

Project Number: MQF-MQP 3305_

CIRCOR Lean Manufacturing System Dynamics

A Major Qualifying Project

Submitted to the Faculty of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the degree of

Bachelor of Science

in

Mechanical Engineering

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ABSTRACT

The principal objective of this project is to evaluate the need for and implementation of lean manufacturing systems at Spence Engineering Company, in Walden, New York. The proposed methods for evaluation and validation include a reconfiguration of the current state plant layout, creating a new value-added re-distribution of parts, integrative CAD model of the proposed layout and optimization of the machining operations. We show how the new layout can eliminate waste, delays, vulnerability and uncertainty in the machining operations and yield greater opportunity for maximization of return on investment at CIRCOR Spence Engineering. The outcome also provides a detailed explanation of the steps taken to implement the changes in the Company. The essentials of lean manufacturing systems and technology are fully integrated into the new model system. The risk of machining down time, making finished part defects, long setup times and unintentional accidents is minimized in the new lean system design at Spence Engineering Company. At every step of the way in the lean system design, value added setup process, cellular planning and sequencing of operations for the same, different or mixed products are established. The lean design system offers a unified framework to machine CIRCOR Spence Engineering components to desired tolerances in a sustained way with maximum rewards and minimum risk of manufacturing failures.

Table of Contents

<i>Abstract</i>	ii
<i>Table of Contents</i>	iii
<i>List of Figures</i>	iv
<i>Acknowledgements</i>	v
Chapter 1: The Role of Lean Manufacturing System Design	1
1. Introduction	1
Chapter 2: The Manufacturing Evolution of CIRCOR Spence Engineering.....	4
2. Introduction	4
2.1 The Engineering Realization of Lean Manufacturing.....	7
2.2 Tools, Techniques and Technology for Eliminating Non-value Added Functions.....	26
2.3 Elimination of Non-Value Added Functions in Manufacturing Machining Process.....	42
2.4 The Seven Types of Non-value Added Functions and Their Recognition	42
2.4.2 Transportation	44
2.4.3 Inventory.....	45
2.4.4 Over Production.....	47
2.4.5 Motion.....	48
2.4.6 Waiting.....	49
2.4.7 Over Process	50
2.4.8 Defect.....	52
2.5 Unofficial Wastes of Lean	53
2.5.2 Resources	53
2.5.3 Creativity.....	54

Chapter 3: CIRCOR Lean Manufacturing System Dynamics.....	55
3. Introduction	55
3.1 Results.....	58
CHAPTER 4: Conclusions	64
REFERENCES.....	70
Appendix A: Spence History.....	72
Appendix B: Product Family Analysis.....	74
Appendix C: Set- Up Sheets.....	78
Appendix D: The Engineering Realization of Lean Manufacturing	81
Appendix E: Tools, Techniques and Technology for Eliminating Non-value Added Functions.....	91
Appendix F: The Seven Types of Non-value Added Functions and Their Recognition	96
Appendix G: Proposed Machine Shop Layout Images	99

List of Figures

Figure 2-1 Original Rider-Ericsson Facility in Walden, NY	4
Figure 2-2 Original Spence Logo	4
Figure 2-3 Army-Navy "E" award	5
Figure 2-4 (top) Watts logo, (bottom) Nicholson logo	6
Figure 2-5 Example of proper workplace flow in a Ford Facility	7
Figure 2-6 Model T interchangeable Parts	8
Figure 2-7 Example of a "5s" workplace	10
Figure 2-8 Venetian Arsenal	12
Figure 2-9 Marc Brunel	12
Figure 2-10 Colt's Armory, Hartford, CT	13
Figure 2-11 Ford Plant	14
Figure 2-12 Kanban and Supermarkets	15
Figure 2-13 Powerful Union	17
Figure 2-14 Line Balancing	21
Figure 2-15 Lean Start	23
Figure 2-16 Kiichiro Toyoda	24
Figure 2-17 Lean Manufacturing Book Created	25
Figure 2-18 Lean Tools and Concepts	32
Figure 2-19 Set-up Time	34
Figure 2-20 Benefits of Set-up Reduction	35
Figure 2-21 Four-Step to achieve SMED	38
Figure 2-22 3P benefits	41
Figure 2-23 - The Seven Wastes	43
Figure 2-24 - Transportation Waste Overview	44
Figure 2-25 - Inventory Waste Overview	45
Figure 2-26 - Example of Excessive Inventory	46
Figure 2-27 - Over Production Overview	47
Figure 2-28 - Motion Waste Overview	48
Figure 2-29 - Waiting Waste Overview	49
Figure 2-30 - Over Process Waste Overview	50
Figure 2-31 - Defect Waste Overview	52
Figure 2-32 - Creativity Waste Overview	54
Figure 3-1 PQP Flowchart	56
Figure 3-2 Project Gantt Chart	56
Figure 3-3 MQP Flowchart	57
Figure 3-4 Proposed Machine Shop Layout 3D Model	59
Figure 3-5 Plant Routings	62

Figure 3-6 Future State Routings by Machine	63
Figure 4-1 - Pinion Machine Drawing (Note: NOT SPENCE PART)	64
Figure 4-2 - Completed Pinion (Note: NOT SPENCE PART)	65
Figure 4-3 - Proposed System Check List	66
Figure 6-1 Paulsen Patent for ED pilot regulator	72
Figure 6-2 The CIRCOR family of Companies	73
Figure 7-1 Product Family Analysis	74
Figure 7-2 Product Family Analysis	74
Figure 7-3 Product Family Analysis Regulator Volume by W/C	75
Figure 7-4 Current State vs. Future State	76
Figure 7-5 Current Plant Layout	76
Figure 7-6 Implementation Plan Going Forward	77
Figure 8-1 - Set-up Sheet for D-Pilot Body	78
Figure 9-1 Lean Timeline	86
Figure 9-2 Lean Systems	87
Figure 9-3 Lean Methods	88
Figure 9-4 Timeline Image	89
Figