=plan–do–check–act)
15. I systematically apply LAMDA Philosophy in the programs I work for (LAMDA=Look-Ask-Model-Discuss-Act)
16. I am familiar with A3 Problem Solving Tool.
17. I am familiar with Value Stream Mapping Methodology.
18. I understand current and future risk/opportunities and solve them before I start the detailed design. [5] (Adapted from Appendix 1:Q19)
19. Decision makers take the time to understand the problems, alternatives, and recommendations before making a decision. [5] (Adapted from Appendix 1:Q7)
20. As a team we take some time to understand root causes before we recommend countermeasures or solutions. [5] (Adapted from Appendix 1:Q11)
21. As a team we explore multiple alternatives before making product engineering decisions. [5] (Adapted from Appendix 1:Q4)

22. As a team we take the time to measure results and reflect upon the effectiveness of the decisions that we make so that we can learn from them. [5] (Adapted from Appendix 1:Q16)

4.2.2.1 Engineer's perception of Manager's Systematic Problem Solving Capabilities

23. Managers in my organization ask challenging questions to solve issues and take decisions. [5] (Adapted from Appendix 1:Q2)
24. Managers in my organization use systematic problem solving to address issues. [5] (Adapted from Appendix 1:Q14)
25. Our groups' leaders tend to change decisions previously agreed. [5] (Adapted from Appendix 1:Q13)
26. Our groups' leaders do not support the decisions they have delegated to their teams. [5] (Adapted from Appendix 1:Q17)

4.2.3 Engineering Knowledge (Creation & Reuse)

The questions that were included in this section are involved with the management of knowledge in the PD organization.

27. It is very easy to find lessons learned information within my organization. [5] (Adapted from Appendix 1:Q18)
28. I always have time to capture lessons learned on my regular job. [5] (Adapted from Appendix 1:Q9)
29. I always apply the lessons learned from previous programs for the development of the parts I am responsible for.
30. When I recognize a problem that we have seen before, I have the ability to find out how we solved it last time. [5] (Adapted from Appendix 1:Q3)
31. We take the time to capture what we've learned so that we can share it with others and reuse it ourselves later. [5] (Adapted from Appendix 1:Q16)
32. I actively search out reusable knowledge as part of our problem-solving and decision-making processes. [5] (Adapted from Appendix 1:Q20)
33. It is very easy to find best practices that help me to do my job. [5] (Adapted from Appendix 1:Q17)
34. It is very easy to capture/update best practices to make my job easier.
35. I actively search out expert input as part of our problem-solving and decision-making processes. [5] (Adapted from Appendix 1:Q20)
36. It is easy for me to locate the expert who can help me to solve a specific problem.

4.2.4 Lean Engineering Standard Work

The questions of this section were developed based on the desirability of the LESW model, assuming that the organization that is willing to apply this survey does not count with such as system.

4.2.4.1 Current Engineering Templates for Part Development

The questions of this section were developed based on the desirability of the LESW model, assuming that the organization that is willing to apply this survey does not count with such as system.

37. There are easy to find templates that help me track a part development from start to end.

4.2.4.2 Desirability of a LESW

38. It would add value to have a tool that guides me designing the parts I am responsible for.
39. It would add value to have a standard checklist that helps me confirm I have fulfilled all design steps for every important milestone.
40. It would add value to have a tool that helps me meeting the engineering requirements for the part I design.

4.2.4.3 Current usage of checklist for part development and track

41. I store my checklists on my own computer drive.
42. I currently own a checklist to confirm that I have followed all required steps to design a part.

4.2.4.4 Practitioner Proficiency Assessment

The practitioner proficiency assessment is an important part of the development of the engineers working in the product development organization, the continuous track on the proficiency of the engineers helps to maintain and foster the problem solving culture in the organization. And the other main purpose is to grow the capabilities of the engineering team. The NACC counts with a practitioner proficiency assessment that is known internally as the EPDP (Engineering Proficiency Development Plan).

43. The main training I received was based on learning by doing.
44. I worked with my supervisor to ensure my EPDP was completed to accurately reflect my skill level
45. I had a mentor that helped me on my doubts and questions during my learning in the company engineering systems
46. The current plan we have to develop my engineering skills reflects the actual needs of a Design Engineer
47. There is enough time to take the required training to improve my engineering skills.

<u>The last two sections of this chapter refer to questions that were particularly developed to the NACC and, not necessarily would apply to any PD organization.</u>

4.2.5 Current NACC Milestone Management System

The questions refer to the system known as the "Milestone Master" which is an internal system that keeps track of the milestones of the engineering programs and the main targets that should be achieved.

48. "Milestone Master" adds value by keeping track of the progress of the parts status per program milestones
49. "Milestone Master" is a tool for status report only
50. "Milestone Master" is a tool that helps engineers to keep track of what needs to be completed by milestone
51. I systematically use "Milestone Master" to be aware of the requirements for every milestone to meet for the parts I am responsible for.

This survey would help to have a better understanding of the actual state of a Product Development organization relative to the Benchmark Model of the Lean Engineering Standard Work. With the results obtained it would be possible to focus on the areas or categories that need more attention in order to improve the performance of the organization. Of course the survey could be adapted according to the specific Product Organization needs.

4.2.6 Three Questions on Engineer's Perception of the Organization

52. It is difficult to keep track of all the web pages I need to update for the part I am responsible for.
53. I know who the authority to decide on each program deliverable is.
54. In my organization it is rewarded the firefighting of issues instead of rewarding the work executed with excellence

4.2.7 Survey pretesting and administration

The survey received feedback from several different engineers, and new questions were incorporated from the frustrations and opinions from the engineers, most of these opinions came directly from PD engineers, supervisors, managers and even a director from the organization.

The survey went through several steps before being implemented. It was elaborated in order to understand the current status of the company regarding several of the needs for both the LESW and the lean engineering tools. The survey was applied to 10 engineers in an excel format in order to improve it based on the feedback of these first participants.

The questionnaire included a total of 60 questions, the first 6 were included in order to identify the population of the PD engineering center and the other 54 are part of the Benchmark Model of LESW questionnaire elaborated in the previous chapter.

The questionnaire followed the standard rules of the Committee on the Use of Humans as Experimental Subjects (COUHES) [19], a longstanding MIT policy that complies with Federal mandate ("The Common Rule," 45 CFR pt. 46) No personal data was gathered in the survey. The survey contained a password in order to limit the audience to the targeted NACC PD population.

A clarification note was added at the start of the survey with the following information:

"*Your participation in this survey is voluntary. You have the right to stop at any time or for any reason without adverse consequences.*

Please note that this questionnaire is completely anonymous and does not request information that would identify the respondents or their respective organizations, such information should not be provided, and, if inadvertently provided by the respondent, will not be used or retained. Reported findings will be non-attributable. Data will be stored securely and will be aggregated for academic and research purposes and referenced in any publications that may result from this survey.

By clicking "next" and starting this survey, you accept these terms."

Once it was polished the survey was uploaded to the web page http://surveymonkey and following the rules of the NACC, a pre-written email was sent to the NACC Product Development director in order to obtain its approval regarding the content and permission to internally apply it. Later on, the email was distributed among the PD community (Refer to Appendix A).

The survey was opened from April 15^{th} to April 27^{th}, 2015. The total population of engineers invited to the survey was 937, from them 600 are engineers located in Mexico as part of the NACC Product Development organization. A total of 120 responses were obtained in two weeks after the survey started, it is very probable that the amount of respondents was reduced due to the fact that the survey was explicitly directed to PD engineers. Nevertheless a few responses came from other areas. The survey took in average 13 minutes for each person to respond.

5 Data Analysis & Findings

"If we wonder often, the gift of knowledge will come."

Arapaho proverb

This chapter provides the information about the survey results.

5.1 Survey Results

Results from the survey were concentrated as raw data, and later on analyzed in Excel in order to obtain the tables and graphs presented on this work. It is important to notice that the number of responses vary in number due to the fact that some of them were skipped by the participants as it was allowed on the initial clarification note. Explanation of the data is included in each of the questions. (Complete Survey included in Appendix A) For this reason two average numbers are given, one reporting the total population and a second one in order to obtain an average number for all the involved areas.

5.1.1 Functional Areas

The following chart shows the total number of engineers that were part of this survey relative to the functional area they work for. A total of 118 persons responded this question.

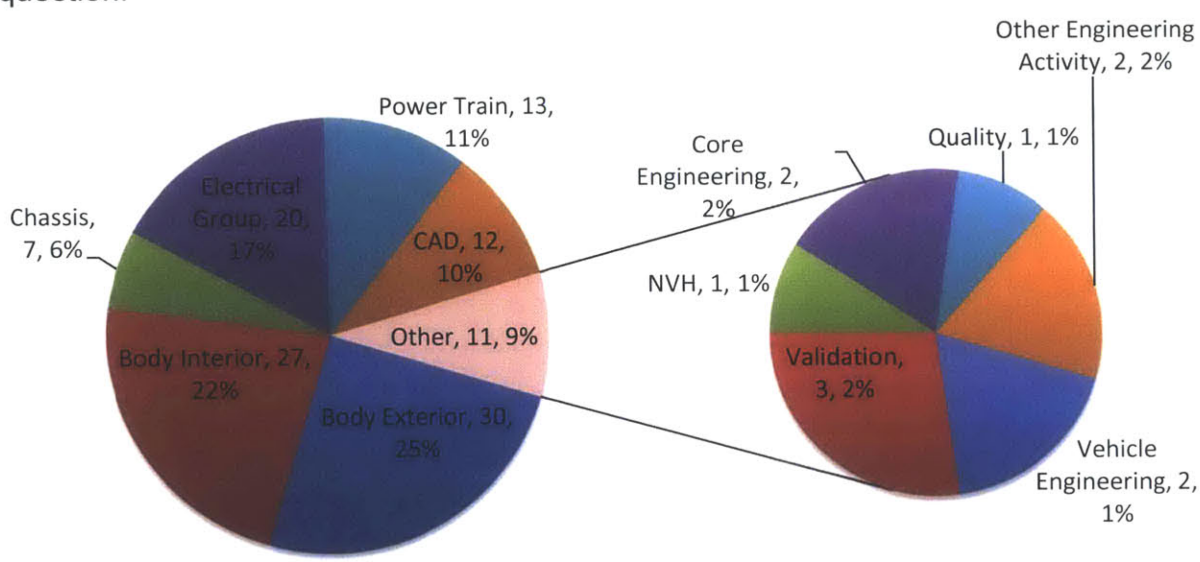


Figure 5-1 Overall General Experience

As it can be seen in the graph above (Figure 5-1), the majority of the respondents came from the Body Exterior and Body Interior areas, the "Other" category was assigned to the minority of different areas with a population below 6% threshold.

5.1.1.1 *Working Experience*

The PD engineers experience is divided in two categories, the first is the "Overall working experience", which considers the general experience of the engineers, and the second one is related to the experience acquired specifically at NACC.

The first category is detailed in the graph below, as it can be seen, the greatest percentages are taken by engineers with more than 1 year but less than 3 years of experience making them 30% of the population and engineers with more than 5 years of experience but less than 5 years with 31% of the population, this reflects the growth intention of the NACC PD organization since an important part of the engineers were hired in the past 7 years, including engineers from other companies who already had engineering experience.

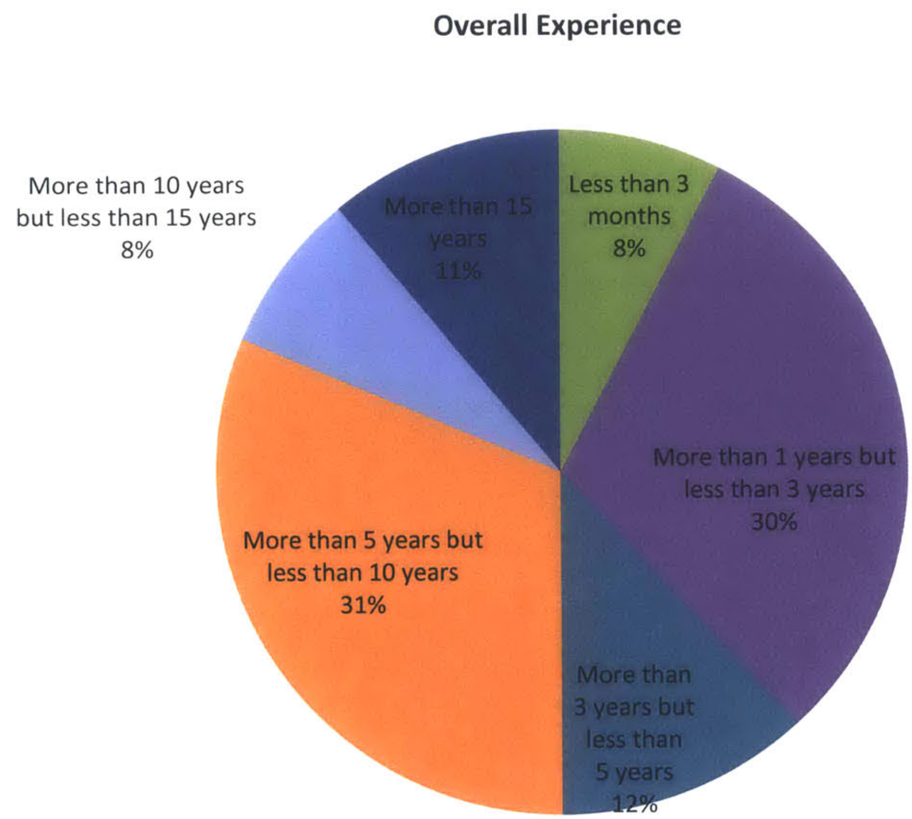


Figure 5-2 Overall Engineering Experience of the Participants

The following chart shows the working experience of the participants solely at NACC (The previous chart considered the overall experience only) as the graph shows, the greatest percentage is taken by engineers with more than 1 year but less than 3 years of experience making them 42% of the total number of participants of this survey, this reflects the growth intention of the NACC PD organization, since the vast majority of the engineers were hired in the past 7 years.

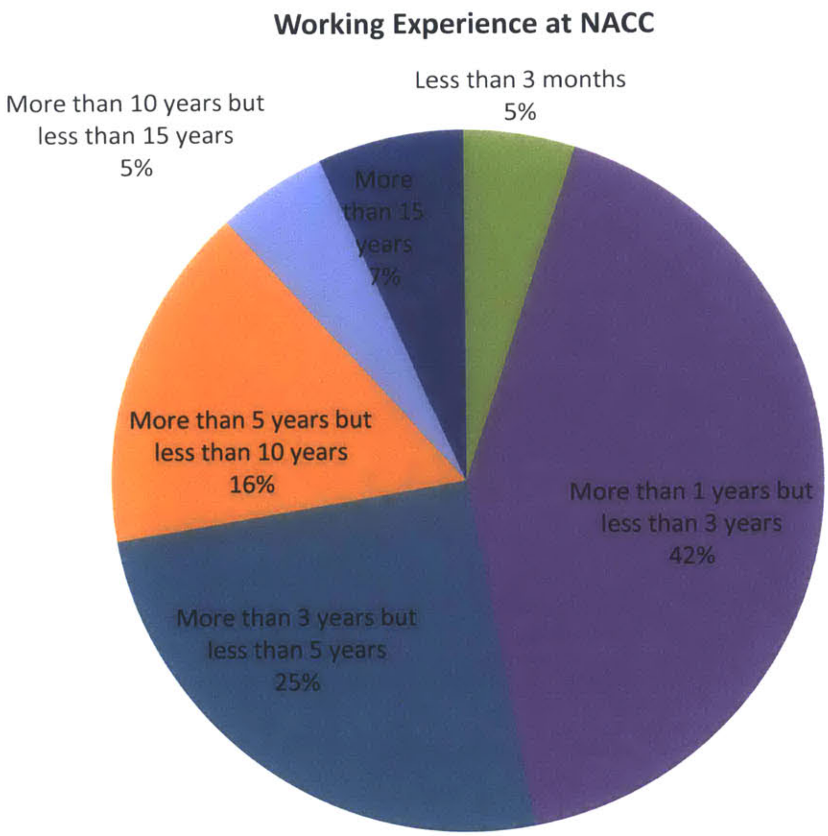


Figure 5-3 Working Experience at NACC

Another important portion of the investigation in order to have a better understanding of the population composing the NACC PD engineering center is the experience of supporting a program. During launch an intensive training takes place because the engineers are pushed to the limits in order to offer the fastest possible responses to issues that need immediate attention. Besides, the collaboration with other areas is also under high pressure. In general engineers with experience are assigned to launches, but in the case of the NACC engineers with a few years of experience are also integrated into the launch team and they learn by doing by supporting other senior engineers.

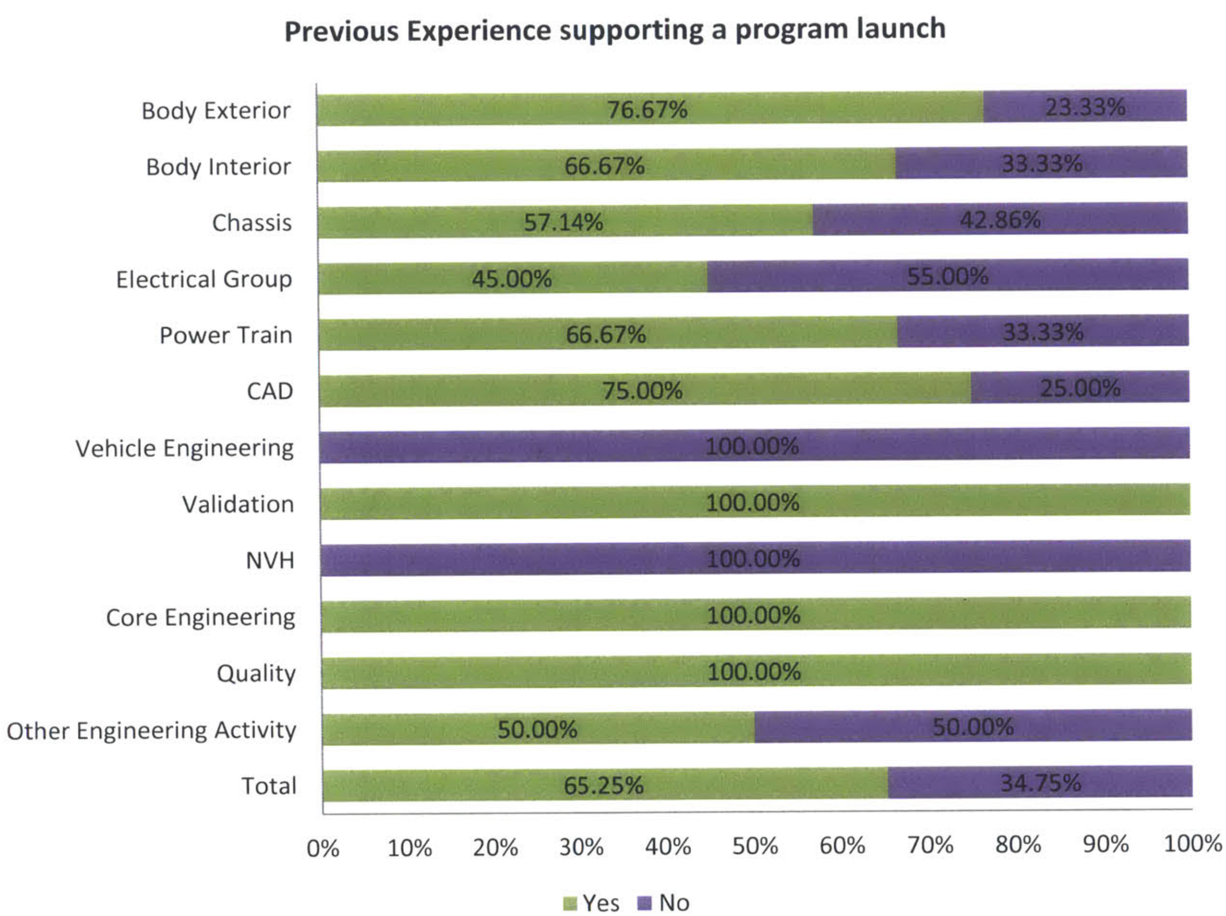


Figure 5-4 Previous Experience Supporting a Program Launch

It is also important to measure the experience of the engineers and if they have gone through a complete engineering program cycle. Starting from the initial concept to the vehicle launch, this provides a lot of the experience to engineers since they have firsthand experience designing a vehicle.

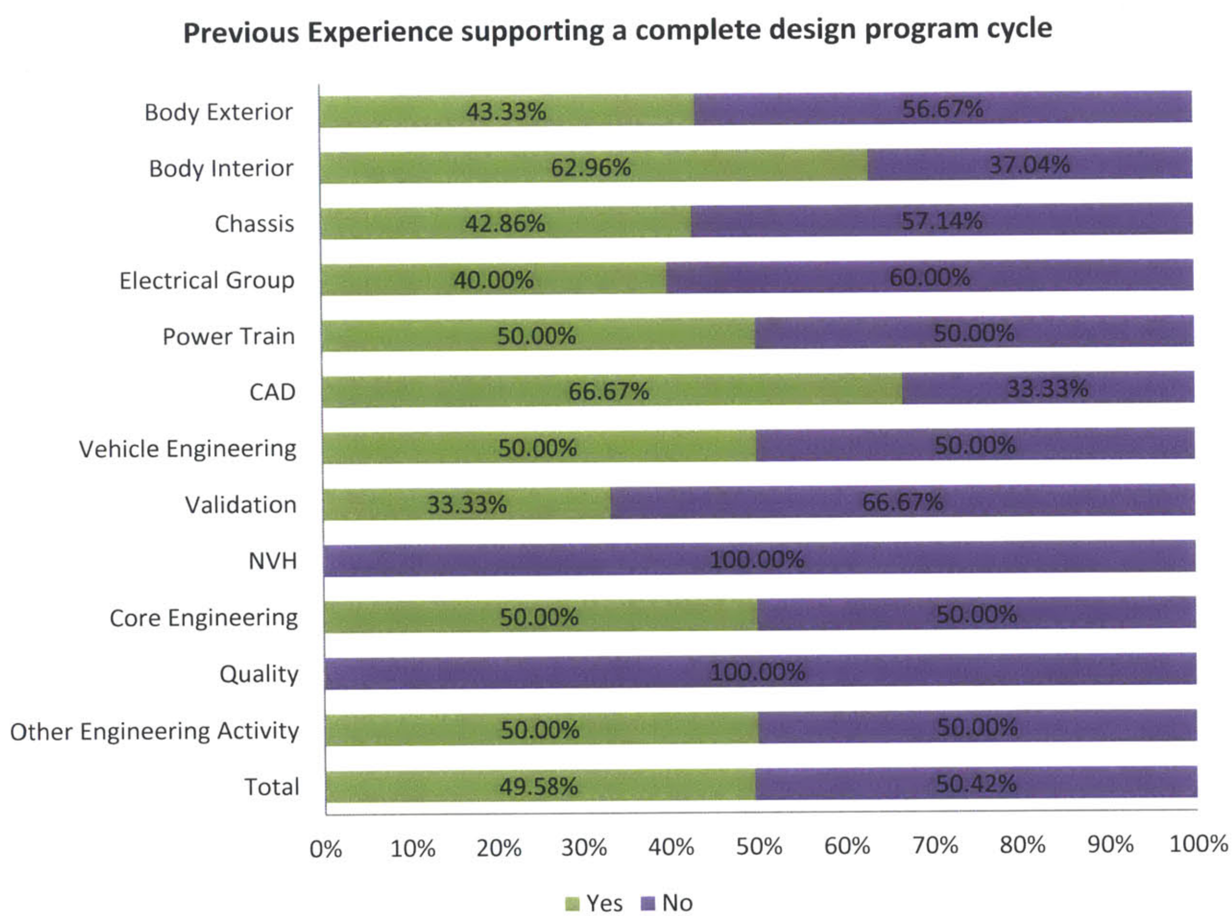


Figure 5-5 Previous Experience Supporting a Program Cycle

5.1.1.2 Academic Level

The total participants has an Engineering Bachelor degree since is part of the requirements to be part of the team, besides this basic degree requirement other higher studies as Masters or Doctoral degrees are welcomed in the organization. Population's Academic Level, overall and by Functional Area:

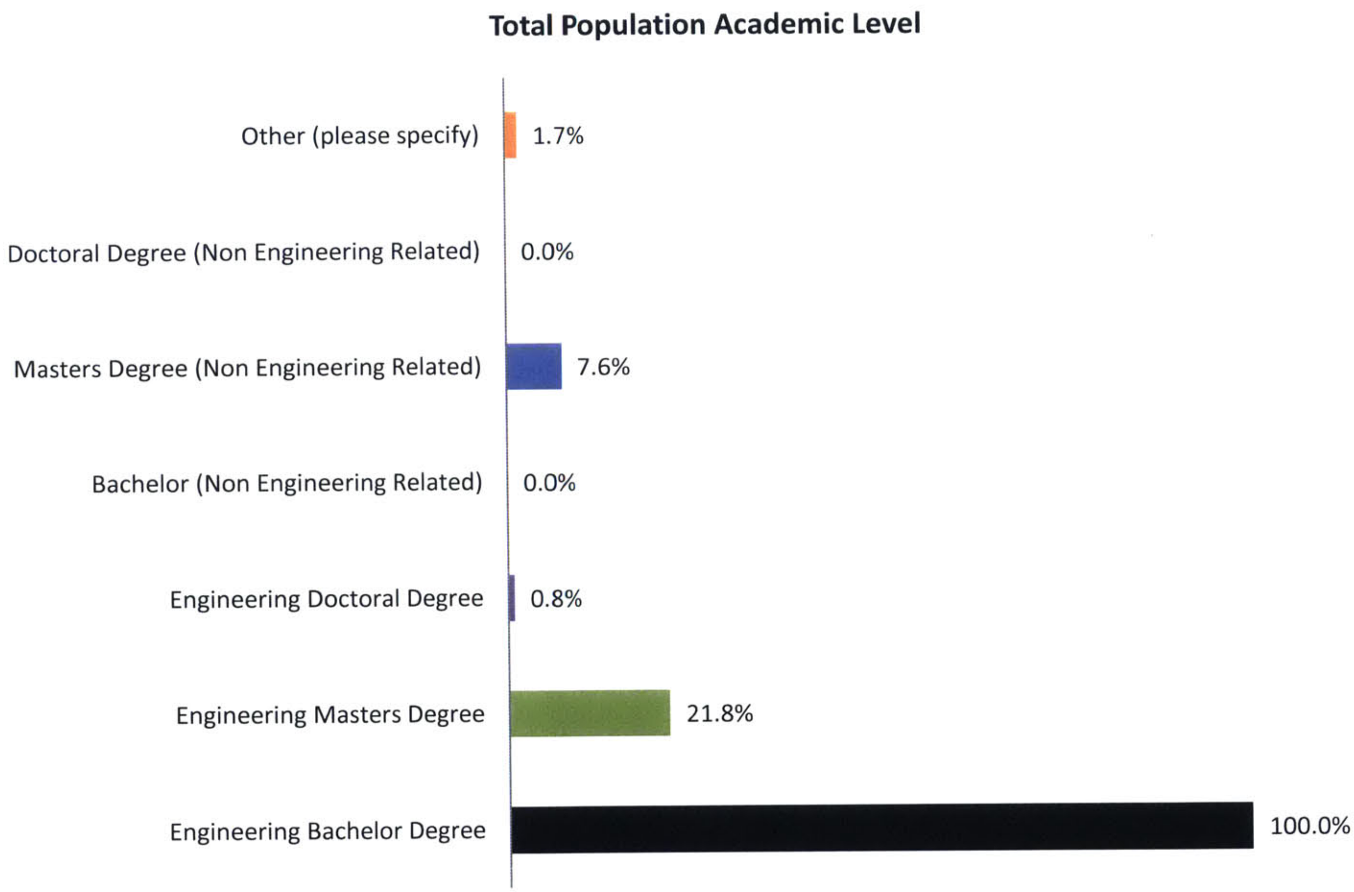


Figure 5-6 Total Population Academic Level

The demographics shown in the previous sections were expected, this because the NACC PD organization is not yet a mature one, generally a mature organization has engineers working for the organization at least 10 years, and in fact some regions are suffering trying to have new engineers being incorporated to the workforce. This is a strong advantage of the PD organization in Mexico; however it is important to recognize that the engineering center is still immature, even considering the population of engineers with more than 15 years of experience. This means that there are still a lot of opportunities to improve the problem-solving capabilities of the engineers.

5.1.1.3 Cronbach's Alpha

For the following questions a Cronbach's alpha calculation was performed in order to group with confidence the responses of the survey that are consistently measuring a very similar characteristic of the organization. The software utilized to for the Cronbach's alpha calculation was the JMP Pro Version 11.2 (11.0) Report Software

The following table provides more information about the parameters that were used in order to evaluate the internal consistency of the group of questions:

Table 2 Cronbach's Alpha Parameters

Internal consistency	Cronbach's Alpha
Excellent (High-Stakes testing)	$\alpha \geq 0.9$
Good (Low-Stakes testing)	$0.7 \leq \alpha < 0.9$
Acceptable	$0.6 \leq \alpha < 0.7$
Poor	$0.5 \leq \alpha < 0.6$
Unacceptable	$\alpha < 0.5$

As well most of the questions were evaluated according to the following scale values:

Table 3 Positive Scale Values

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Scale	5	4	3	2	1

In some cases it was required to reverse the scales, this because some questions were worded on purpose in a different way; thus giving a result that need to be reversed in order to keep the consistency of the parameters being evaluated.

Table 4 Reversed Scale Values

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Weight	1	2	3	4	5

A clarification note (Reversed) will be placed on the questions that required the reversing of the Scale Values.

An average response value was used on those groups of questions that met the criteria based on the Table 2 of previous page, and the group was considered as a single category. The average response value was also used to calculate the gap to the desired optimal value, and the optimum value is considered to be the highest, which is five. The purpose of obtaining the gap value is to use it to prioritize and address the most urgent issues in the organization.

The following sections cover the categories shown in the Benchmark Model of LESW that was presented on Chapter 4.2.

5.1.2 Waste

This section reports the average values the answers related to the sources of waste. It starts with an overall perception of waste and later the sources of waste such as Meetings, Design Rework and Overload are reported following the benchmark model of LESW.

5.1.2.1 Waste (Overall Perception)

This category resulted on a low Cronbach's Alpha number with a value of 0.0364, the reason for this low number is due to the nature of the questions which measures different things, the first question is measuring the level of awareness of the sources of waste and the second one is measuring the perception of the programs meeting the schedules. However the average value of both questions are quite close, and for reporting purposes only the average on the response value of the entire population for these two questions is 3.4757.

The two questions included in this category are the following ones:

1) I understand the sources of waste in Product Development.
Average on the response value of the entire population: 3.37

2) The programs in which I have participated have consistently met their respective schedules
Average on the response value of the entire population: 3.57

5.1.2.2 Waste (Meetings)

This category involves four questions measuring different aspects of the quality of the meetings, the Cronbach's number for this group of questions resulted on a value of 0.5215 which is relatively low; in this specific case it means that although the questions were related, there was a huge discrepancy on the responses from the different groups and individual responses per se. For reporting purposes only the average on the response value of the entire population for this category is 3.1927.

This category includes the following questions:

3) All the meetings I attend lead to valuable outcomes for the project I work for.
Average on the response value of the entire population: 3.39

4) Most of the meetings I attend are just for status report. (Reversed)
Average on the response value of the entire population: 2.63

5) Issues or proposals have to be presented to forums that add no value for resolution. (Reversed)
Average on the response value of the entire population: 2.99

6) I know exactly what path to follow in order to obtain final decisions for my issues/proposals.
Average on the response value of the entire population: 3.75

5.1.2.3 Waste (Design Rework)

In regards to this source of waste, the Design Rework had a more stable value on the responses as the general perception in the organization.

The applied questions on this group are the following ones:

7) There are few design reworks late in development for general parts in my area.
8) There are few design reworks originated by program late changes.
9) In general there are few design reworks after final CAD release.
10) For the parts I am responsible for I have experienced few design reworks after final CAD release

The average value for this group is 3.3550 which represent values closer to neutral, Please note that individual average values for each question are not included since the Cronbach's Alpha value is 0.7616, which means that the questions are related and could be grouped in a reliable manner.

5.1.2.4 Waste (Overload)

In regards to this source of waste, overload is part or the vicious cycle of waste previously shown on Figure 2-10 of Chapter 2.5. The responses in this category of "Overload" were more homogeneous obtaining a Cronbach's Alpha value of 0.7017.

The applied questions on this group are the following ones:

11) Workload distribution is equitable for all engineers.
12) I have more tasks assign to me than I can realistically complete in the scheduled time and at the required quality. (Reversed)
13) I am overloaded with non-engineering work related activities. (Reversed)

Questions 2 and 3 were reversed in order to keep consistency on the performance evaluation of the organization. The average value of the entire population is 3.037 which represent values closer to neutral.

5.1.3 Systematic Problem Solving Capabilities

Systematic Problem Solving Capabilities are essential in any lean organization. In regards to this category, it was possible to group nine evaluating questions since the found Cronbach's Alpha number for this group of questions obtained a value of 0.7929.

The applied questions on this group are the following ones:

14) I systematically apply PDCA Philosophy in the programs I work for (PDCA=plan–do–check–act)
15) I systematically apply LAMDA Philosophy in the programs I work for (LAMDA=Look-Ask-Model-Discuss-Act)
16) I am familiar with A3 Problem Solving Tool
17) I am familiar with Value Stream Mapping Methodology
18) I understand current and future risk/opportunities and solve them before I start the detailed design.
19) Decision makers take the time to understand the problems, alternatives, and recommendations before making a decision.
20) As a team we take some time to understand root causes before we recommend countermeasures or solutions.
21) As a team we explore multiple alternatives before making product engineering decisions.
22) As a team we take the time to measure results and reflect upon the effectiveness of the decisions that we make so that we can learn from them.

The average value of the Functional Areas is 3.3657, which represent values a little bit higher than neutral.

5.1.3.1 Engineer's perception of Manager's Systematic Problem Solving Capabilities

It is important to evaluate the perceived application of "Systematic Problem Solving" by the managers, since they are in fact responsible of ensuring the application of lean tools in the organization. In regards to this category the found Cronbach's Alpha number was 0.7025.

The applied questions on this group are the following ones:

23) Managers in my organization ask challenging questions to solve issues and take decisions.
24) Managers in my organization use systematic problem solving to address issues.
25) Our groups' leaders tend to change decisions previously agreed. (Reversed)
26) Our groups' leaders do not support the decisions they have delegated to their teams. (Reversed)

The average value of the responses is 3.4021, which represent values a little bit higher than neutral.

5.1.4 Engineering Knowledge (Creation & Reuse)

As it was described though the previous chapters, the "Knowledge Capture and Reuse" is very important especially for Product Development organizations, in fact this is an opportunity of transforming waste into value by documenting the lessons learned of the organization. It was possible to group 6 evaluating questions for this category based on the fact that the reported Cronbach's Alpha number was 0.7484

The applied questions on this group are the following ones:

27) It is very easy to find lessons learned information within my organization.
28) I always have time to capture lessons learned on my regular job
29) I always apply the lessons learned from previous programs for the development of the parts I am responsible for.
30) When I recognize a problem we have seen before, I have the ability to find out how we solved it last time.
31) We take the time to capture what we've learned so that we can share it with others and reuse it ourselves later.
32) I actively search out reusable knowledge as part of our problem-solving and decision-making processes.

The average response value of the engineering functional areas is 3.3181, which represent values closer to "Agreement".

5.1.4.1 Best Practices

Best Practices could be integrated on LESW as required; in general Best Practices are those that could be applied for any kind of activity, and not necessarily those related to engineering activities. Best Practices provides the best steps to follow in an organization for any kind of process, and the PD organization should take advantage of using them by including them as part of the activities as needed. For this category two questions were included and it was possible to group them since both obtained a Cronbach's Alpha value of 0.8109.

The applied questions on this group are the following ones:

33) It is very easy to find best practices that help me to do my job.
34) It is very easy to capture/update best practices to make my job easier.

The average value of the Functional Areas is 3.0896, which represent values closer to Neutral.

5.1.4.2 Experts Knowledge

For this category it was not possible to obtain a Cronbach's number since the second question was added late and only 18 responses were obtained. For this reason the questions are reported independently.

35) I actively search out expert input as part of our problem-solving and decision-making processes.
    Average on the response value of the entire population: 4.1321

36) It is easy for me to locate the expert who can help me to solve a specific problem.
    Average on the response value of the entire population: 3.8571

5.1:5 Lean Engineering Standard Work

It was desired to evaluate the current status of LESW in two steps, the first one with the aim to understand if something was currently being used to track the part development from start to end and the second step was related to the desirability of a system that represents the LESW in the organization.

5.1.5.1 Current Engineering Templates for Part Development

The intention of this question was to understand if templates were already being used at the organization, helping engineers to develop their parts from start to end and if these templates are easy to find across the organization.

The survey question is the next one:

37) There are easy to find templates that help me track a part development from start to end.

The responses in this category general reject the existence of these templates with an average response value of the entire population of 2.9573.

5.1.5.2 Current usage of checklist for part development and track

This section included two questions required to evaluate the usage of checklists during the development of a part/component/system. The Cronbach's number was relatively low with a value of 0.5158, for this reason individual average results are included in the questions shown below.

38) I store my checklists on my own computer drive (Reversed)
    Average on the response value of the entire population: 2.11

39) I currently own a checklist to confirm that I have followed all required steps to design a part. (Reversed)
    Average on the response value of the entire population: 3.38

Since the purpose is to evaluate the performance of the organization, the two questions were reversed, this because storing checklists on each engineer computer drive or owning them is not a good lean practice; instead the organization should have a set of standardized check lists.

For reporting purposes only, the average value of the entire population is 2.31, being the values reversed it means that it is a common practice to have individual checklists per engineer which is not a good lean practice.

5.1.5.3 Desirability of a LESW

Since the LESW does not exist in the current organization, this section reports straight from the normal Scale Values, this because the desirability of the LESW is not actually evaluating current performance, it reflects the need or desire to have such a system.

The questions regarding the desirability of a system similar to LESW consisted of three questions that were grouped together since they met a high Cronbach's Alpha number of 0.8214.

40) It would add value to have a tool that guides me designing the parts I am responsible for.
41) It would add value to have a standard checklist that helps me confirm I have fulfilled all design steps for every important milestone.
42) It would add value to have a tool that helps me meeting the Engineering Requirements for the part I design

The average response by areas is 3.3824, which means that most of the participants are in agreement willing to have a system that represents an important part of the LESW. It is important to note that the first question had an average result of 4.19 which is the highest recorded average value in the survey.

5.1.5.4 Practitioner Proficiency Assessment

The NACC PD organization already has a system to measure the Proficiency level of the engineers, which is known as the EPDP (Engineering Proficiency Development Plan)

One question is treated independently, after making combinations it was found that this question was not related to the other four, for this reason this specific question is treated independently.

43) The main training I received was based on learning by doing.
Average on the response value of the entire population: 2.78

A total of four questions were created to measure the Engineering Proficiency Level of the Organization. The group of four questions gave a Cronbach's α of 0.6193 which is within the range of "acceptable".

44) I worked with my supervisor to ensure my EPDP was completed to accurately reflect my skill level

45) I had a mentor that helped me on my doubts and questions during my learning in the company engineering systems.

46) The current plan we have to develop my engineering skills reflects the actual needs of a Design Engineer

47) There is enough time to take the required training to improve my engineering skills

The average on the response value of the entire population for this four questions is 3.03

5.1.6 Current NACC Milestone Management System

This section reports the usefulness of the "Milestone Master" system in the Product Development organization. The purpose of this system is to keep track of the most important milestones of the CPDP and make sure that the needed deliverables are met for the parts being developed. In order to evaluate this performance a set of four questions were established with one of them reversed in order to have consistency in the results. This set of questions was made specifically for the NACC organization and not necessarily applies to any PD organization.

48) "Milestone Master" adds value by keeping track of the progress of the parts status per program milestones.
49) "Milestone Master" is a tool for status report only (Reversed)
50) "Milestone Master" is a tool that helps engineers to keep track of what needs to be completed by milestone
51) I systematically use "Milestone Master" to be aware of the requirements for every milestone to meet for the parts I am responsible for.

The Cronbach's Alpha result of the four set of questions was of 0.7132, with an average response from the entire population of 3.089, which is closer to "Neutral" as an average response.

5.1.7 Three Questions on Engineer's Perception of the Organization

This category consisted on three questions that were not possible to group because each one measures different aspects of the organization, in fact for these set of questions Cronbach's Alpha was very low obtaining a value 0.3187.

52) I know who is the authority to decide on each program deliverable
    Average on the response value of the entire population: 3.73

53) In my organization it is rewarded the firefighting of issues instead of rewarding the work executed with excellence (Reversed)
    Average on the response value of the entire population: 2.87

54) It is difficult to keep track of all the web pages I need to update for the part I am responsible for. (Reversed)
    Average on the response value of the entire population: 2.70

For reporting purposes only the average value of the entire population is 3.045.

5.2 Chapter conclusions

The survey responses previously documented, have provided very interesting information that will be analyzed in more detail in the following chapter, however, before going further with a deeper analysis, it would be useful to define the treatment that will be used for of each of the group of questions, based on the Cronbach's alpha values that each of these groups have obtained.

Since a low Cronbach's alpha value means that the selected group of questions is not interrelated, then, those groups of questions need to be treated differently from the questions with a high reliability, meaning a higher Cronbach's alpha values. It is important to do this considering that these results will be carried on to the next chapter for the Gap analysis.

Other questions were not grouped; the reasons are detailed in the following paragraphs.

5.2.1 Group of questions with a Low Cronbach's alpha value

The following groups obtained a Cronbach's alpha value below 0.6:

- Waste (Overall Perception): The reason of obtaining a low Cronbach's alpha number was because the two questions of this group were evaluating different things, in fact this was the lowest of all groups with a value of 0.0364. The first question was referred to the level of awareness of waste (in general), and the second was focused on engineering programs meeting the planned schedules. Both of these questions are important, for this reason both are kept in the next Gap analysis as independent questions.

- Waste (Meetings): This group of four questions obtained a relative low Cronbach's number of 0.5215, in this case the reason was due to the high disparity in the engineer's answers, based on the perception of the meetings in which they participate. Cronbach's alpha also is a measurement of the dispersion in the results of a group of questions, when the dispersion is high; the Cronbach's alpha value is low. For this reason the group is maintained into the gap analysis with the caveat that this group is not completely reliable.

- Engineering Knowledge (Current Checklist Status): The two questions reported as a group obtained a relative low Cronbach's number of 0.5158, also for this case the reason was due to the high disparity in the engineer's answers. It is important to know the level of usage of checklist and if the engineers individually maintain those checklists or if these are shared among the engineering groups. For this reason the group is maintained into the gap analysis, again, with the caveat that this group is not completely reliable.

- Engineer's Organizational Perception: This group consists of three questions that obtained a very low Cronbach's alpha value of 0.3187. The questions were not interrelated, thus measuring different aspects of how the organization is managed. The questions will be treated as independent questions in the gap analysis and are not discarded, since they are measuring important aspects of the management organization that could have an effect in the performance of the LESW.

5.2.2 Group of questions with a High Cronbach's alpha value

The following groups obtained a Cronbach's alpha value above 0.6; no further description is required since these groups met the required threshold value, meaning that each group contains interrelated questions, thus measuring something similar:

- Waste (Design Rework)
- Waste (Overload)
- Best Practices
- Systematic Problem Solving
- Engineering Knowledge (Creation & Reuse)
- Engineering Knowledge (Best Practices)
- Lean Engineering Standard Work (Desirability)
- Engineering Proficiency Level
- Current Engineering Milestones and Requirements Management

5.2.3 Questions not integrated to any group

The following questions will be treated as independent from the groups since due to its nature it was not possible to include them in any of the previous named groups.

35. I actively search out expert input as part of our problem-solving and decision-making processes.
36. It is easy for me to locate the expert who can help me to solve a specific problem.
37. There are easy to find templates that help me track a part development from start to end.
43. The main training I received was based on learning by doing.

This clarification was required in order to provide a background on the treatment of the different groups and questions that are included in the gap analysis of the following chapter.

Regarding the interview, additional comments are provided in the Chapter 7.2 (Conclusions)

6 Implications

The purpose of this section is making sense of all the gathered data.

6.1 Gap Analysis

The purpose of this section is to compare the current status of the organization vs. the proposed LESW model. This chapter is subdivided following the structure of the LESW model.

Currently the NACC PD organization does not have a system that could be compared to the LESW; however, as it was previously explained on Chapter 3, the NACC had previously undergone an overhauling process, by implementing the thirteen lean principles which are based on the Toyota Product Development System. For this reason, it was anticipated some level of knowledge and familiarity to the lean practices in the organization. The following subchapters provide more details on the findings of the previous Chapter 5.

An average response value was used on those groups of questions that met the criteria based on the Table 2 of Chapter 5. , and the group was considered as a single category. The average response value was also used to calculate the gap to the desired optimal value, and the optimum value is considered to be the highest, which is five. The purpose of obtaining the gap value is to use it to prioritize and address the most urgent issues in the organization.

The following sections cover the categories shown in the Benchmark Model of LESW that was presented on Chapter 4.2.

6.1.1 Sources of Waste Detection

In the Benchmark model several ways for detecting waste were mentioned, and, as it was stated, all of them could be valid and are chosen based on the organization needs. A deeper analysis has to be carried out in order to understand the most evident sources of waste from all engineering activities. The sources of waste that were chosen for this analysis are based on the ones proposed by Katherine Radeka.

1) Waste (Overall Perception): Based on the survey results, it was discovered that there is not a homogeneous understanding regarding the overall sources of waste in the PD organization. If waste is not detected or if it is taken as an inherent part of the organization, then there is no opportunity for improvement. This means that the organization needs to implement a consistent training on lean practices and apply it to the engineers' daily work, including, of course, the

detection of sources of waste. Other important point to note is that the general perception is that the programs are not meeting the established milestones. Waste detection goes hand in hand with the performance of the organization, if lean practices are implemented then the immediate result will be an improvement on the performance of the organization helping to meet and plan realistically the milestones to be met on each of the programs. This category did not reach the desired Cronbach's alpha threshold, for this reason the two questions are reported independently in the spider chart.

2) Waste (Meetings): Regarding this topic the findings are reported in 4 subcategories:

    a. Meetings providing valuable outcomes: The general perception of meetings providing actual valuable outcomes is low; improving this perception will lead to faster responses in the product development organization by freeing available time and focusing on actual outcomes from the meetings.
    b. Meetings are for status report only: Although it is always needed to report statuses in order to control the correct advance of the programs, it is also important to avoid as much as possible the use of meetings for status report only. If LESW model is implemented, a lot of the status reporting will be done through automatic processes, this will allow engineers stop doing this status reporting activity and have more time to concentrate on engineering and innovation. Management will also be benefited, since they will be able to have an overall status of the issues from the automatic reports in real time.
    c. Presenting issues or proposals to forums that provide no resolution: Again there is a big opportunity on making the meetings more efficient by having a strict agenda and do whatever is possible to obtain a resolution, this does not mean that the resolution is forced; it only means that the meeting must have as part of the purpose obtaining resolutions and if no resolution is obtained, then define clear follow up task for the next follow up meeting.

    d. Presenting issues or proposals to forums that provide no resolution Engineers have big discrepancies in regards to the required path to follow in order to obtain a resolution to their engineering issues or proposals. This leads again to waste in time. This situation could be improved by creating a clear hierarchy and A3 documents that provide the needed process to obtain an approval.

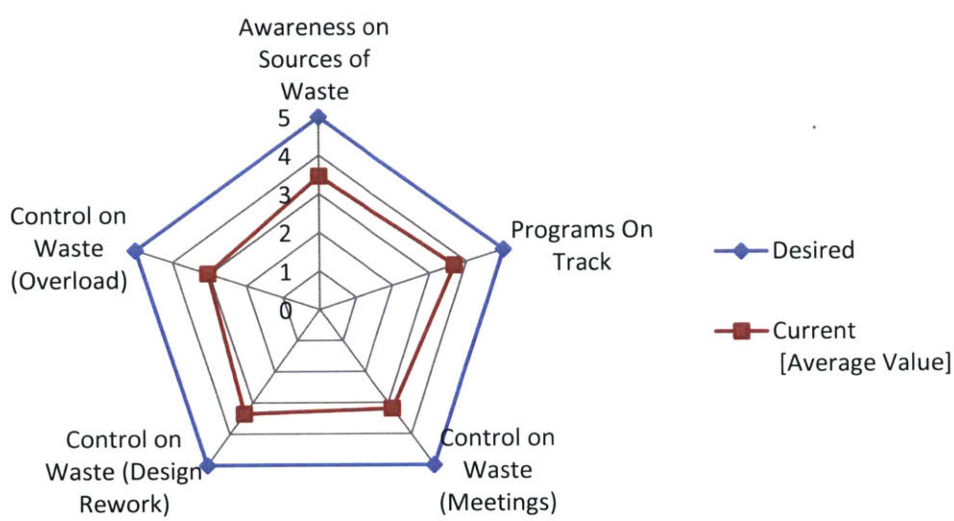
3) Design Rework: Design rework is in general a waste resultant from other activities that were not performed correctly. Some examples of this situation could be: The lack of checklists, lack of lessons learned, or late changes in the product definition. So this waste is considered both a symptom, resulting from other kind of wastes and a waste itself, because it requires time to correct it. In

some cases the design rework occurs once the product was launched, which implies high costs to cover warranty campaigns and could harm the reputation of the company.

4) Overloaded resources: Overload is an important element of the vicious cycle of waste previously shown on Figure 2 8. Overload is almost inherent to the Product Development system where cycles of load work vary through time, but it is always important to keep track of the workload amount within the engineering groups, in order to anticipate for the peaks in workload in certain periods of the product development. In this regard the performance of NACC is above neutral, meaning that it is not a systemic issue within the whole organization, however this issue is present and needs to be improved. The balance between the headcount and the available work is a delicate task, especially under the competitive situation that a PD organization may face, the engineering headcount could be a very expensive resource for the entire organization, however if overload is present, and not addressed correctly, it could lead to disastrous results that could be a lot more costly than the added headcount to cover a program in a proper way.

The following spider chart serves as a visual aid to report this group:

Figure 6-1 Sources of Waste [Current Status]



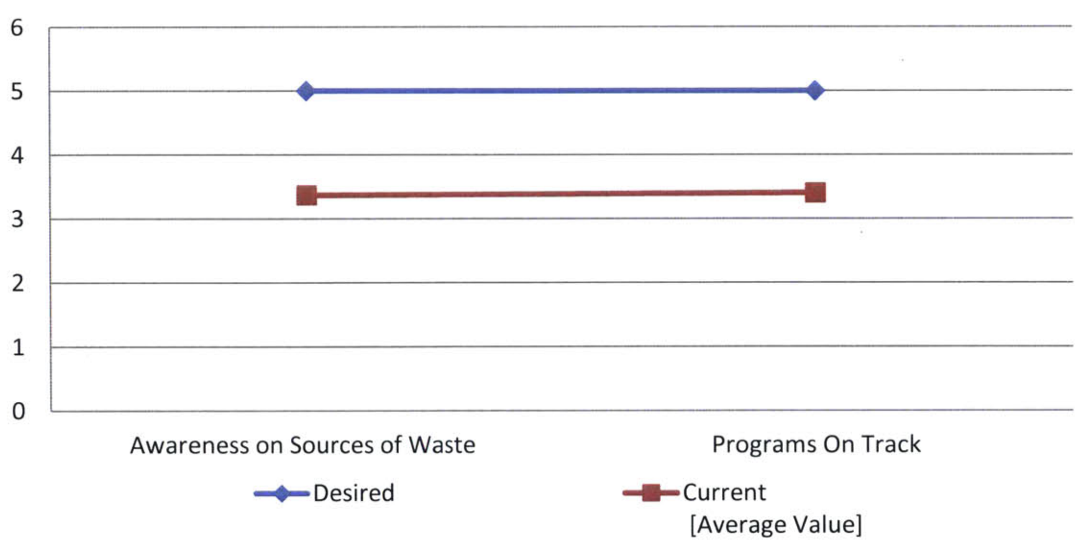
Waste Control Performance	Current [Average Value]	Gap
Awareness on Sources of Waste	3.46	1.54
Programs On Track	3.68	1.32
Control on Waste (Meetings)	3.19	1.81
Control on Waste (Design Rework)	3.35	1.65
Control on Waste (Overload)	3.04	1.96

This chart (Figure 6-1) provides a quick overview of the most important problems related to waste. Each of the waste sources, defined in the chart above, would need to be studied in more detail in order to and address them to improve the processes, and integrate the improved lean activities into the LESW model. Waste can be eliminated by using the Value-Stream mapping methodologies in order to maximize the value of each of the engineering activities.

6.1.2 Systematic Problem Solving Culture

The importance of this block lays in the ubiquitous need of integrating a Problem Solving Culture into the whole organization, by using the best-known lean tools to all its activities. And it serves at the same time as a "knowledge purification" process by applying continuous improvement to the already documented knowledge coming from the LESW. The most popular lean tools are PDCA, LAMDA, A3 Reports, Value Stream Mapping, Product Development Value Stream Mapping, Best Practices, just to name a few examples, but also new practices, methodologies or ideas may be integrated in to this block in order to keep updated the continuous improvement.

Figure 6-2 Systematic Problem Solving Culture



Problem-Solving Performance	Current [Average Value]	Gap
Systematic Problem Solving	3.37	1.63
Manager's Problem Solving Skills	3.40	1.60

This chart (Figure 6-2) provides a quick overview of the most important problems related to waste. Each of the waste sources, defined in the chart above, would need to be studied in more detail in order to address them to improve the processes, and integrate the improved lean activities into the LESW model. Waste can be eliminated by using the Value-Stream mapping methodologies in order to maximize the value of each of the engineering activities.

6.1.3 Application of the "The Four Value Streams of Lean Product Development"

The "Four Value Streams of Lean Product Development" play a very important role in the LESW model since the focus of every organization is to maximize the value to be offered to the final client. The system is continuously being improved by taking advantage of the knowledge coming from the lessons learned, and integrating it into the engineering activities. The model also allows space for innovation since it transfers tacit knowledge to explicit knowledge, freeing time to the engineer, which, otherwise would be used to "reinvent the wheel". The great benefit from this system is that it includes the engineer as an active participant in the learning process, if the engineer finds new ways of performing the activities, which are proven to be better than the previous ones, then, these processes are incorporated or are being updated into the activity. This block also fosters innovation, since if an issue is found in an activity, which is defined as a source of waste, and then the engineers can look for different innovative ideas to overcome these issues.

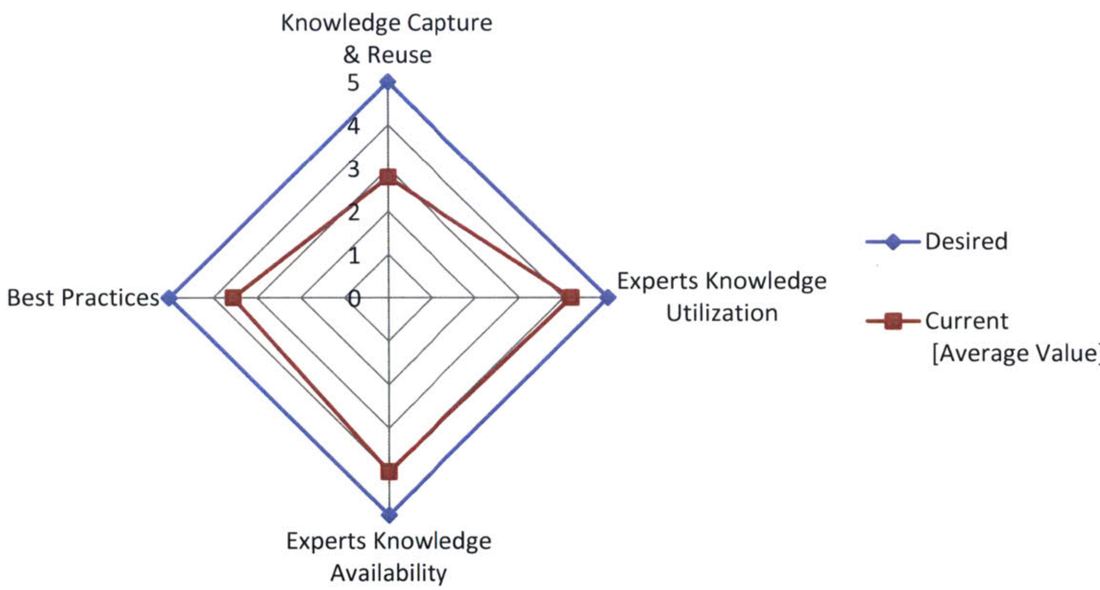
The model, interestingly, is actually transforming waste into value; this is done by documenting the learning from previous mistakes. This knowledge is then transferred to the lessons learned repository, helping to avoid repeating these now known mistakes. The "Four Value Streams" model (Figure 2-11) integrates Customer Value Stream, Product Design and Test Value Stream and Production value Stream in a continuous improvement system by applying one of the most valuable tools in Lean Engineering known as LAMDA (Look-Ask-Model-Discuss-Act) and all the learning is integrated into the Knowledge Creation Value Stream, this is the reason of why this value stream is surrounding the other three value-streams, and at the same time, is using the LAMDA process for continuous improvement.

Note: This section does not have an associated chart since this is integrated in the Systematic Problem Solving Culture but treated as an independent element of the LESW model.

6.1.4 Engineering Knowledge (Creation & Reuse)

The Knowledge-Creation Value Stream plays a very important role in the transformation of tacit knowledge into explicit knowledge, which is coming from all the other Value Streams described in the block model known as "Engineering Knowledge (Creation and Reuse)", this explicit knowledge is then incorporated into the Lean Engineering Standard Work activities.

Figure 6-3 Engineering Knowledge (Creation and Reuse)



Knowledge Management Performance	Current [Average Value]	Gap
Knowledge Capture & Reuse	2.79	2.21
Expert's Knowledge Utilization	4.17	0.83
Expert's Knowledge Availability	4.00	1.00
Best Practices	3.55	1.45

From the chart (Figure 6-3) we can observe that the current status in the organization for the "Knowledge Capture and Reuse" has a big gap, situating it below the "neutral" value, from this spider plot this is the lowest value related to knowledge management. The other area that is still not being exploited is the "Best Practices" area.

Interestingly the expert's knowledge utilization and availability have the highest rank among this group, and that means that the engineers are relying more in their expert's point of view in order to provide solutions to their engineering doubts or proposals.

As part of the knowledge management of the LESW, the knowledge captured in the lessons learned is then integrated into the "Six Elements of Engineering Standard Work" that are part of LESW, which are described in the following chapter.

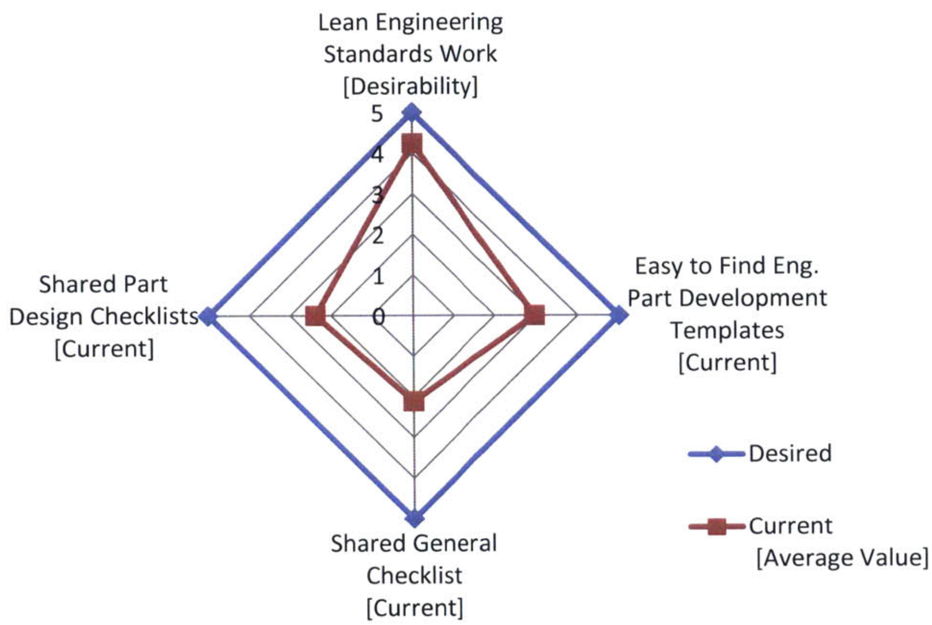
6.1.5 Lean Engineering Standard Work

This is the heart of the proposed system; it contains all the vital information required for the engineers' activities. The LESW is composed of "living documents" that help the engineers to develop the parts they are responsible for. All the information captured by the "Knowledge-Value Stream" is improved by the blocks known as "Systematic Problem Culture" and "Engineering Knowledge (Creation & Reuse)". This knowledge is then distributed to the "Six Elements of Engineering Standard Work" which are an intrinsic part of the Lean Engineering Standard Work model.

The following figure (Figure 6-4) integrates the following chapters into a single chart for visual purposes only showing the current and desired status of the LESW model:

- Current Engineering Templates for Part Development (Chapter 5.1.5.1)
- Current usage of checklist for part development and track (Chapter 5.1.5.2)
- Desirability of a LESW (Chapter 5.1.5.3)

Figure 6-4 Current and Desired Status of LESW



LESW [Desired & Current Status]	Current [Average Value]	Gap
Easy to Find Eng. Part Development Templates [Current] - (Chapter 5.1.5.1)	2.96	2.04
Shared General Checklist [Current] - (Chapter 5.1.5.2)	2.11	2.89
Shared Part Design Checklists [Current] - (Chapter 5.1.5.2)	2.38	2.62
Lean Engineering Standards Work [Desirability] - (Chapter 5.1.5.3)	4.24	0.76

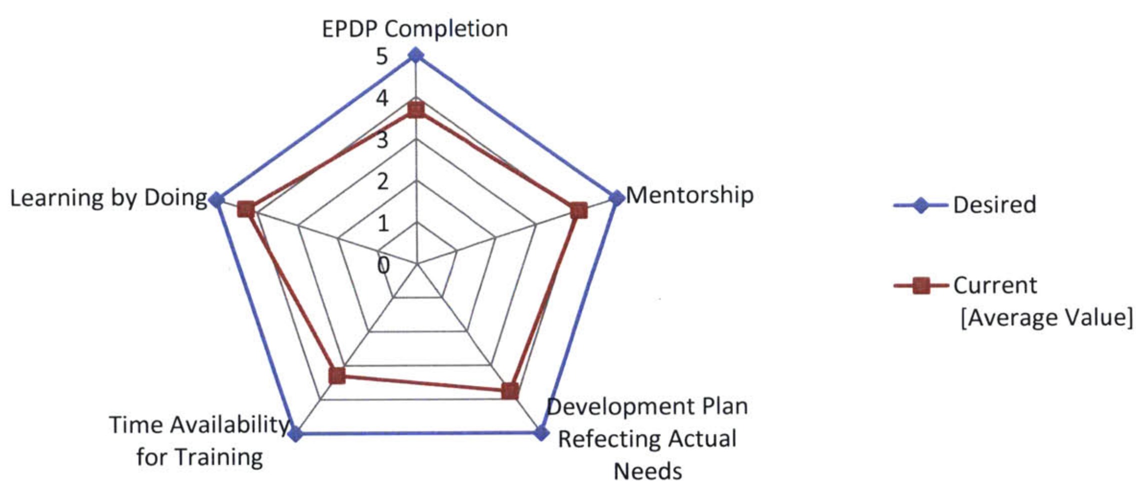
From the chart we can see that the desirability of the LESW ranks as one of the highest value from all the survey average values. This provides a very clear idea that the engineers are actually looking for a system such as the LESW. On the other hand the evaluations regarding the current status of the checklists being shared are very low, meaning that the engineers are keeping the checklists for themselves instead of using standardized formats (Based on the original survey responses from questions 41 and 42).

6.1.5.1 Practitioner Proficiency Assessments

The "Practitioner Proficiency Assessments" provides the information of the support required depending on the "Proficiency Level" of the engineer. This could be adapted to the Proficiency Level currently being used by any Product Development organization.

Depending on the level of maturity of the organization the performance of the team could be assessed by this tool, since engineers with little or no experience will take generally more time to complete the activity, compared to a senior engineer who is capable of executing the activity faster and with more reliability. The level of experience can be linked to the actual time it took to complete the activity, and after going through several programs it would be easier to forecast the time, and required experience to complete a program. This portion of the framework provides a way to determine which engineers were skilled in what engineering practices. This test is administered to all engineers for the engineering tasks they are to work. Ratings are given to the engineers and based on the resultant category the engineers were classified on different competency levels. It would also serve to assess the headcount required by the organization depending on the number of programs the organization is working.

Figure 6-5 Practitioner Proficiency Assessments



Practitioner Proficiency Performance	Current [Average Value]	Gap
EPDP Completion	3.68	1.32
Mentorship	4.07	0.93
Development Plan Reflecting Actual Needs	3.76	1.24
Time Availability for Training	3.29	1.71
Learning by Doing	4.27	0.73

From the chart above we can obtain valuable information that describes the current status of the NACC PD organization relative to the "Practitioner Proficiency Assessments". One of the biggest areas of opportunity lies in the "Time Availability for Training", the engineers are not being able to improve their skills because they do not have enough time for taking the required training. The other areas are not that bad being the "Learning by Doing" the one with the smallest gap of the entire survey. The other elements such as "Mentorship" and "Development Plan Reflecting the Actual Needs" have a respectable gap value of 0.93 and 1.24.

6.1.6 Current NACC Milestone Management System and Three Questions on Engineer's Perception of the Organization

This report integrates the two last sections of the survey, which were specifically designed for the NACC; the first comes from Chapter 5.1.6 – "Current NACC Milestone Management System" and the second comes from the set of three questions included in Chapter 5.1.7. - "Three Questions on Engineer's Perception of the Organization"

In order to simplify the report, the performance analysis of the two chapters is integrated into a single spider plot (Figure 6-6), which includes the following areas that were elaborated in order to characterize the performance of the NACC on the following areas:

The first performance metric is related to the "Milestone Master" which is a NACC internal management tracking system that keeps track of the tasks that must be achieved on each milestone for every single engineering program. The system is based on the CPDP (Corporate Program Development System).

- Current Performance of the NACC Milestone Management System
  - The purpose is to check how effectively this system is working in the organization

The subsequent performance metrics are the "Three Questions on Engineer's Perception of the Organization" that measures different important aspects of the organization.

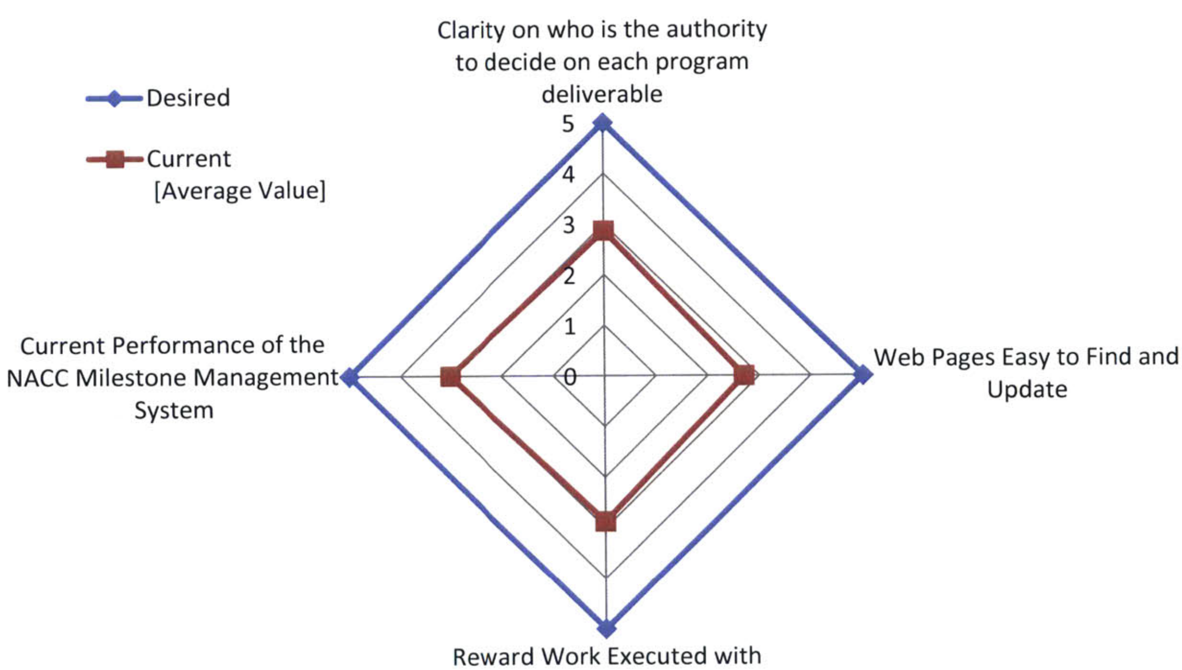
- Clarity on who is the authority to decide on each program deliverable
  - This measurement is important because it could delay decisions if the engineers are not aware of the authority hierarchy of the programs they work with.

- Web Pages Easy to Find and Update
    - This measurement provides an idea of the effectiveness of the intranet system in the organization, a lot of times the organization has huge intranet systems that offer important information to the users, but, if it is not easy to use and if the web pages are located in too different areas, then this makes difficult to perform the tasks. The objective of the LESW model is to include links to those web pages that are required to complete a task, this helps to improve the time required to execute each task or activity.

- Reward Work Executed with Excellence
    - This measurement helps to understand the reward system offered by the management that in fact is part of the culture of the organization. If the work done with excellence is rewarded and included as part of the performance review of the engineers, then they will be motivated to excel in this area, this helps to detect the problems early in the development which has proven to be the best way to reduce costs. However if the contrary occurs, meaning that the firefighting is the one being rewarded, then the motivation is focused on resolving issues late in the process causing a lot of waste

Although these questions were created for the NACC, these could be adapted to the desired organization to be evaluated.

<u>Figure 6-6 NACC "Milestone Manager" performance and “and Three Questions on Engineer's Perception of the Organization</u>



Performance of the "Milestone Manager" and three Questions on Engineer's Perception of the Organization	Current [Average Value]	Gap
Current Performance of the NACC Milestone Management System	3.01	1.99
Clarity on who is the authority to decide on each program deliverable	2.87	2.13
Web Pages Easy to Find and Update	2.70	2.30
Reward Work Executed with Excellence	2.87	2.13

From the figure above (Figure 6-6) we can see that all these four areas are very homogenous and very close to the "neutral value", still, there is still a big gap in terms of performance of almost 2 units. The worst case is the one related to the "Web Pages Easy to Find and update"

6.2 Recommendations

The previous gap results provide rich information that is presented in the next tables sorted by magnitude. The purpose of doing this is to help the organization to focus on the most immediate issues based on the LESW model. The sorting is independent from each of the categorized groups.

1) Rank (From largest to smallest gap value)
2) Category (Main categories based on the previous groups)
3) Gap Value
4) Recommendations

It is important to note that the recommendations are based on the LESW model and my personal experience as an engineer currently working for a Product Development Organization.

Rank	Category	Sub-Category	Gap	Recommendations
1	LESW [Current & Desired Status]	Shared General Checklist [Current]	2.89	1- This is the largest gap of the whole survey, meaning that the engineers are currently using independent checklist to do their work. The result of operating in this way is a lack of consistency on the quality of the work being done and this may lead to tasks that are not executed on time on each of the milestone deliverables. The LESW will have specific tasks that may contain standardized checklists in order to confirm that the work has been completed; this will assure a consistent execution. 2- The advantage of the LESW is that the engineer is part of the system, so if they find that the activity needs to be updated then they communicate this to the expert in order to update the activity and the embedded checklists.
2	LESW [Current & Desired Status]	Shared Part Design Checklists [Current]	2.62	This is the second largest gap of the whole survey, and it is related to the previous section, but in this case it is specifically related to the checklists that are required to develop a part, component or system. The same kind of improvements will be obtained by implementing the LESW method, as it was described in the previous section.
3	Performance of the "Milestone Manager" and three Questions on Engineer's Perception of the Organization	Web Pages Easy to Find and Update	2.30	Interestingly this is the third largest gap in the NACC PD organization. As it was previously stated the amount of information that is available in the intranet of the NACC is overwhelming. This leads to a lot of confusion and a lot of time wasted when looking for information to perform the daily jobs of the engineers. The LESW will provide the most valuable information to be executed by each of the required deliverables; this will save a lot of time and will guarantee that no tasks are forgotten.

Rank	Category	Sub-Category	Gap	Recommendations
4	Knowledge Management Performance	Knowledge Capture & Reuse	2.21	This is the fourth biggest gap of all the survey, this means, that even though the organization already has in place a "knowledge management system", the organization is not taking advantage of it. The benefit of implementing the LESW is that the system provides a very structured frame that allows a good knowledge management, it is embedded in each of the activities and promotes a continuous capture of lessons learned that later will be integrated into the engineering core knowledge as part of the documented requirements and checklists.
5	Performance of the "Milestone Manager" and three Questions on Engineer's Perception of the Organization	Reward Work Executed with Excellence	2.13	Also this gap is quite large; this means that the organization is still rewarding the firefighting instead of rewarding the work executed with quality. It is recommended to track the amount done by each engineer and confirm that the tasks were executed with quality. This kind of work is the one that offers the highest value to any organization and it needs to be rewarded accordingly.
6	LESW [Current & Desired Status]	Easy to Find Eng. Part Development Templates [Current]	2.04	This section is showing the current status of templates that help engineers in the development of the parts they are responsible for. And from the gap result it is concluded that the templates are not being used as expected. The advantage of using the LESW model is that it will guide the engineers through the development of the parts, subsystem or systems and will help them understand the interrelation that might occur with other components or functional areas. The LESW will be the main template to be followed not only to develop the parts but also to keep the pace of the project development helping the engineers to fulfill each of the required milestones.
7	Performance of the "Milestone Manager" and three Questions on Engineer's Perception of the Organization	Current Performance of the NACC Milestone Management System	1.99	The current system being used to track the most important deliverables at NACC is known as the "Milestone Manager", this system is very helpful by defining the deliverables of every milestone. However this system lacks the detail of the specific activities that need to be done by each engineer and does not count with the "Six Elements of the Lean Engineering Standard Work". For this reason a lot of times the deliverables are not properly executed, this leads to delays in the programs, quality issues and inconsistencies in the deliverables.

Rank	Category	Sub-Category	Gap	Recommendations
8	Waste Control Performance	Control on Waste (Overload)	1.96	1- Create a detailed forecast of current and future programs in order to distribute workload according headcount 2- Obtain data from the actual time required for each activity from the LESW model 3- Update the needed headcount according to the data obtained from LESW 4- Apply workstream value in order to eliminate or improve processes for each of the engineering activities
9	Waste Control Performance	Control on Waste (Meetings)	1.81	1- Create a "Meetings Best Practice" to be followed for the entire organization 2- Run meetings with a clear agenda and desired outcomes 3- Create Best Practices on flow diagrams for approval sequence and distribute within the entire organization
10	Practitioner Proficiency Performance	Time Availability for Training	1.71	The Practitioner Proficiency Performance is one of the most important metrics of the organization, this metric, measures the capabilities and maturity of the engineers. Being able to evaluate these capabilities will provide to the management a better sense of the time required to execute each of the activities in the program and the maturity level of the engineering group to receive programs according to its complexity. For this reason it is mandatory to provide to the engineers the required time they need to take their training. 1-It is an intrinsic part of every Product Development Organization to have variation on the workload as the engineering programs progress. For this reason it is convenient to plan for training, taking advantage of the periods in which the workload is low. 2- If engineers are working on different programs with different phases then it is recommended to allocate for some planned time for training that does not disrupt the program milestone deliverables. 3- LESW will help with the plan of the workload based on the activities to be performed for each milestone. This will allow management to foresee the proper times to be dedicated for training.
11	Waste Control Performance	Control on Waste (Design Rework)	1.65	1- rework is a far more complex situation since it is both a symptom and a source of waste 2- Apply the systematic problem solving and the four value streams analysis.

Rank	Category	Sub-Category	Gap	Recommendations
12	Problem Solving Performance	Systematic Problem Solving Culture	1.63	1- The gap value obtained represents an organization that already have a "Problem Solving " as part of its culture, however this is not the number required for a mature PD organization 2- It is recommended to continue with training on "Problem Solving" methodologies 3- Integrate Problem Solving methodologies as part of the training of the EPDP which is related to the "Practitioner Proficiency Performance"
13	Problem Solving Performance	Manager's Problem Solving Skills	1.60	1- From the obtained gap numbers, there could be a relation between the capabilities of the managers on "Problem Solving" to the "Problem-Solving" capabilities of the entire engineering group, if the managers do not enforcing its application, then this is transmitted to the engineers as a matter of low priority. If the managers have little knowledge on Problem-Solving, then the knowledge cannot be cascaded to the engineers, and as a consequence the knowledge will be lost overtime. 2- It is recommended that the management increase their level of knowledge regarding the "Problem Solving" tools, so they can help the less experienced engineers to solve issues and reinforce its application through all the company.
14	Waste Control Performance	Awareness on Sources of Waste	1.54	1- Establish Training on "Sources of Waste detection" to all Product Development engineers and all people involved on the PD process. 2- Enforce the application of Problem Solving not only at the working level but also at management level.
15	Knowledge Management Performance	Best Practices	1.45	Best Practices offer the most efficient process to execute any task, for this reason, best practices should be used ubiquitously in the organization. At the NACC the best practices are generic, these are practices that are not "function specific" and are documented separately from the LESW model. However the Best Practices can be referenced in each of the activities as required.
16	Waste Control Performance	Programs On Track	1.32	1- The implementation of LESW will help to maintain programs on track in real time; this helps to think strategically regarding the tasks prioritization. 2- The current system known as "Milestone Manager" tracks the deliverables per milestone, however a lot of times the milestones are not met because the deliverables are not providing enough level of detail, this leads to confusion and delays. The LESW will include detailed information on each of the activities assuring the correct completion of each of the deliverables.

Rank	Category	Sub-Category	Gap	Recommendations
17	Practitioner Proficiency Performance	EPDP Completion	1.32	The Practitioner Proficiency Performance is known in the NACC as the EPDP (Engineering Proficiency Development Plan), this evaluation is an important part of the LESW model that need to be updated and planned according to the product development organization needs. 1- It is recommended that management reinforces the thorough application of the EPDP, and include as part of the performance review of both the engineer and his/her supervisor. 2- Sometimes the EPDP is not done because there is little available time to do it in the proper way, for this reason it is important to mark its completion as an important part of the development of the engineers by evaluating it at least twice a year as part of mi mid-cycle and final cycle performance reviews.
18	Performance of the "Milestone Manager" and three Questions on Engineer's Perception of the Organization	Clarity on who is the authority to decide on each program deliverable	1.27	Each program has a management level hierarchy that approves the proposals or engineering issues. However it is sensed that this hierarchy is not well comprehended by the engineers. It is recommended to deploy a clear overview of the hierarchy and the required flow diagrams to proceed with the product and engineering approvals.
19	Practitioner Proficiency Performance	Development Plan Reflecting Actual Needs	1.24	The development plan needs to be created according to the engineering skills that are mandatory for the engineering organization as part of the development plan of the entire organization. 1-If the organization is planning to support global programs then a certain level of expertise is expected; it is recommended to assess the actual capabilities of the team in order to avoid false expectations due to the lack of experience and training of the engineers. 2- It is recommended to make an annual evaluation of the planned development of the teams in terms of training and skills to be considered mandatory. 3-It is recommended to maintain updated the development plan according to the forefront technologies and lean engineering tools.
20	Knowledge Management Performance	Experts Knowledge Availability	1.00	Although the gap is not "zero" for this section, the performance is quite good, at the moment it is not a priority.

Rank	Category	Sub-Category	Gap	Recommendations
21	Practitioner Proficiency Performance	Mentorship	0.93	Mentorship has been a tradition in the NACC, for this reason the gap is low and is not considered a priority. Although mentorship is highly valued in the organization it is recommended to apply it in parallel to the application of the LESW. The thorough development of the LESW activities will help to develop the skills of the engineers, and when it is mixed with the mentoring support the result will be a very fast learning curve of the new hires.
22	Knowledge Management Performance	Experts Knowledge Utilization	0.83	This section has a low gap and it is not considered a priority
23	LESW [Current & Desired Status]	Lean Engineering Standards Work [Desirability]	0.76	This section is measuring the desirability of a system similar to the LESW, since the gap value is small we can conclude that the engineers desire the implementation of the LESW model. This is the second smallest gap of all the survey sections. This reinforces the recommendation to implement the LESW in the NACC product development organization.
24	Practitioner Proficiency Performance	Learning by Doing	0.73	Learning by doing is another tradition of the NACC, this was an expected result based on the traditions and culture of the organization. For this reason this is not a priority. However it is recommended to guide the engineers with little experience by following the LESW activities, these will need to be approved by the supervisor or mentor. By doing this the engineer will gain the required confidence to continue with his/her development.

This set of recommendations were developed for the current status of the NACC, however they can serve as a point of reference for any other organization that is experiencing similar issues.

6.3 Implementation

This section provides a series of recommendations to implement the LESW model based on different authors' opinions, an interview of a program manager of another Product Development company, and my personal experience as a Product Development Engineer. It starts with an interview done with one of the heads of a Product Development organization, the interview is centered on his opinions regarding the concept of LESW (Lean Engineering Standard Work).

6.3.1 Interview

The chief program manager from a Product Development organization, who preferred to remain in anonymity, contributed with a valuable part of the initial assessment regarding the implementation of the proposed LESW. He provided interesting opinions regarding the usefulness of this thesis as a valuable tool to improve the CPDP (Corporate Product Development Process), this interview served to understand important aspects to be considered in the thesis development.

In 2004 his Product Development Organization invested over one billion dollars to develop and implement a tailored "Workflow-Management software" that controlled the development process from the most basic activity levels of the engineering organization. This software was part of every engineer's desktop, and the activities for every single day walked the engineer through design rules and creation of standards, with the purpose of making sure the engineer was doing his/her job exactly as expected and in the same way across the organization.

However the project was cancelled around 2008/2009 because "the engineers were turning off their brains; they were doing everything by rote, designing products that were not satisfactory to the customer", besides that and more importantly they were not part of the design and implementation of the system. They depended on third persons that took the decision of what was the best for the process to be followed and the rules to be applied on every design. This resulted on design rules that were incorporated in order to maximize the profitability of the product based on current manufacturing possibilities and limits. So manufacturing was never challenged to work on designs right on the edge of performance, and since the engineers were only following the "Workflow Management Options" they never attempted to challenge the system. As a consequence a vicious cycle was created, where the less impacting result was to develop "extremely boring designs, close to be defined as ugly" and not only that, it jeopardized several projects because the engineers did not capture hazards that might occur on the designs since those hazards were not included on the workflow process.

This situation led to an uncontrollable amount of quality issues found in the field and the loss of practice of the engineers to think and create, which are one of the basic characteristics of a capable engineer.

Based on this experience and after reviewing the proposal of the LESW the chief program manager made the following recommendations and insight questions:

1) Standardization needs to be handled with care because if it is taken wrong it could be confining.
2) Carefully define how far you want to go defining the engineer's activities, "How much is too much?" "...You do not want ending up in the same situation as our company did."
3) "Who will be reviewing the activities to confirm that they contain the right information?"
4) It is mandatory to understand the amount of work that will be required for the implementation of this proposed system. "You need to have an idea before bringing this proposal to your management asking for support."
5) "Standardization should never become part of a bureaucratic process." This LESW needs to be as simple and lean as possible.
6) The Lean Engineering Standard Work should be easy!
7) My recommendation is to start concentrating efforts on:

    i. Activities where the biggest mistakes are found
    ii. Repetitive activities
    iii. Activities difficult to manage
    iv. Activities that the engineers find frustrating or inefficient.

8) The secret is to standardize operations looking for paths that are the easiest to achieve the desired outcome, so the engineers will see that following the standard is the easiest and faster way to perform their job.
9) Always walk through the processes finding waste.

These past experience shared by the leader from another Product Development organization offer an interesting opportunity to learn in order to avoid committing the same mistakes, and carefully consider implementing new ways of work applying systems thinking in order to understand the possible risks of new policies being deployed in the organization.

6.3.2 Implementation recommendations

Based on the LESW model, the interview, and my personal experience the following implementation insights and recommendations are provided.

First of all, the implementation of the LESW model necessarily needs the support of the upper management, not only in terms of verbal commitment, but also in terms of resources being allocated for the implementation efforts. And in order to obtain this support it is required to understand the current status of the organization in order to understand the magnitude of the change, and to prepare a plan to be presented to the upper management. This is the usefulness of the survey in order to address the weaknesses of the organization compared to the LESW model.

There is an advantage in the NACC obtaining support from the upper management, and this is the case since, as it was explained in previous chapters, the NACC had previously received management support by following Morgan & Liker 13 principles that comprise the "The Toyota Product Development System". This situation in the NACC makes a big difference compared to an organization in which the upper management has never been exposed to these principles; in general, a company that has no experience in lean engineering needs time to go through the required cultural changes, and typically, since the upper management performance is evaluated based on immediate results, they can lose patience too easily and too quickly, especially if they expect a prompt improvement in cost savings. For this reason it necessary to expose the upper management to first-hand experience in the lean engineering tools so they can understand that the benefits will not be immediate, as some learning curve needs to occur.

Initially Pratt & Whitney went through hard times implementing ESW, because at the beginning they lacked the support and few resources were allocated, especially things did not move fast because the original team was not composed of lean engineering "hard-core believers". Pratt & Whitney case faced three challenges that slowed progress:

1) "The difficulty of making explicit what had been deeply embedded as tacit knowledge and know-how in engineers' minds and work practices
2) The enormity of the task of deconstructing the integrated design of a product as complex as a jet engine into clearly defined, prescriptive process steps and flows
3) The fact that the steering group still lacked authority to involve all Pratt engineers in the change process. Buy-in by rank-and file engineers and their managers was therefore limited" [13] [17]

The previous paragraph shows the importance of the implementation strategy to be presented to the upper management, and the challenges that are very common in PD organizations regarding the task of transferring tacit knowledge to explicit knowledge and understanding the current activities being executed by the engineers in order to accomplish the milestone programs. Besides that the three challenges mentioned above shows the need of the upper management support in this task. It was not until Paul Adams, who was a highly experienced and renowned executive at Pratt & Whitney that the ESW received enough support to move and implement it in one of the most important programs at the time.

In the implementation strategy it is also important to understand the purpose of the LESW and the kind of culture and bureaucracy that will naturally develop through the implementation of the model. The main purpose of the LESW is to help the engineers through the development of the components, sub-systems and systems they are responsible for, and not a system that will be seen as a cumbersome additional task

[13] H. K. Bowen and C. Purrington, Pratt & Whitney: Engineering Standard Work, Cambridge: Harvard Business School, 2006.

they have to fulfill and eventually shirk. A desired consequence of helping the engineer by using the system is that the management will be benefited by obtaining actual data of the activities performed by the engineers, which will provide better planning on time and resources, at the same time it will improve the program control by confirming the actual statuses of the required activities that need to be completed in order to meet the program milestones.

According to an article written by Paul Adler and Bryan Borys, [20] an organization could have (or develop) two different kinds of bureaucracies based in the use of formalization (the extent of written rules, procedures, and instructions); one being negative, known as "Coercive bureaucracy" which “stifles creativity, fosters dissatisfaction, and demotivates employees”[14], this bureaucracy uses formalization in an effort to force engineers to obtain compliance. And one positive one, known as the "Enabling bureaucracy", which “provides needed guidance and clarifies responsibilities, thereby easing role stress and helping individuals be and feel more effective”[15], this bureaucracy uses formalization to enable engineers to master their tasks.

In general, managers are challenged in finding the right bureaucracy in order to create a value-adding organization. This situation creates a dichotomy regarding the best approach for implementing LESW, in one hand it will require some level of coercion to implement the model, and, in other hand LESW needs to be seen as an enabling system in where the engineers will see it as a helping system; in which they are actual participants continuously looking for improvements. If too much control is exerted the most probable result is the rise of a coercive bureaucracy which is not the purpose of the LESW model.

After reviewing different recommendations the ones that seem to fit in the LESW model are the following ones:

1) <u>Develop a LESW leader.</u>
   According to Jim Womak in his book “Lean Thinking”, he recommends that the first step of the organizational change and implementation of lean concepts is to find an internal change agent, this person needs to be “someone who has the respect of the organization, is unrelenting, and is perhaps even a bit tyrannical, and who will drive the change process through the inevitable difficulties it will encounter” [10]. This seems to be in contradiction with the main purpose of the LESW model. However the intent is to assimilate the way the model operates and once understood, the engineers will see that the LESW will enable them to work in a more efficient way, and that they are an essential part of the system by looking for continuous improvement. In this way the final result is an enabling

---

[14] P. S. Adler and B. Borys, “Two Types of Bureaucracy: Enabling and Coercive”, Administrative Science Quarterly, 1996.
[15] P. S. Adler and B. Borys, “Two Types of Bureaucracy: Enabling and Coercive”, Administrative Science Quarterly, 1996.

bureaucracy. It is important that the person that will be leading the implementation knows very well the LESW model and the lean engineering tools with first-hand experience in lean product development. In the case of Pratt & Whitney, the highly regarded executive Paul Adams was chosen because he had a strong will and passion to push the ESW through the entire organization.

2) <u>Understand your Current Status vs. LESW</u>.
It is recommended to apply the survey in order to focus in the areas that require more attention and have an idea of the current status of your organization.

3) <u>Obtain upper-management support.</u>
The success of implementing the system depends on the level of involvement and commitment of the upper management; they need to be intensely participating in the transformation process, they need to send a strong message that they are willing to move in this direction. This support and commitment works in both ways, the upper management involvement is absolutely needed by supplying the required resources and selecting the best people to lead the change, and the commitment of the whole participating team. You should never allow that your team members are working in isolation, working as a team will provide the required synergy to move in a fast pace and in the desired direction.

4) <u>Focus on your customer</u>.
The start point is to focus on the gap areas detected by the survey, later it is required to apply the "Four Value Streams of Lean Product Development" in order to guarantee that the efforts are focused to offer value to the customer. Agreeing with the recommendations from the interview, it is recommending starting the value-stream analysis on:

   a. Activities where the biggest mistakes are found
   b. Repetitive activities
   c. Activities difficult to manage
   d. Activities that the engineers find frustrating or inefficient.

5) <u>Start with a pilot project</u>.
The pilot program or project will serve to involve and obtain the commitment of all the involved parties into the LESW model. The pilot project will document the required activities to meet the milestones with the help of the experts; this starting point could be refined by gaining experience and documenting the lessons learned and especially involving the engineers that are actually executing the activities. Through this process several sources of waste will be discovered, in fact one of the most important objectives of the pilot project is to capture the learning, if this is not done then the effort itself is considered as a waste. Another important recommendation is to choose a pilot project with high visibility, common sense is to select a small project as a pilot in order to lower risks of failure, instead, Katherine Radeka recommends to "think about piloting

new countermeasures on your largest, highest stake, most important projects. Why? They are more visible, and there is more pull for them to succeed"[16]. In the case of Pratt & Whitney their organization chose the flagship development program at that time, their intention was to move faster developing a program since the beginning, this would offer all attention and willingness to succeed and beat the timing of previous programs.

The above recommendations are based on the chapter "Getting to Culture Change: The Heart of Lean PD" of the "Toyota Product Development System" and adapted for the LESW case, the recommendations were also enriched with some notes from Katherine's Radeka Book and the UTC case.

[16] K. Radeka, The Mastery of Innovation: A Field Guide to Lean Product Development, 1St Edition ed., C. P. Press, Ed., CRC Productivity Press, 2012.

7 Conclusions

7.1 Reflections & Conclusions

This thesis was developed in order to provide value to the NACC by standardizing the engineering activities in the Product Development organization, the result was the development of the LESW model, this model was developed by combining 3 basic sources of information, Morgan & Liker's "Toyota Product Development System", Katherine Radeka's "The Mastery of Innovation" and the UTC "Engineering Standard Work" patent.

As it was previously mentioned at the beginning of the thesis, the "replacement rate & showroom age are major determinants of market share, which drives capacity utilization, which in turn drives profitability and ultimately stock and bond prices" [9], this means that waste is a luxury that cannot be afforded in the competitive world of the automotive industry, waste can jeopardize the time to hit the market and it could dramatically affect the reputation of a company if waste is transformed into a quality problem and found in the field. For this reason a system such as the LESW system is needed, which deals with waste elimination by creating a Systematic Problem Solving Culture that is constantly checking the value of each of the activities done by the engineers.

The "Toyota Product Development System", was taken as one of the main sources of information since the authors, Morgan & Liker are well known at NACC due that the 13 principles that comprise the Lean Product Development System were adopted at the product development organization and integrated into the CPDP (Corporate Product Development Process). The CPDP establishes clear milestones required to develop a vehicle, however the actual activities being performed by the engineers are not standardized, which leads to waste in the entire organization and generates inconsistencies in the way engineers work.

Since the purpose of a lean product development system is to maximize value, it is then necessary to create activities that help to reach the customer wants and needs, by defining the most important value streams in the organization Radeka proposes a model that provides a strong framework to operate in a virtuous cycle. This framework of "The Four Value Streams of Product Development", described in more detail on Chapter 2.5.1, was integrated into the LESW in order to have a continuous improvement system embedded into the model.

The LESW model also integrates a knowledge management block described in chapter 2.1.2 known as "Engineering Knowledge (Creation and Reuse)" based on Nonaka's book "Knowledge Creating Company"; in his book Nonaka provides vital information about the dynamics of knowledge present in any organization, where knowledge could be transformed back and forth from tacit-knowledge to explicit-knowledge, in order to create value through the innovative minds of the engineers.

The LESW counts with its fundamental element, the ESW model, which was originally developed by Pratt & Whitney (As a subsidiary of United Technologies Corporation- UTC). This system presented on chapter 2.6 provides a framework that controls the engineering activities, and as a result it is possible to achieve repeatable, capable and efficient processes in the entire PD organization.

From the mentioned sources of information the LESW was developed and composed of five elements:

1) Sources of Waste Detection
2) Systematic Problem Solving Culture
3) Application of the "The Four Value Streams of Lean Product Development"
4) Engineering Knowledge (Creation & Reuse)
5) The Six Elements of Engineering Standard Work

The elements of the LESW model were described in more detail on Chapter 3, and were transformed into a survey on Chapter 4.2, this survey which was based on the LESW model was created in order to assess the current status of the organization being evaluated vs. the proposed LESW model. The results of this survey were later used to create a Gap Analysis which results were used to evaluate the most important issues to be addressed in order to successfully implement the LESW model.

Chapter 6 provides the gap analysis addressing them through several recommendations that could apply to other PD organizations. At the end of the chapter an interview to a high rank chief engineer is presented, his insights are very valuable and considered as part of the implementation efforts of the LESW model.

Based on all the previous information offered in this chapter, we are able to come back to the two initial research questions and provide the following conclusions relative to the status of the NACC:

1) <u>LESW: Does the system already have embedded in its system a similar and efficient process as the LESW?</u>
   According to the responses obtained through the survey we can conclude that the NACC Product Development organization does NOT have embedded a system similar to the LESW model.

2) <u>Lean Tools: Does the organization currently consistently apply the lean engineering tools?</u>
   We can conclude that the lean engineering tools are known in the organization but are not consistently applied, by implementing the LESW model; the use of the lean engineering tools will be ubiquitously used in every engineering activity, for the simple reason that the lean engineering tools are part of the LESW model.

It is important to remark that the intention of the LESW model is to offer a system that will serve to help the engineers to execute and control their tasks and not a model that will be seen by the engineering community as a cumbersome one. For this reason it is important to include the engineer as an active participant in order to create an "enabling bureaucracy" that will evolve through continuous improvement. Through the application of the LESW program management becomes easier offering live data that can be used to have better control over the program and address the required resources for future programs because it is possible to know how long the fulfillment of every activity takes. Of course there will be variations because not every program is the same, but at least it will provide an idea of the status of the program.

With the use of the "Practitioners Proficiency Assessment" it will be possible to have an idea of the capabilities of the product development organization aiming to have consistency not only in the work being executed, but also on the desired qualities of the engineering community. Another benefit obtained from this assessment is that those companies that have international operations (such as the NACC) could have information about the engineering skills by region, and based on that it will be easier to know if a program can be transferred from one region to another for strategic reasons.

It is interesting that although the ESW was developed for the aerospace industry, the main frame could be applied to different organizations, including the automotive industry. In general the big difference between the two is the production volume, in the case of the aerospace industry the volume is far less compared to that of the automotive industry. However it is clear that both industries are subject to very strict regulations, and the products need to comply with these regulations and the LESW model serves to have a better control over the engineering activities in order to comply with them. Besides that, both industries are very competitive and fast development times are a valuable asset needed to survive in this environment. None of the industries can afford to commit mistakes, and at the same time both need to be as efficient as possible. I believe that the LESW flexibility comes from the fact that is a robust system that is actively fighting errors, inconsistencies, and forgetfulness, which are part of the human nature; by implementing the LESW model the system will become more stable dealing with this kind of issues, and these issues are an inherent part of every product development organization.

One thing that could be done in this thesis is to have more interviews. The one that was offered by the Chief engineer of the Product development organization was really useful and provided valuable insights on the implementation of the system. More interviews with engineers and at higher levels in the organization would have enriched the thesis with different perspectives, and recommendations.

It would be extremely valuable to apply the survey to other NACC product development organizations, and understand if there are systemic issues across the different regions.

7.2 Thesis Limitations

This thesis is focused on the Mexican Product Development Organization of the NACC. The actual implementation of the LESW model is out of the scope of this thesis due to the amount of resources and time required to verify the identified outcomes, which are:

- Increased productivity
- Increased Value creation
- Improved motivation of employees
- Improved Definition of Roles and responsibilities
- Reduced learning curve of new employees
- Established clear policies for the work well done
- Continuous improvement of the standard

It is also out of the scope of this thesis to recommended technology to implement the LESW system, the thesis proposes a framework, a model that can be later translated to a software or a web-based system that will need to be carefully tested with the engineers and program management in order to validate its usability.

7.3 Future Research Recommendations

The LESW model offered in this thesis provides a basic framework; each organization would need to invest more time and resources to understand the best solution in a case-by-case scenario regarding the way it is implemented. Not only regarding its elements or the recommended questions included in the survey, but also the chosen technology for its deployment, the UTC organization used a web-based system in order to integrate all the elements of the ESW, this would also be the recommendation of the LESW system.

It is important to develop a system that could be easily maintained and flexible enough to incorporate improvements as the organization learns from the system and the engineers provides feedback with the purpose of to keep it as part of the continuous improvement efforts. It is very important to know what the actual feedback from the engineers is, in order to make the required adjustments of the system so it works as the initial intent, and that is to help them to work in an orderly way while developing a new part.

It is recommended to continue the investigation of the LESW model with a future thesis that verifies the outcomes of the proposed system, for this and per the recommendations made in the implementation section, it would be required to implement it on one of the most important projects of the NACC programs.

Regarding the implementation it is important to mention that there are other implementation tools that were developed to handle organizational changes, such as the LAI-Enterprise-Self-Assessment-Tool (LESAT), this “tool is designed to both measure the current state and envision a future state, which allows users to assess and prioritize gaps between the current state and a desired future state”[17] [21] but its evaluation was out of the scope of this thesis.

[17] D. Nightingale, "The LAI-Enterprise-Self-Assessment-Tool (LESAT)," MIT, Cambridge, 2012.

8 Appendices

8.1 Appendix A (Survey Results)

Survey approval email.

Dear NACC of Mexico PD,

I cordially invite you to participate in the following questionnaire; your responses will be used to understand certain aspects of your Product Development organization. This study is part of my thesis "Lean Engineering Standard Work" at the Massachusetts Institute of Technology (MIT) as part of the System Design and Management (SDM) program.

This Survey will take approximately 15 minutes of your valuable time and it is primarily directed to Product Development Engineers.

And please do not hesitate to contact me if there are any questions or comments regarding this questionnaire at @mit.edu

To participate in this study, please follow the attached link by April 22nd 2015.

https://www.surveymonkey.com/s/K6PTKYQ

(Please note that this questionnaire is completely anonymous and does not request information that would identify the respondents or their respective organizations, such information should not be provided, and, if inadvertently provided by the respondent, will not be used or retained. Reported findings will be non-attributable. Data will be stored securely and will be aggregated for academic and research purposes and referenced in any publications that may result from this survey.)

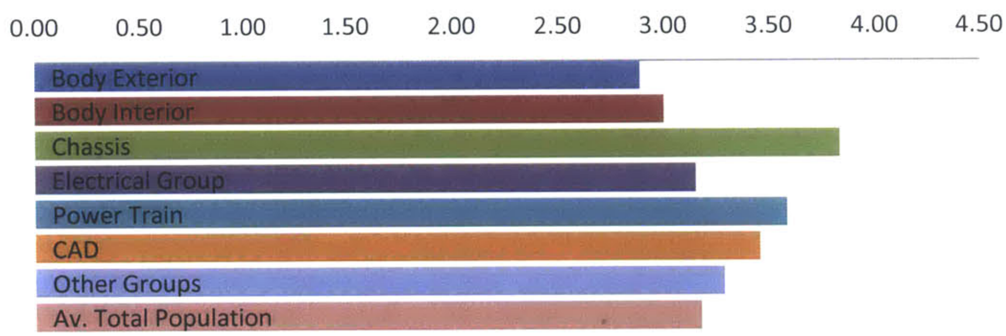
Thank you in advance for your support.

Mario Alberto Rubio Monroy

8.1.1 Waste

8.1.1.1 Waste (Overall Perception)

1) I understand the sources of waste in Product Development.

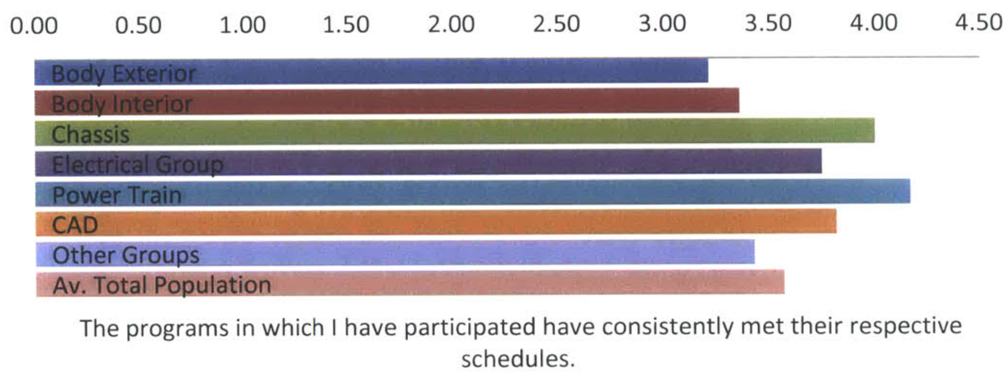


I am overloaded with non engineering work related activities

Body Exterior	2.89
Body Interior	3.00
Chassis	3.83
Electrical Group	3.15
Power Train	3.58
CAD	3.45
Other Groups	3.29
Av. Total Population	3.18

Figure 8-1 Level of Understanding of sources of waste in Product Development

2) The programs in which I have participated have consistently met their respective schedules

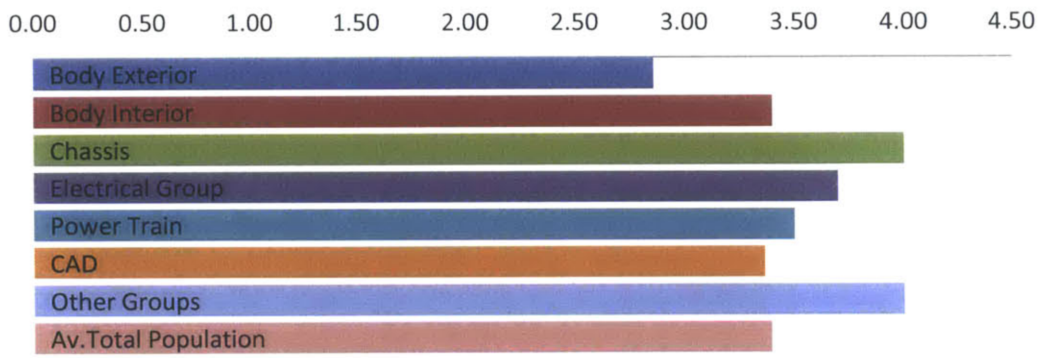


Body Exterior	3.21
Body Interior	3.36
Chassis	4.00
Electrical Group	3.75
Power Train	4.17
CAD	3.82
Other Groups	3.43
Av. Total Population	3.57

Figure 8-2 Performance on programs consistently meeting schedules

8.1.1.2 Waste (Meetings)

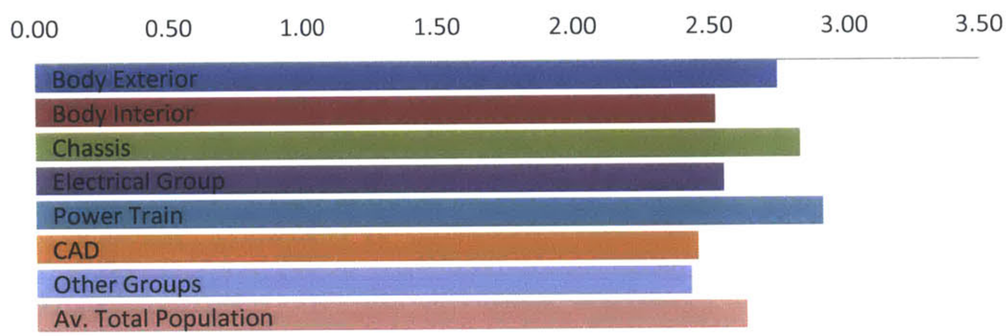
3) All the meetings I attend lead to valuable outcomes for the project I work for.



	All the meetings I attend lead to valuable outcomes for the project I work for.
Body Exterior	2.86
Body Interior	3.40
Chassis	4.00
Electrical Group	3.70
Power Train	3.50
CAD	3.36
Other Groups	4.00
Av.Total Population	3.39

Figure 8-3 Performance on meetings adding value to Projects

4) Most of the meetings I attend are just for status report. (Reversed)
Note: In order to maintain consistency in the performance scale, the scale values for this question were reversed so that the highest score reflects a desirable aspect in the organization. The figure description was rephrased to reflect this.

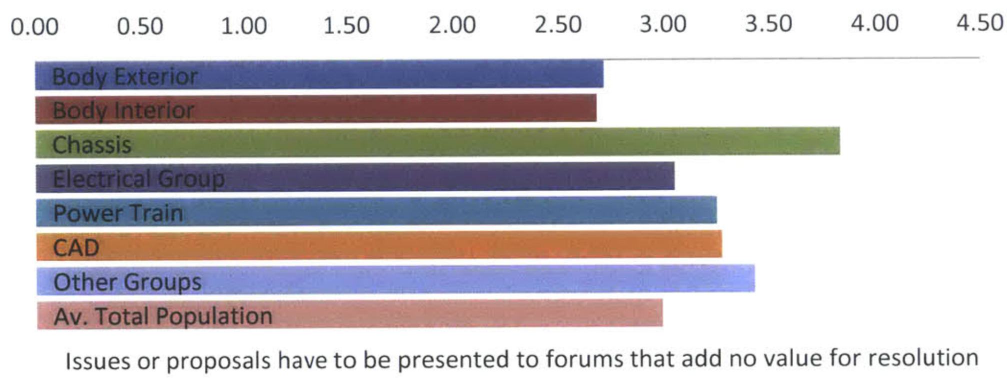


	Most of the meetings I attend are just for status report.
Body Exterior	2.75
Body Interior	2.52
Chassis	2.83
Electrical Group	2.55
Power Train	2.92
CAD	2.45
Other Groups	2.43
Av. Total Population	2.63

Figure 8-4 Performance of meetings not only used for status report

5) Issues or proposals have to be presented to forums that add no value for resolution. (Reversed)

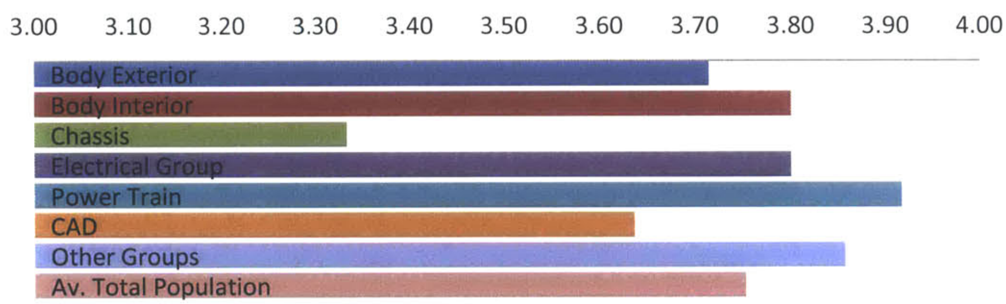
Note: In order to maintain consistency in the performance scale, the scale values for this question were reversed so that the highest score reflects a desirable aspect in the organization. The figure description was rephrased to reflect this.



Body Exterior	2.71
Body Interior	2.68
Chassis	3.83
Electrical Group	3.05
Power Train	3.25
CAD	3.27
Other Groups	3.43
Av. Total Population	2.99

Figure 8-5 Issues presented on forums adding value

6) I know exactly what path to follow in order to obtain final decisions for my issues/proposals.

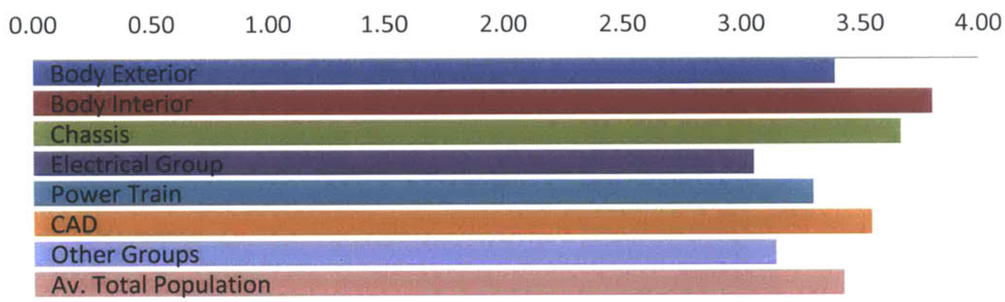


	I know exactly what path to follow in order to obtain final decisions for my issues/proposals.
Body Exterior	3.71
Body Interior	3.80
Chassis	3.33
Electrical Group	3.80
Power Train	3.92
CAD	3.64
Other Groups	3.86
Av. Total Population	3.75

Figure 8-6 Performance on knowing the path to obtain final decisions

8.1.1.3 Waste (Design Rework)

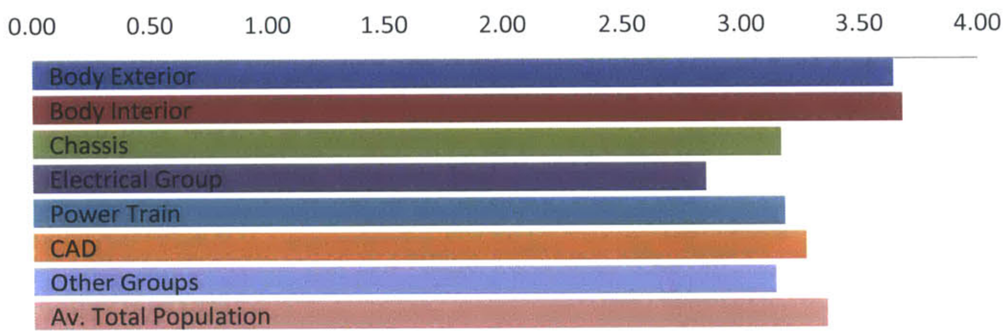
7) There are few design reworks late in development for general parts in my area.



	There are few design redesign(rework) late in development for general parts in my area.
Body Exterior	3.39
Body Interior	3.80
Chassis	3.67
Electrical Group	3.05
Power Train	3.30
CAD	3.55
Other Groups	3.14
Av. Total Population	3.43

Figure 8-7 Performance on design rework

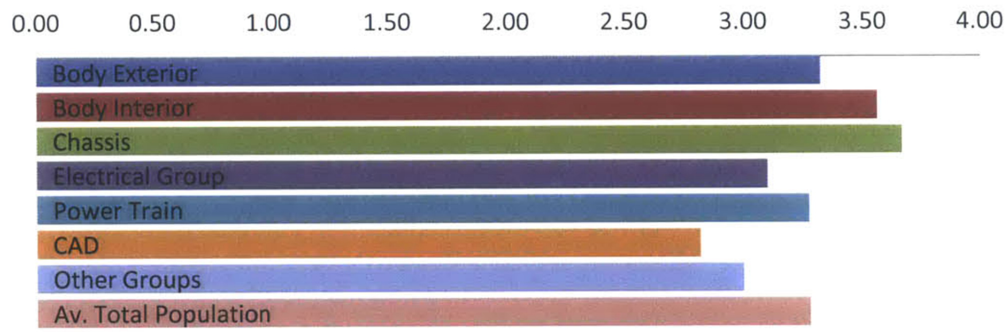
8) There are few design reworks originated by program late changes.



	There are few design loopbacks(rework) originated by program late changes
Body Exterior	3.64
Body Interior	3.68
Chassis	3.17
Electrical Group	2.85
Power Train	3.18
CAD	3.27
Other Groups	3.14
Av. Total Population	3.36

Figure 8-8 Performance on rework originated by program late changes

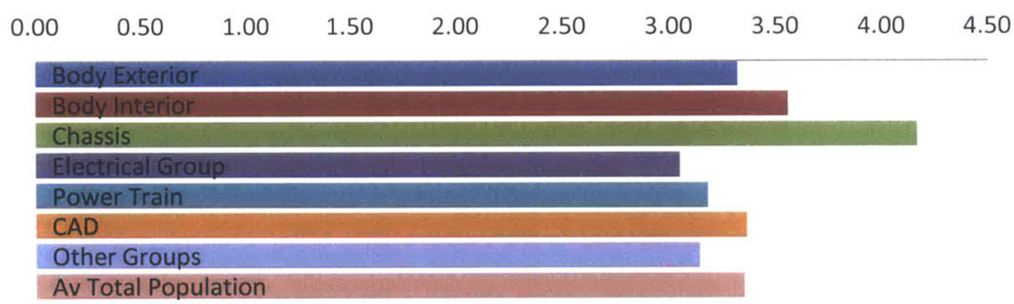
9) In general there are few design reworks after final CAD release.



	In general there are few design rework/redisign after final CAD release
Body Exterior	3.32
Body Interior	3.56
Chassis	3.67
Electrical Group	3.10
Power Train	3.27
CAD	2.82
Other Groups	3.00
Av. Total Population	3.28

Figure 8-9 Performance on design rework after CAD release

10) For the parts I am responsible for I have experienced few design reworks after final CAD release

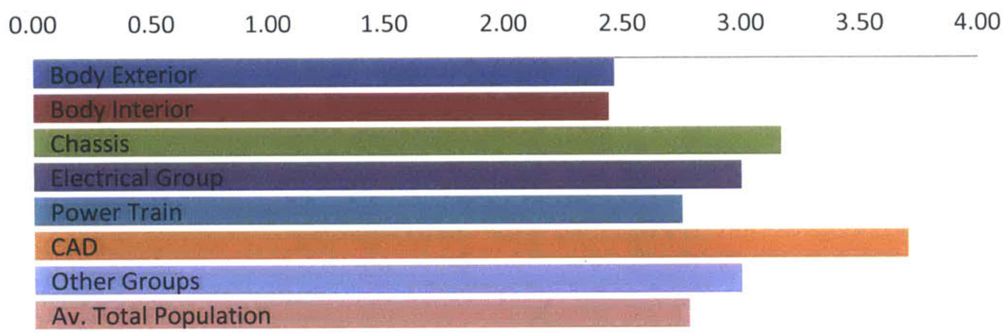


	For the parts I am responsible for I have experienced few design loopbacks after final CAD release
Body Exterior	3.32
Body Interior	3.56
Chassis	4.17
Electrical Group	3.05
Power Train	3.18
CAD	3.36
Other Groups	3.14
Av Total Population	3.35

Figure 8-10 Performance on design rework by engineer

8.1.1.4 Waste (Overload)

11) Workload distribution is equitable for all engineers.

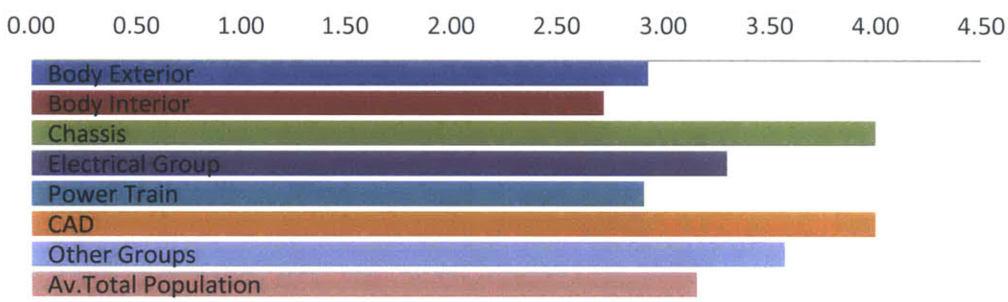


	Workload distribution is equitable for all engineers.
Body Exterior	2.46
Body Interior	2.44
Chassis	3.17
Electrical Group	3.00
Power Train	2.75
CAD	3.70
Other Groups	3.00
Av. Total Population	2.78

Figure 8-11 Performance on workload distribution

12) I have more tasks assign to me than I can realistically complete in the scheduled time and at the required quality. (Reversed)

Note: In order to maintain consistency in the performance scale, the scale values for this question were reversed so that the highest score reflects a desirable aspect in the organization. The figure description was rephrased to reflect this.



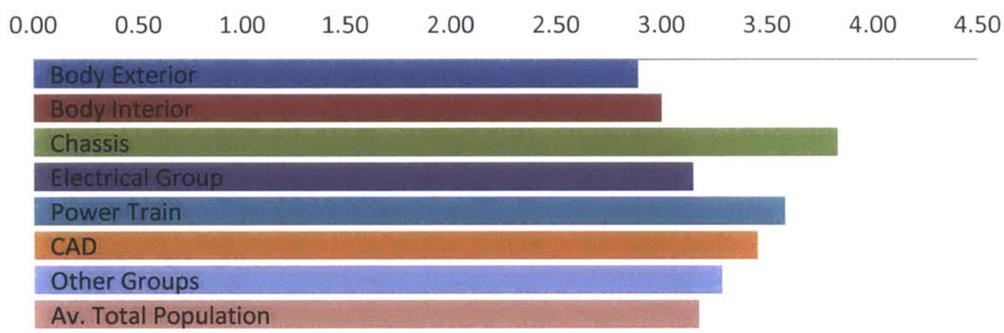
I have more tasks assign to me than I can realistically complete in the scheduled time and at the required quality

Body Exterior	2.93
Body Interior	2.72
Chassis	4.00
Electrical Group	3.30
Power Train	2.91
CAD	4.00
Other Groups	3.57
Av.Total Population	3.16

Figure 8-12 Performance on workload distribution by engineer

13) I am overloaded with non-engineering work related activities. (Reversed)

Note: In order to maintain consistency in the performance scale, the scale values for this question were reversed so that the highest score reflects a desirable aspect in the organization. The figure description was rephrased to reflect this.

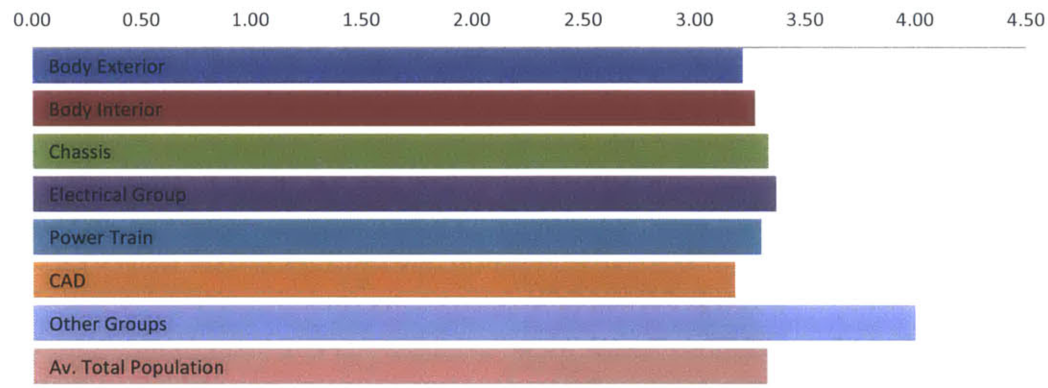


	I am overloaded with non engineering work related activities
Body Exterior	2.89
Body Interior	3.00
Chassis	3.83
Electrical Group	3.15
Power Train	3.58
CAD	3.45
Other Groups	3.29
Av. Total Population	3.18

Figure 8-13 Performance on overload on non-engineering activities

8.1.2 Systematic Problem Solving Capabilities

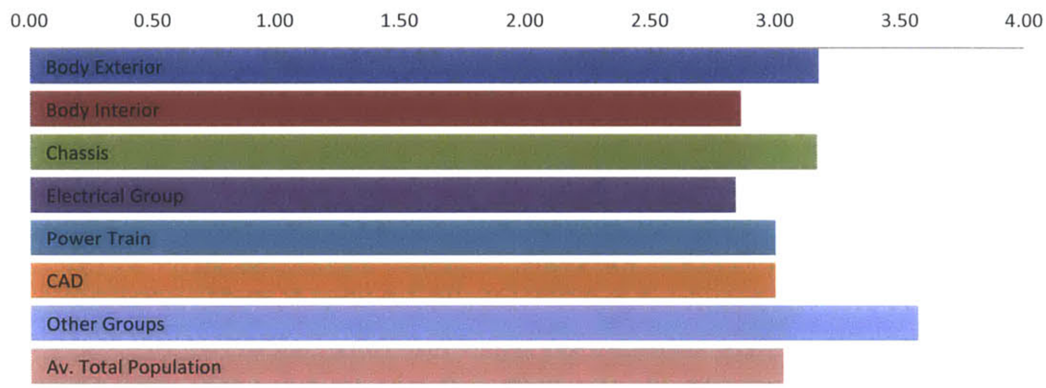
14) I systematically apply PDCA Philosophy in the programs I work for (PDCA=plan–do–check–act)



	I systematically apply PDCA Philosophy in the programs I work for (PDCA=plan–do–check–act)
Body Exterior	3.22
Body Interior	3.27
Chassis	3.33
Electrical Group	3.37
Power Train	3.30
CAD	3.18
Other Groups	4.00
Av. Total Population	3.33

Figure 8-14 Performance on Applicatin of PDCA

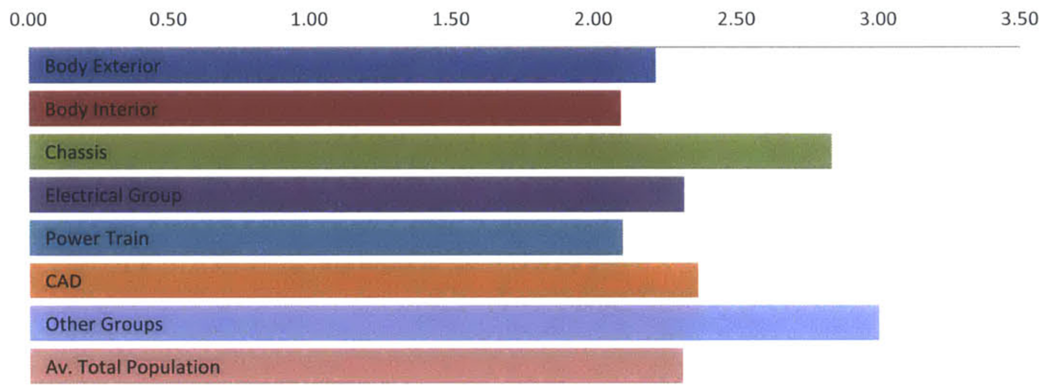
15) I systematically apply LAMDA Philosophy in the programs I work for (LAMDA=Look-Ask-Model-Discuss-Act)



	I systematically apply LAMDA Philosophy in the programs I work for (LAMDA=Look-Ask-Model-Discuss-Act)
Body Exterior	3.17
Body Interior	2.86
Chassis	3.17
Electrical Group	2.84
Power Train	3.00
CAD	3.00
Other Groups	3.57
Av. Total Population	3.03

Figure 8-15 Performance on the use of LAMDA

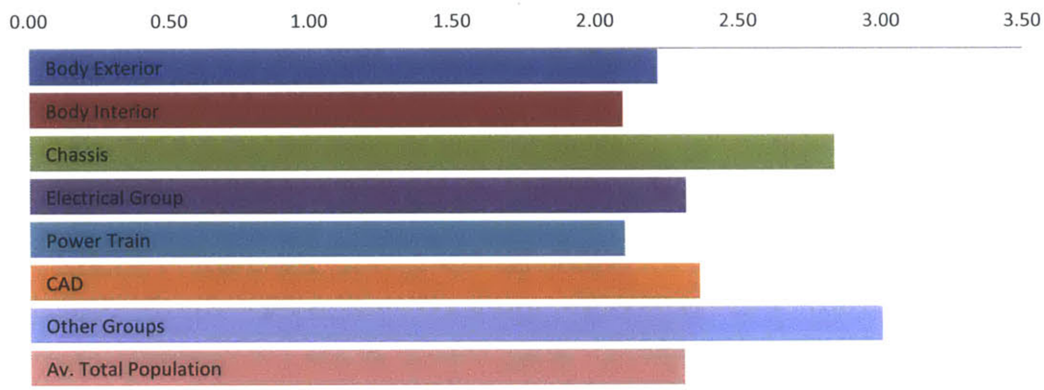
16) I am familiar with A3 Problem Solving Tool



	I systematically apply A3 Problem Solving Tool
Body Exterior	2.22
Body Interior	2.10
Chassis	2.83
Electrical Group	2.32
Power Train	2.10
CAD	2.36
Other Groups	3.00
Av. Total Population	2.31

Figure 8-16 Performance on the use of A3 Problem Solving Tool

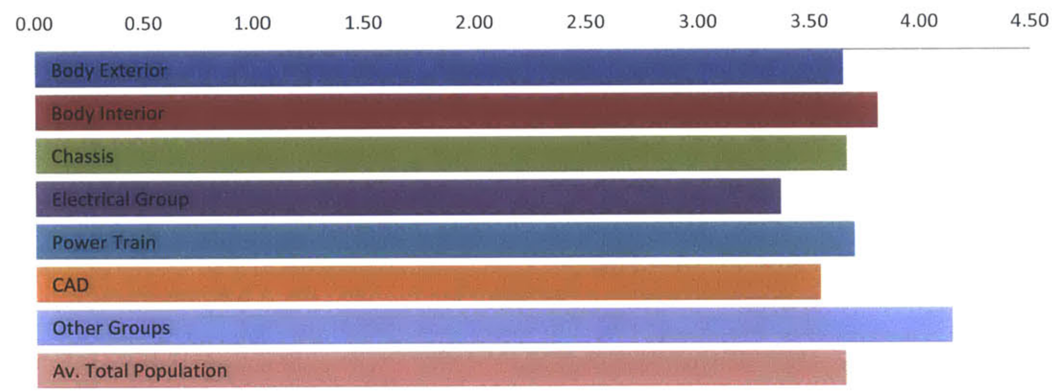
17) I am familiar with Value Stream Mapping Methodology



	I systematically apply A3 Problem Solving Tool
Body Exterior	2.22
Body Interior	2.10
Chassis	2.83
Electrical Group	2.32
Power Train	2.10
CAD	2.36
Other Groups	3.00
Av. Total Population	2.31

Figure 8-17 Performance on the use of Value Stream Mapping Methodology

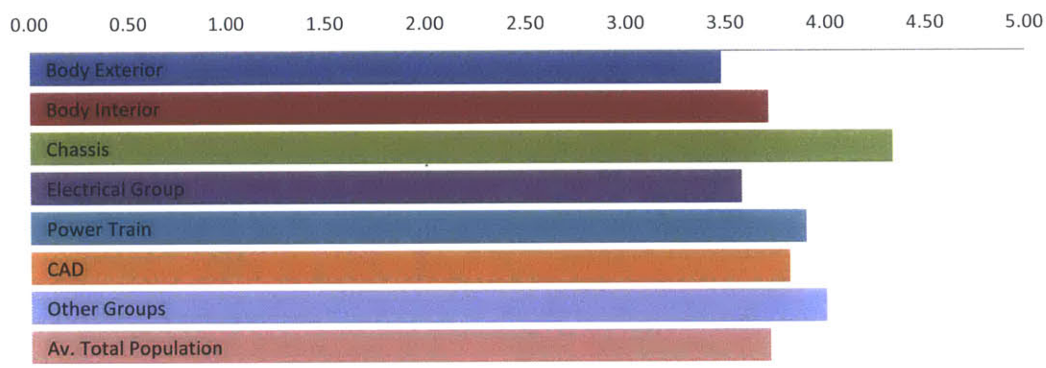
18) I understand current and future risk/opportunities and solve them before I start the detailed design.



	I understand current and future risk/opportunities and solve them before I start the detailed design.
Body Exterior	3.65
Body Interior	3.81
Chassis	3.67
Electrical Group	3.37
Power Train	3.70
CAD	3.55
Other Groups	4.14
Av. Total Population	3.66

Figure 8-18 Performance on risk/opportunities analysis before starting detailed design

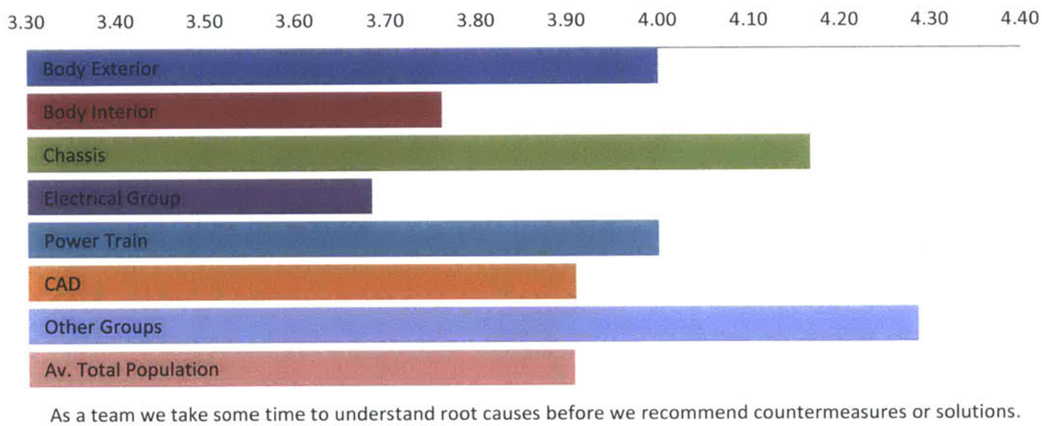
19) Decision makers take the time to understand the problems, alternatives, and recommendations before making a decision.



	Decision makers take the time to understand the problems, alternatives, and recommendations before making a decision.
Body Exterior	3.48
Body Interior	3.71
Chassis	4.33
Electrical Group	3.58
Power Train	3.90
CAD	3.82
Other Groups	4.00
Av. Total Population	3.72

Figure 8-19 Performance of decision makers evaluating problems and alternatives before making decisions

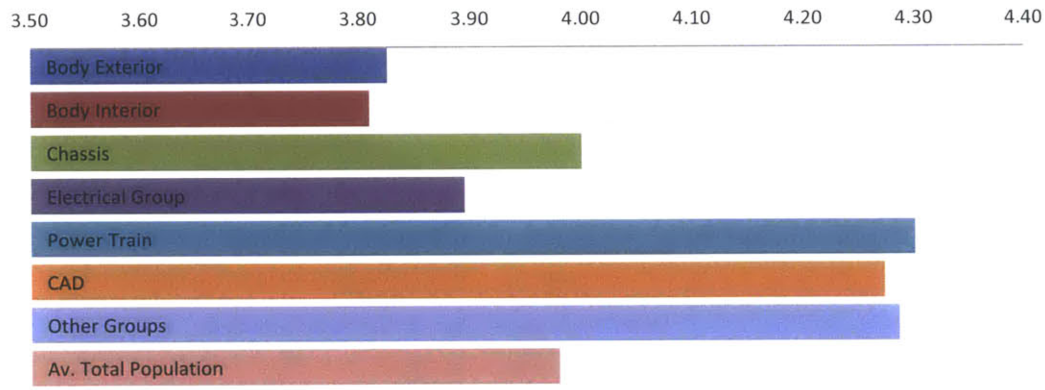
20) As a team we take some time to understand root causes before we recommend countermeasures or solutions.



Body Exterior	4.00
Body Interior	3.76
Chassis	4.17
Electrical Group	3.68
Power Train	4.00
CAD	3.91
Other Groups	4.29
Av. Total Population	3.91

Figure 8-20 Performance on root cause analysis

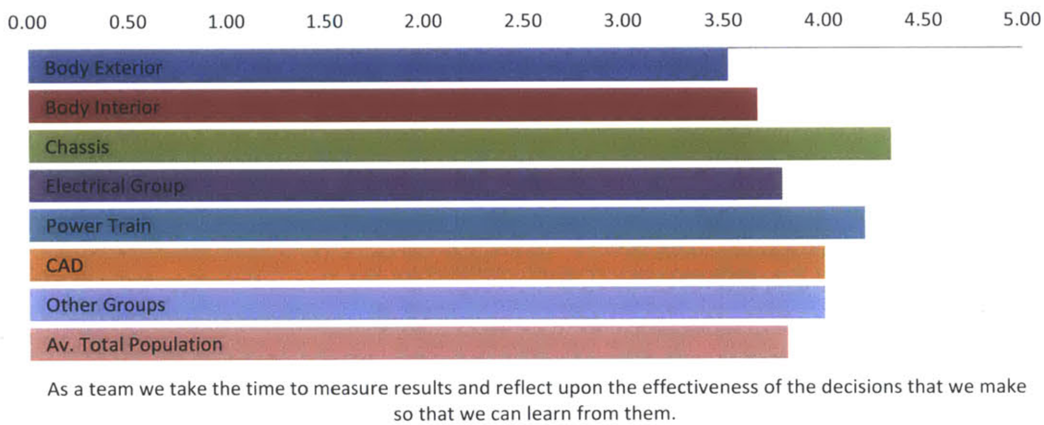
21) As a team we explore multiple alternatives before making product engineering decisions.



	As a team we explore multiple alternatives before making product engineering decisions.
Body Exterior	3.83
Body Interior	3.81
Chassis	4.00
Electrical Group	3.89
Power Train	4.30
CAD	4.27
Other Groups	4.29
Av. Total Population	3.98

Figure 8-21 Performance of team analysis on alternatives before making engineering decisions

22) As a team we take the time to measure results and reflect upon the effectiveness of the decisions that we make so that we can learn from them.

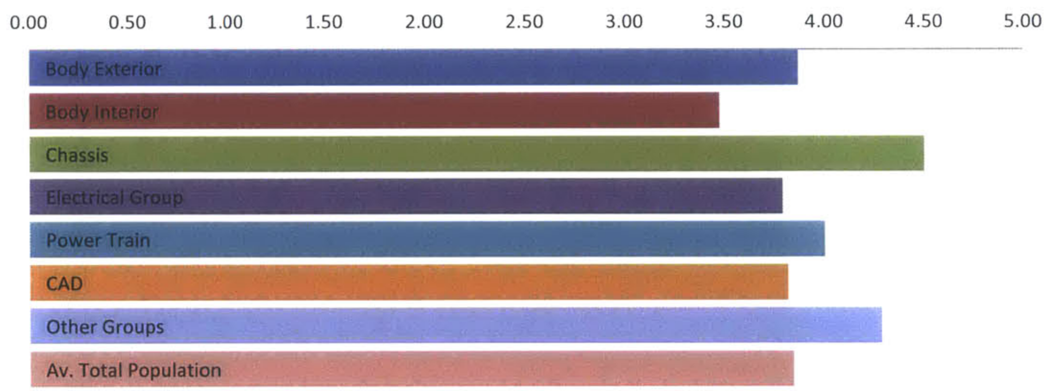


Body Exterior	3.52
Body Interior	3.67
Chassis	4.33
Electrical Group	3.79
Power Train	4.20
CAD	4.00
Other Groups	4.00
Av. Total Population	3.81

Figure 8-22 Performance on teams reflection uppon effectiveness of the taken decisions

8.1.2.1 Engineer's perception of Manager's Systematic Problem Solving Capabilities

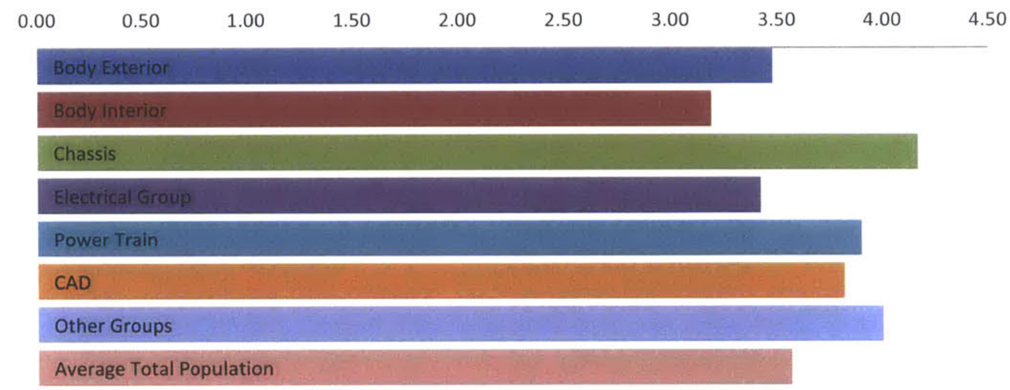
23) Managers in my organization ask challenging questions to solve issues and take decisions.



	Managers in my organization ask challenging questions to solve issues and take decisions.
Body Exterior	3.87
Body Interior	3.48
Chassis	4.50
Electrical Group	3.79
Power Train	4.00
CAD	3.82
Other Groups	4.29
Av. Total Population	3.85

Figure 8-23 Performance on managers asking challenging questions

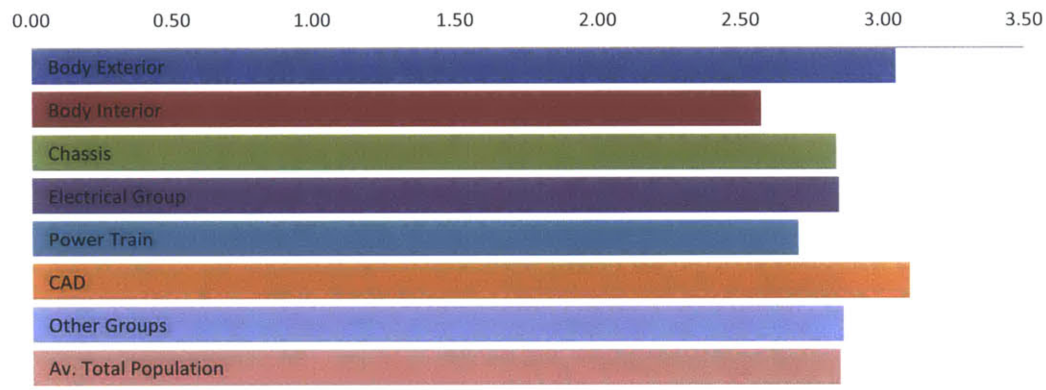
24) Managers in my organization use systematic problem solving to address issues.



	Managers in my organization use systematic problem solving to address issues.
Body Exterior	3.48
Body Interior	3.19
Chassis	4.17
Electrical Group	3.42
Power Train	3.90
CAD	3.82
Other Groups	4.00
Average Total Population	3.57

Figure 8-24 Performance of managers using Systematic Problem Solving to address issues

25) Our groups' leaders tend to change decisions previously agreed. (Reversed)

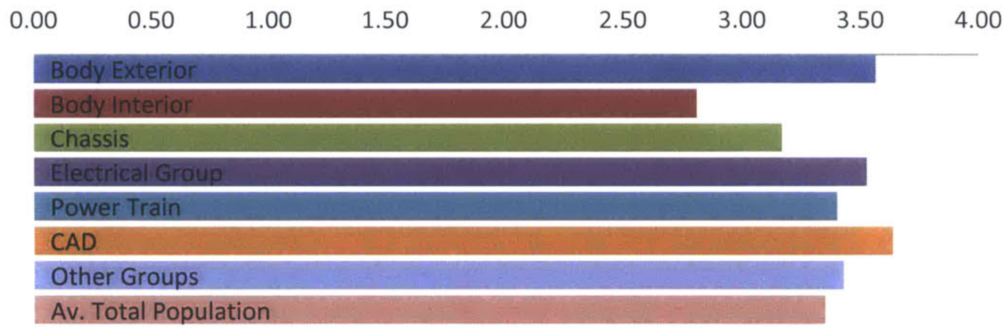


	Our groups' leaders tend to change decisions previously agreed.
Body Exterior	3.04
Body Interior	2.57
Chassis	2.83
Electrical Group	2.84
Power Train	2.70
CAD	3.09
Other Groups	2.86
Av. Total Population	2.85

Figure 8-25 Performance of leaders maintaining previously agreed decisions.

26) Our groups' leaders do not support the decisions they have delegated to their teams. (Reversed)

Note: In order to maintain consistency in the performance scale, the scale values for this question were reversed so that the highest score reflects a desirable aspect in the organization. The figure description was rephrased to reflect this.

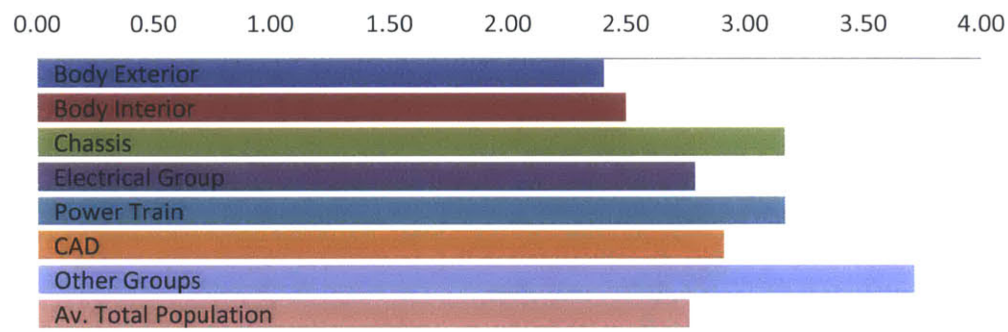


	Our groups' leaders do not support the decisions they have delegated to their teams.
Body Exterior	3.57
Body Interior	2.81
Chassis	3.17
Electrical Group	3.53
Power Train	3.40
CAD	3.64
Other Groups	3.43
Av. Total Population	3.35

Figure 8-26 Performance on Group Leaders supporting delegated decisions

8.1.3 Engineering Knowledge (Creation & Reuse)

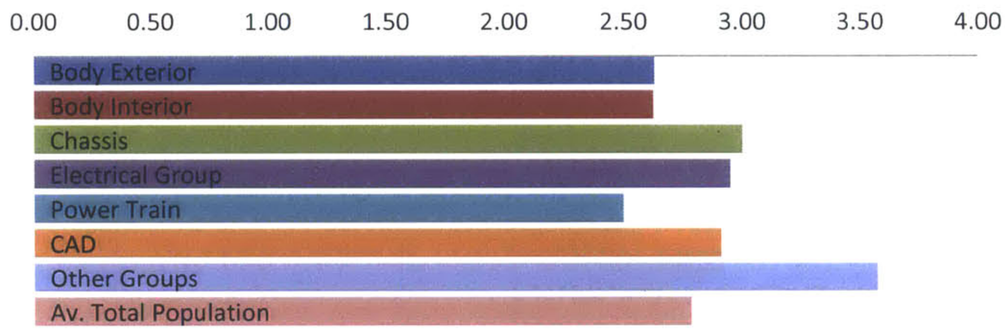
27) It is very easy to find lessons learned information within my organization.



	It is very easy to find lessons learned information within my organization
Body Exterior	2.41
Body Interior	2.50
Chassis	3.17
Electrical Group	2.79
Power Train	3.17
CAD	2.91
Other Groups	3.71
Av. Total Population	2.76

Figure 8-27 Performance of ease on finding lessons learned

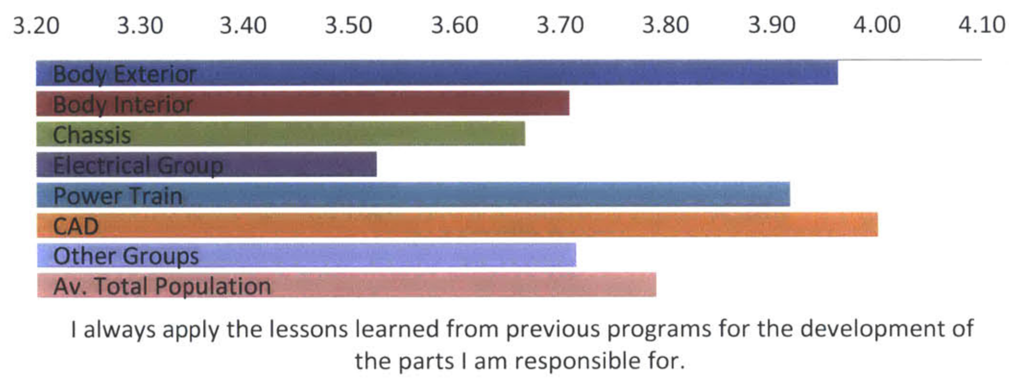
28) I always have time to capture lessons learned on my regular job



	I always have time to capture and document lessons learned on my regular job
Body Exterior	2.63
Body Interior	2.63
Chassis	3.00
Electrical Group	2.95
Power Train	2.50
CAD	2.91
Other Groups	3.57
Av. Total Population	2.78

Figure 8-28 Performance on time availability to capture Lessons Learned

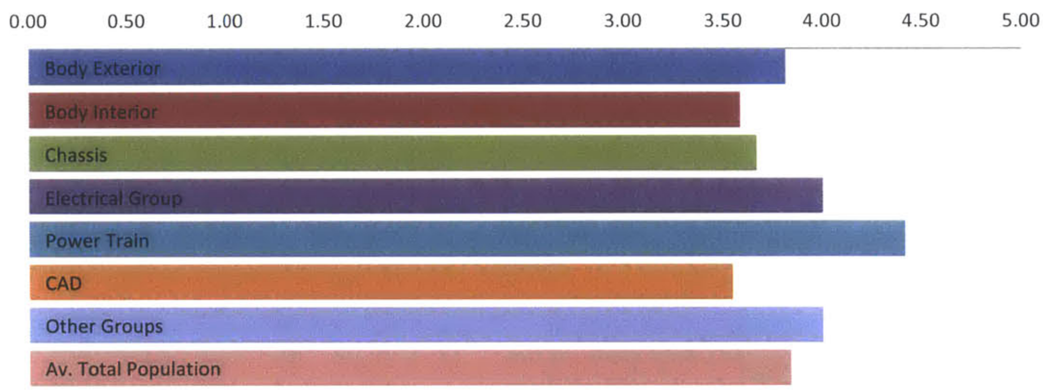
29) I always apply the lessons learned from previous programs for the development of the parts I am responsible for.



Body Exterior	3.96
Body Interior	3.71
Chassis	3.67
Electrical Group	3.53
Power Train	3.92
CAD	4.00
Other Groups	3.71
Av. Total Population	3.79

Figure 8-29 Performance on application of lessons learned from previous programs

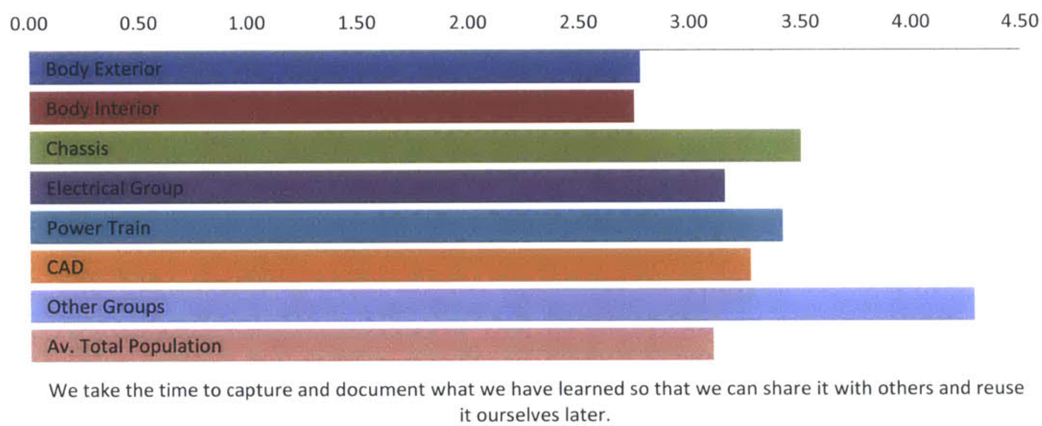
30) When I recognize a problem we have seen before, I have the ability to find out how we solved it last time.



	When I recognize a problem that we have seen before, I have the ability to find out how we solved it last time.
Body Exterior	3.81
Body Interior	3.58
Chassis	3.67
Electrical Group	4.00
Power Train	4.42
CAD	3.55
Other Groups	4.00
Av. Total Population	3.84

Figure 8-30 Performance of ability to find previous solutions

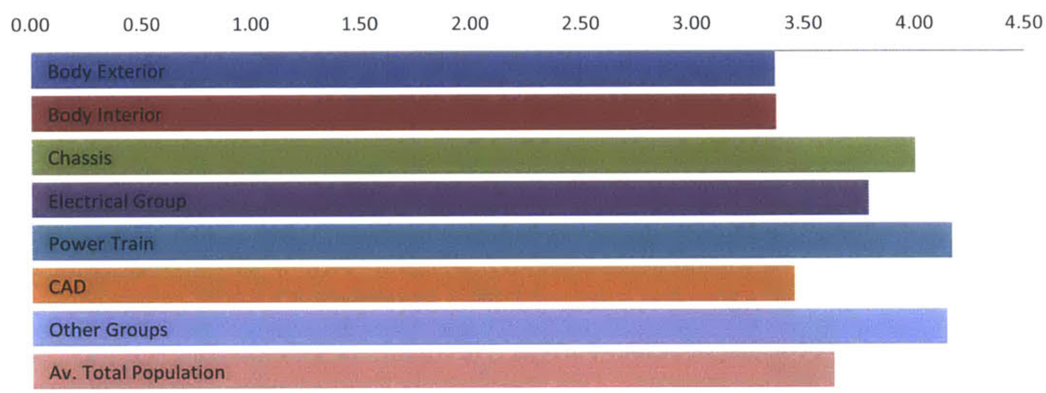
31) We take the time to capture what we've learned so that we can share it with others and reuse it ourselves later.



Body Exterior	2.78
Body Interior	2.75
Chassis	3.50
Electrical Group	3.16
Power Train	3.42
CAD	3.27
Other Groups	4.29
Av. Total Population	3.10

Figure 8-31 Performance on available time dedicated to capture and sharing of lessons learned

32) I actively search out reusable knowledge as part of our problem-solving and decision-making processes.

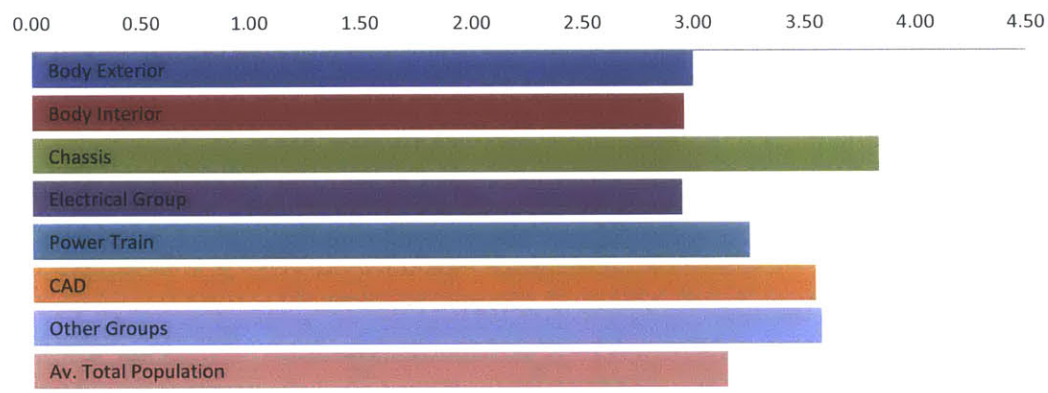


	I actively search out reusable knowledge as part of our problem-solving and decision-making processes.
Body Exterior	3.37
Body Interior	3.38
Chassis	4.00
Electrical Group	3.79
Power Train	4.17
CAD	3.45
Other Groups	4.14
Av. Total Population	3.63

Figure 8-32 Performance on knowledge being reused as part of problem-solving and decision-making processes

8.1.3.1 Best Practices

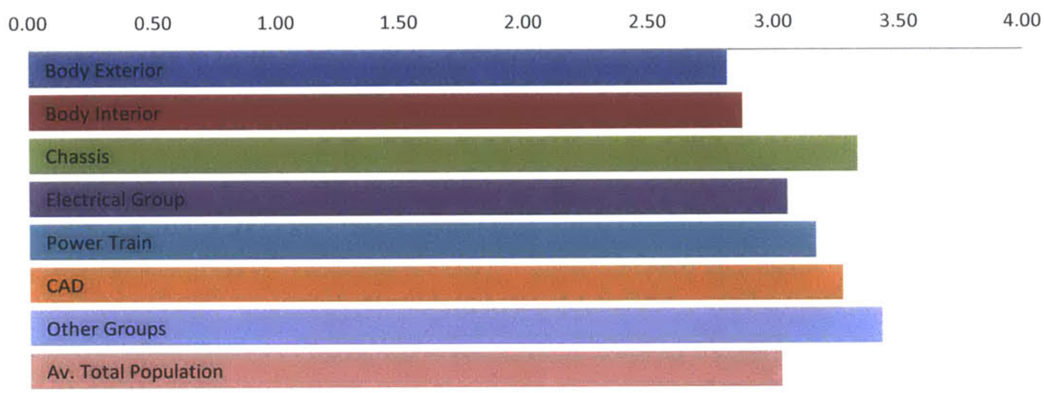
33) It is very easy to find best practices that help me to do my job.



	It is very easy to find best practices that help me to do my job
Body Exterior	3.00
Body Interior	2.96
Chassis	3.83
Electrical Group	2.95
Power Train	3.25
CAD	3.55
Other Groups	3.57
Av. Total Population	3.15

Figure 8-33 Performance of Best Practices Easy to find

34) It is very easy to capture/update best practices to make my job easier.

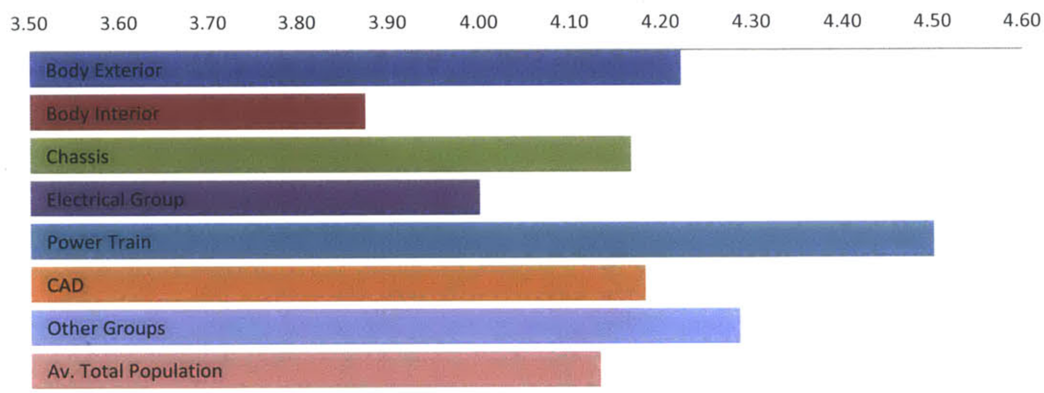


	It is very easy to capture/update best practices to make my job easier
Body Exterior	2.81
Body Interior	2.88
Chassis	3.33
Electrical Group	3.05
Power Train	3.17
CAD	3.27
Other Groups	3.43
Av. Total Population	3.03

Figure 8-34 Performance on ease to capture & update Best Practices

8.1.3.2 Experts Knowledge

35) I actively search out expert input as part of our problem-solving and decision-making processes.

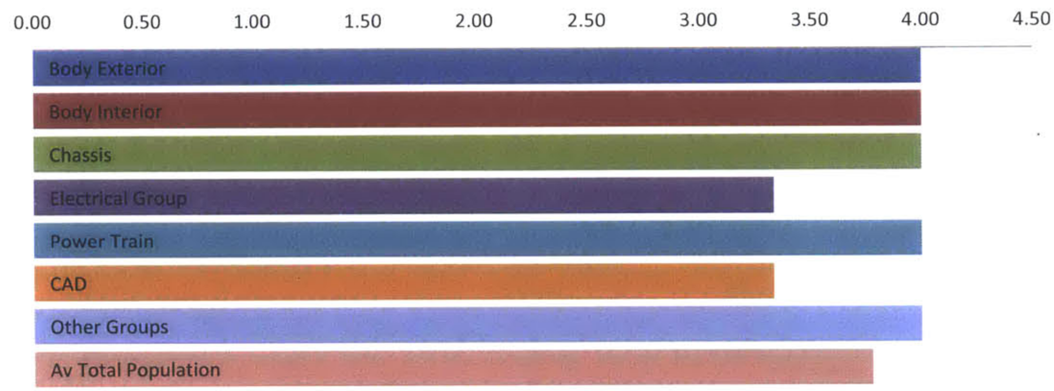


I actively search out expert input as part of our problem-solving and decision-making processes.

Body Exterior	4.22
Body Interior	3.88
Chassis	4.17
Electrical Group	4.00
Power Train	4.50
CAD	4.18
Other Groups	4.29
Av. Total Population	4.13

Figure 8-35 Performance on experts knowledge use

36) It is easy for me to locate the expert who can help me to solve a specific problem.



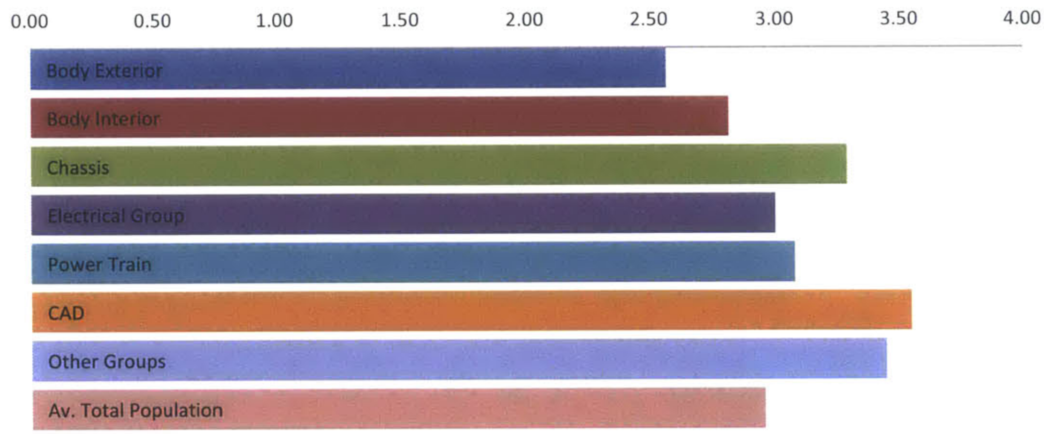
	It is easy for me to locate the expert who can help me to solve a specific problem
Body Exterior	4.00
Body Interior	4.00
Chassis	4.00
Electrical Group	3.33
Power Train	4.00
CAD	3.33
Other Groups	4.00
Av Total Population	3.78

Figure 8-36 Performance on ease to find an expert

8.1.4 Lean Engineering Standard Work

8.1.4.1 Current Engineering Templates for Part Development

37) There are easy to find templates that help me track a part development from start to end.



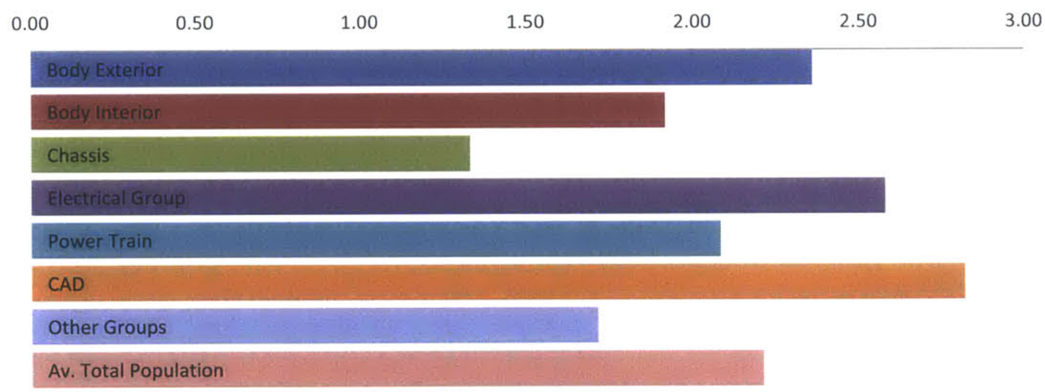
	There are easy to find templates that help me track a part development from start to end.
Body Exterior	2.57
Body Interior	2.81
Chassis	3.29
Electrical Group	3.00
Power Train	3.08
CAD	3.55
Other Groups	3.44
Av. Total Population	2.96

Figure 8-37 Performance on ease to find part development templates

8.1.4.2 *Current usage of checklist for part development and track*

38) I store my checklists on my own computer drive (Reversed)

Note: In order to maintain consistency in the performance scale, the scale values for this question were reversed so that the highest score reflects a desirable aspect in the organization. The figure description was rephrased to reflect this.

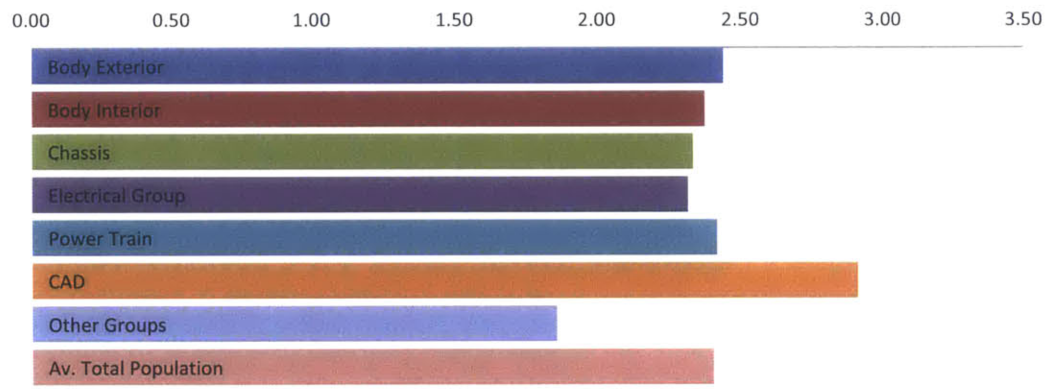


	I store my checklists on my own computer drive
Body Exterior	2.36
Body Interior	1.92
Chassis	1.33
Electrical Group	2.58
Power Train	2.08
CAD	2.82
Other Groups	1.71
Av. Total Population	2.21

Figure 8-38 Performance on shared checklists

39) I currently own a checklist to confirm that I have followed all required steps to design a part. (Reversed)

Note: In order to maintain consistency in the performance scale, the scale values for this question were reversed so that the highest score reflects a desirable aspect in the organization. The figure description was rephrased to reflect this.

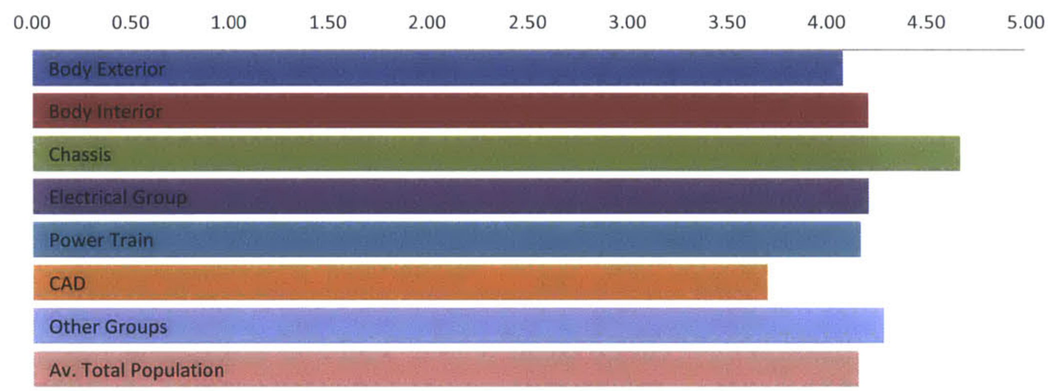


	I currently own a checklist to confirm that I have followed all required steps to design a part.
Body Exterior	2.44
Body Interior	2.38
Chassis	2.33
Electrical Group	2.32
Power Train	2.42
CAD	2.91
Other Groups	1.86
Av. Total Population	2.40

Figure 8-39 Performance on shared checklist to confirm steps were folowed to design a part

8.1.4.3 Desirability of a LESW

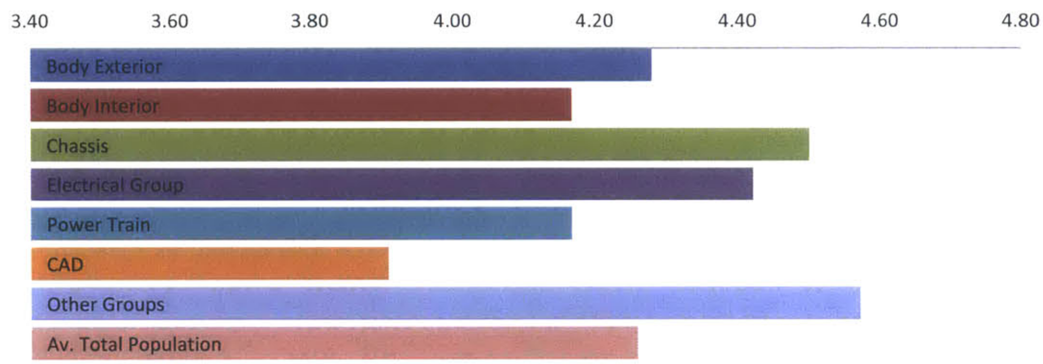
40) It would add value to have a tool that guides me designing the parts I am responsible for.



	It would add value to have a tool that guides me in designing the parts I am responsible for
Body Exterior	4.08
Body Interior	4.21
Chassis	4.67
Electrical Group	4.21
Power Train	4.17
CAD	3.70
Other Groups	4.29
Av. Total Population	4.16

Figure 8-40 Desirability of the LESW

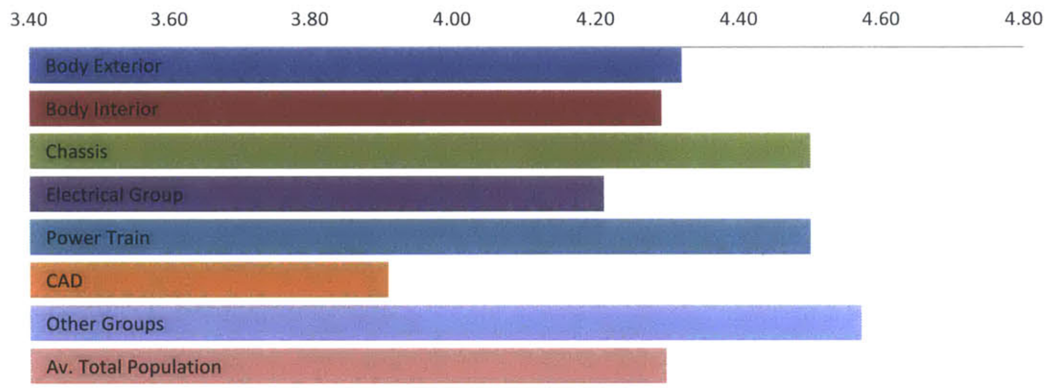
41) It would add value to have a standard checklist that helps me confirm I have fulfilled all design steps for every important milestone.



	It would add value to have a standard checklist that helps me confirm I have fullfilled all design steps for every important milestone
Body Exterior	4.28
Body Interior	4.17
Chassis	4.50
Electrical Group	4.42
Power Train	4.17
CAD	3.91
Other Groups	4.57
Av. Total Population	4.26

Figure 8-41 Desirability of checklists to confirm fullfilment of steps for every imprtant milestone

42) It would add value to have a tool that helps me meeting the Engineering Requirements for the part I design

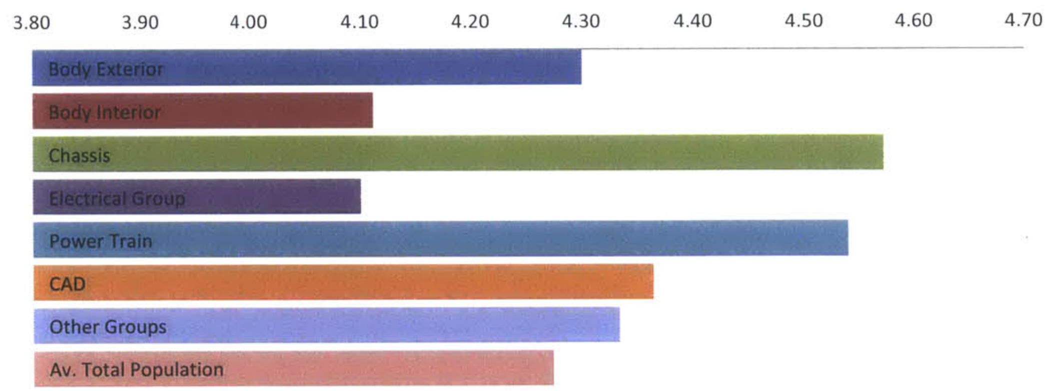


	It would add value to have a tool that helps me in meeting the Engineering Requirements for the part I design
Body Exterior	4.32
Body Interior	4.29
Chassis	4.50
Electrical Group	4.21
Power Train	4.50
CAD	3.91
Other Groups	4.57
Av. Total Population	4.30

Figure 8-42 Desirability for a tool to meet Engineering Requirements

8.1.4.4 Practitioner Proficiency Assessment

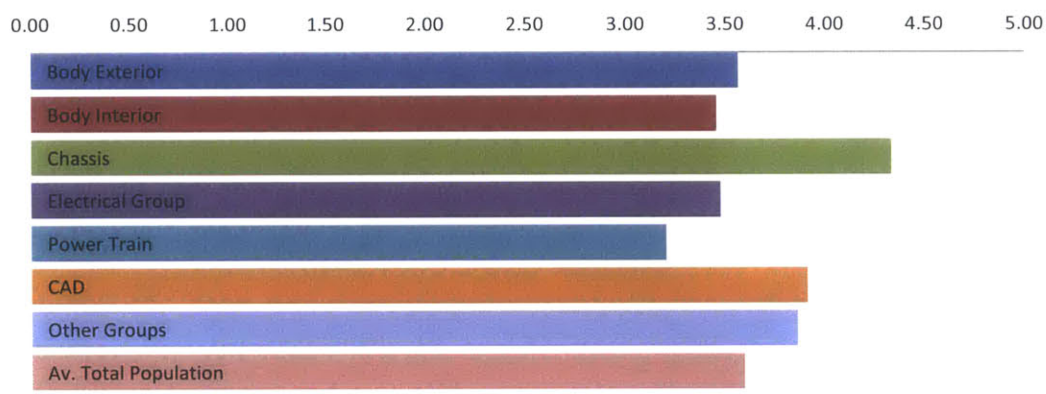
43) The main training I received was based on learning by doing.



	The main training I received was based on learning by doing
Body Exterior	4.30
Body Interior	4.11
Chassis	4.57
Electrical Group	4.10
Power Train	4.54
CAD	4.36
Other Groups	4.33
Av. Total Population	4.27

Figure 8-43 Performance on learning by doing

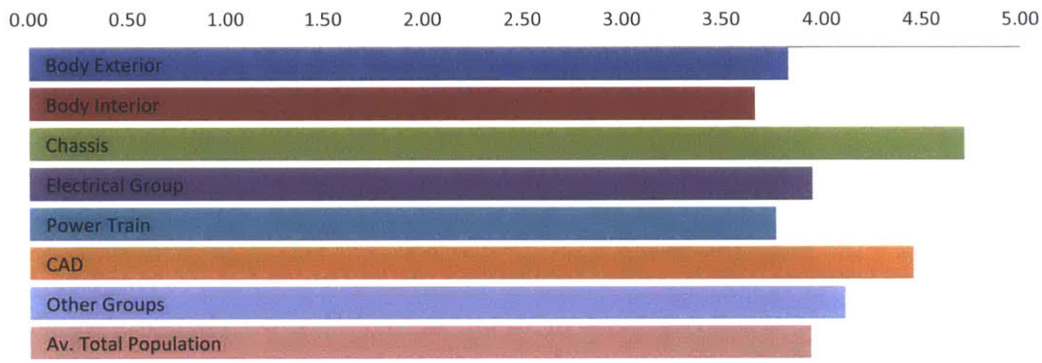
44) I worked with my supervisor to ensure my EPDP was completed to accurately reflect my skill level



	I worked with my supervisor to ensure my EPDP was completed to accurately reflect my skill level
Body Exterior	3.57
Body Interior	3.45
Chassis	4.33
Electrical Group	3.47
Power Train	3.20
CAD	3.91
Other Groups	3.86
Av. Total Population	3.59

Figure 8-44 Performance on EPDP aplication with supervisor to accurately reflect skill levels

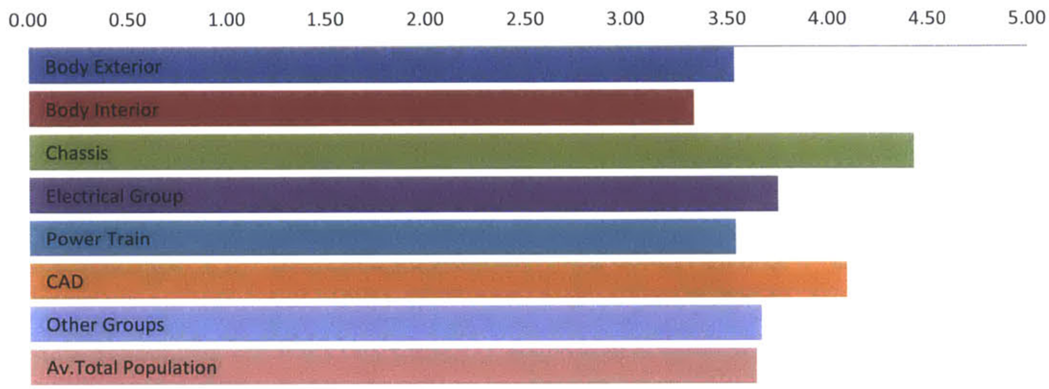
45) I had a mentor that helped me on my doubts and questions during my learning in the company engineering systems.



	I had a mentor that helped me on my doubts and questions during my learning in the company engineering systems
Body Exterior	3.83
Body Interior	3.67
Chassis	4.71
Electrical Group	3.95
Power Train	3.77
CAD	4.45
Other Groups	4.11
Av. Total Population	3.94

Figure 8-45 Performance on mentorship

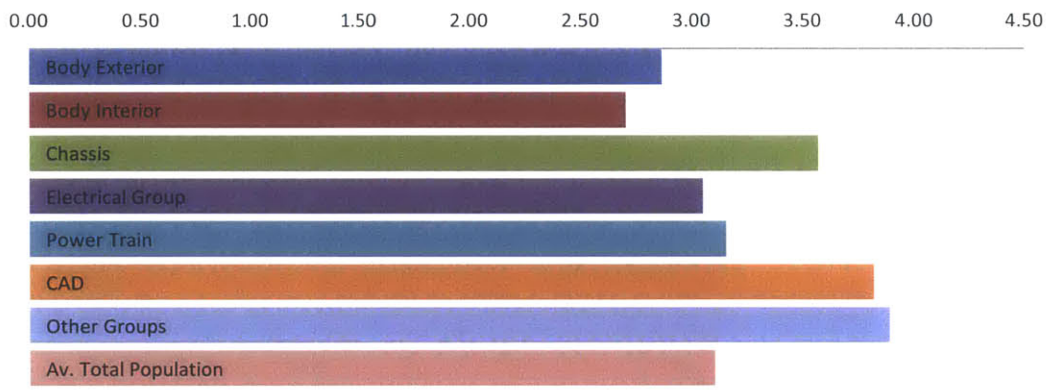
46) The current plan we have to develop my engineering skills reflects the actual needs of a Design Engineer



	The current plan we have to develop my engineering skills reflects the actual needs of a Design Engineer
Body Exterior	3.53
Body Interior	3.33
Chassis	4.43
Electrical Group	3.75
Power Train	3.54
CAD	4.09
Other Groups	3.67
Av.Total Population	3.64

Figure 8-46 Peformance of current plan reflecting actual skill development needs

47) There is enough time to take the required training to improve my engineering skills

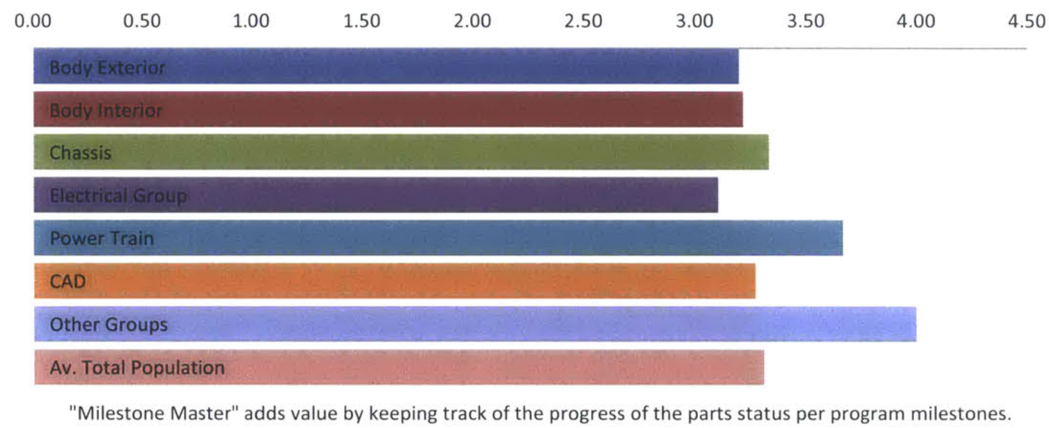


	There is enough time to take the required training to improve my engineering skills
Body Exterior	2.87
Body Interior	2.70
Chassis	3.57
Electrical Group	3.05
Power Train	3.15
CAD	3.82
Other Groups	3.89
Av. Total Population	3.10

Figure 8-47 Performance on time availability to take training

8.1.5 Current NACC Milestone Management System

48) “Milestone Master” adds value by keeping track of the progress of the parts status per program milestones.

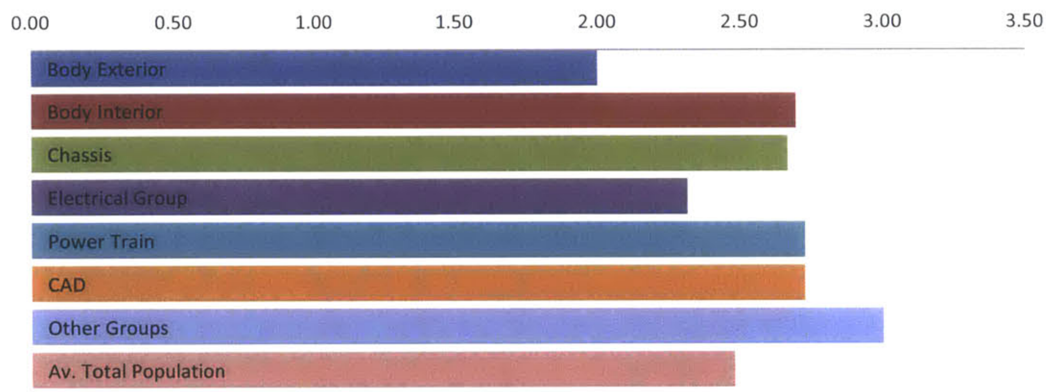


Body Exterior	3.20
Body Interior	3.22
Chassis	3.33
Electrical Group	3.11
Power Train	3.67
CAD	3.27
Other Groups	4.00
Av. Total Population	3.31

Figure 8-48 Performance of "Milestone Master" adding value to keep track of the progress of part status per programs milestones

49) “Milestone Master” is a tool for status report only (Reversed)

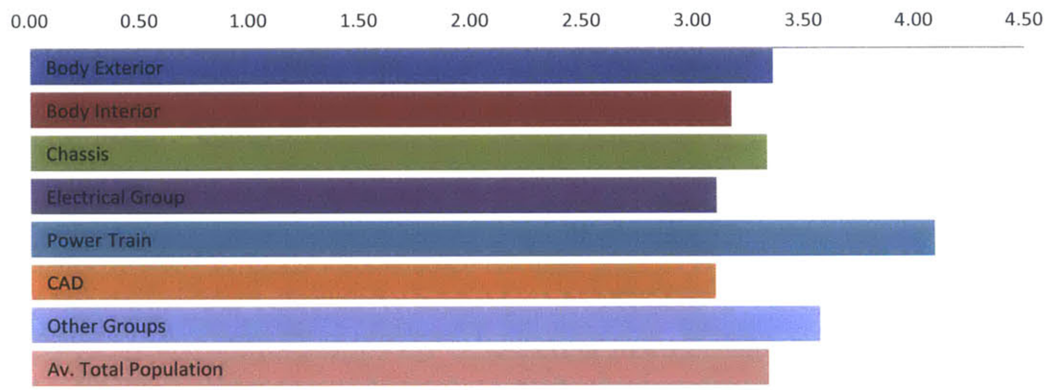
Note: In order to maintain consistency in the performance scale, the scale values for this question were reversed so that the highest score reflects a desirable aspect in the organization. The figure description was rephrased to reflect this.



	"Milestone Master" is a tool for status reporting only
Body Exterior	2.00
Body Interior	2.70
Chassis	2.67
Electrical Group	2.32
Power Train	2.73
CAD	2.73
Other Groups	3.00
Av. Total Population	2.48

Figure 8-49 "Milestone Master” Usability Performance

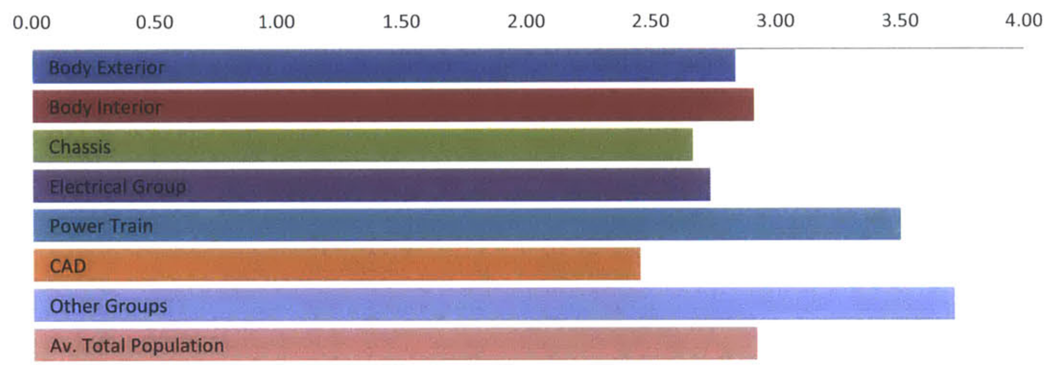
50) "Milestone Master" is a tool that helps engineers to keep track of what needs to be completed by milestone



	Milestone Master is a tool that helps engineers to keep track of what needs to be completed by milestone
Body Exterior	3.36
Body Interior	3.17
Chassis	3.33
Electrical Group	3.11
Power Train	4.09
CAD	3.10
Other Groups	3.57
Av. Total Population	3.34

Figure 8-50 "Milestone Master" performance helping engineers to keep track of milestone activities completion

51) I systematically use “Milestone Master” to be aware of the requirements for every milestone to meet for the parts I am responsible for.

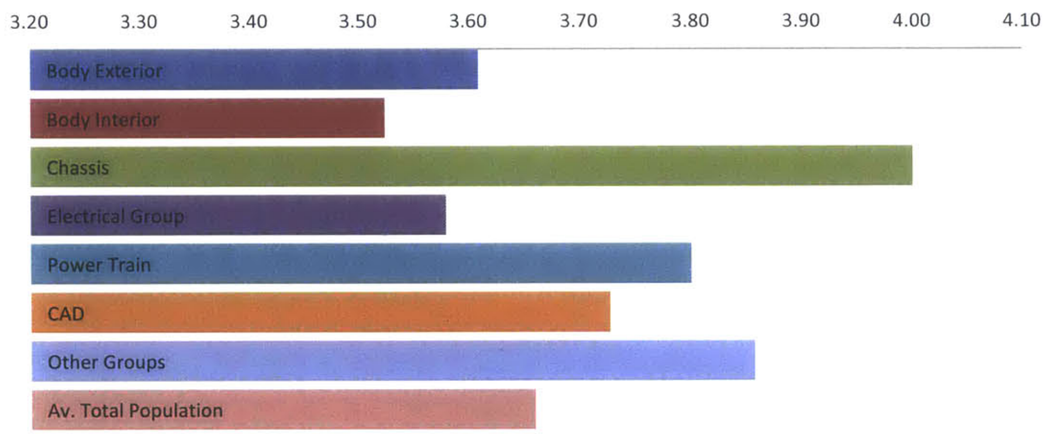


	I systematically use Milestone Master to be aware of the requirements for every milestone to meet for the parts I am responsible for.
Body Exterior	2.84
Body Interior	2.91
Chassis	2.67
Electrical Group	2.74
Power Train	3.50
CAD	2.45
Other Groups	3.71
Av. Total Population	2.92

Figure 8-51 "Milestone Master" Performance to provide awareness of milestone requirements for the parts being developed

8.1.6 Three Questions on Engineer's Perception of the Organization

52) I know who is the authority to decide on each program deliverable

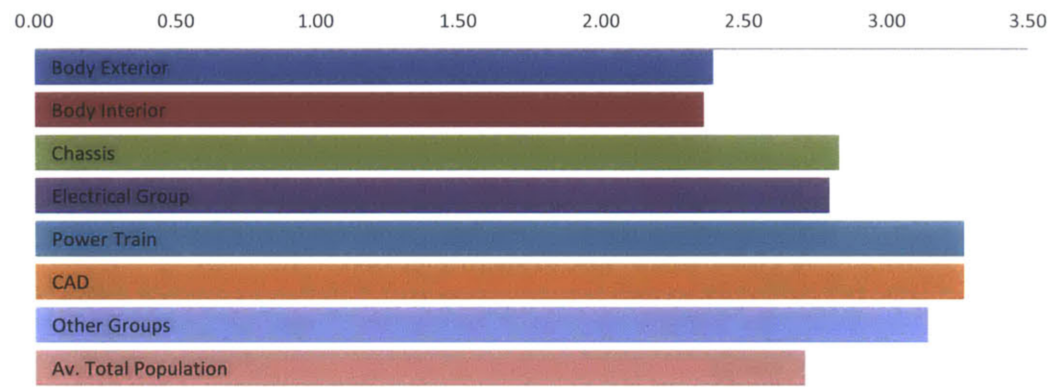


	I know who is the authority to decide on each program deliverable.
Body Exterior	3.61
Body Interior	3.52
Chassis	4.00
Electrical Group	3.58
Power Train	3.80
CAD	3.73
Other Groups	3.86
Av. Total Population	3.66

Figure 8-52 Performance on clarity of hierarchy to take decisions on each program deliverable

53) In my organization it is rewarded the firefighting of issues instead of rewarding the work executed with excellence (Reversed)

Note: In order to maintain consistency in the performance scale, the scale values for this question were reversed so that the highest score reflects a desirable aspect in the organization. The figure description was rephrased to reflect this.

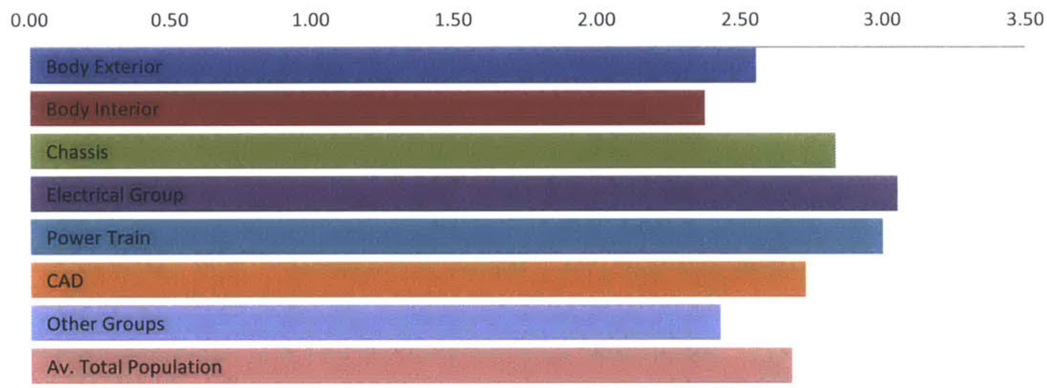


	My organization rewards firefighting of issues relatively more than work executed with excellence the first time
Body Exterior	2.39
Body Interior	2.36
Chassis	2.83
Electrical Group	2.80
Power Train	3.27
CAD	3.27
Other Groups	3.14
Av. Total Population	2.71

Figure 8-53 Performance on rewarding the work done with excellence the first time

54) It is difficult to keep track of all the web pages I need to update for the part I am responsible for. (Reversed)

Note: In order to maintain consistency in the performance scale, the scale values for this question were reversed so that the highest score reflects a desirable aspect in the organization. The figure description was rephrased to reflect this.



	It is difficult to keep track of all the web pages I need to update for the part I am responsible for.
Body Exterior	2.56
Body Interior	2.38
Chassis	2.83
Electrical Group	3.05
Power Train	3.00
CAD	2.73
Other Groups	2.43
Av. Total Population	2.68

Figure 8-54 Performance on ease to update web pages for part development

9 Bibliography

[1] Wikipedia, "Muda (Japanese term)," 20 May 2015. [Online]. Available: http://en.wikipedia.org/wiki/Muda_(Japanese_term).

[2] Wikipedia, "Mura (Japanese term)," 20 May 2015. [Online]. Available: http://en.wikipedia.org/wiki/Mura_(Japanese_term).

[3] Wikipedia, "Muri (Japanese term)," 20 May 2015. [Online]. Available: http://en.wikipedia.org/wiki/Muri_(Japanese_term).

[4] J. Womak, "MURA, MURI, MUDA?," Lean Enterprise Institute, 20 May 2015. [Online]. Available: http://www.lean.org/womack/DisplayObject.cfm?o=743. [Accessed 20 May 2015].

[5] K. Radeka, The Mastery of Innovation: A Field Guide to Lean Product Development, 1St Edition ed., C. P. Press, Ed., CRC Productivity Press, 2012.

[6] IMVP, "IMVP- International Motor Vehicle Program," Massachussets Institute of Technology, [Online]. Available: http://global.mit.edu/projects/project/international-motor-vehicle-program-imvp/.

[7] J. Womac, D. Jones and D. Roos, The Machine That Changed the World, M. P. Company, Ed., Macmillan Publishing Company, 1990.

[8] J. Oehmen and E. Rebentisch, "Waste in Lean Product Development," 2010.

[9] BofA Merrill Lynch Global Research, "Car Wars 2013-2016 "The automotive product pipeline for the U.S. market"," BofA Merrill Lynch Global Research, 2012.

[10] J. M. Morgan and J. K. Liker, The Toyota Product Development System, Integrating People, Process and Technology, New York: Productivity Press, 2006.

[11] H. McManus, "Product Development Value Stream Mapping (PDVSM)," MIT (Massachussets Institute of Technology), Cambridge, 2005.

[12] ASQ, "ASQ (American Society for Quality)," 22 05 2015. [Online]. Available: http://asq.org/learn-about-quality/project-planning-tools/overview/pdca-cycle.html. [Accessed 22 05 2015].

[13] "LAMBDA Definition," 2015. [Online]. Available: http://www.triz-journal.com/lamda-and-triz-knowledge-sharing-across-the-enterprise/.

[14] I. Nonaka and H. Takeuchi, The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation, 1st Edition ed., Oxford University Press, 1995.

[15] E. Trist, B. Higgin, J. Murray and A. Pollack, Organizational Choice, London: Tavistock Publications, 1963.

[16] Kaizen Institute, "Kaizen Institute," Kaizen Institute, 22 05 2015. [Online]. Available: http://www.kaizen.com/about-us/definition-of-kaizen.html. [Accessed 22 05 2015].

[17] H. K. Bowen and C. Purrington, Pratt & Whithney: Engineering Standard Work, Cambridge: Harvard Business School, 2006.

[18] V. Saxena, S. Srinivasan and J. Adams, "Engineering Standard Work Method and System". United States Patent US7496860B2, 24 February 2009.

[19] COUHES, "Committee on the Use of Humans as Experimental Subjects

(COUHES)," [Online]. Available: https://couhes.mit.edu/.

[20] P. S. Adler and B. Borys, "Two Types of Bureaucracy: Enabling and Coercive", Administrative Science, 1996.

[21] D. Nightingale, "The LAI-Enterprise-Self-Assessment-Tool (LESAT)," MIT, Cambridge, 2012.

[22] P. &. Whitney, "Pratt & Whitney: "Where we've been'," Pratt & Whitney, [Online]. Available: http://www.pw.utc.com/Where_Weve_Been .

[23] Harvard Business School, "Great American Business Leaders of the Twentieth Century: Frederick Rentschler," 01 05 2015. [Online]. Available: http://www.hbs.edu/leadership/database/leaders/frederick_b_rentschler.html.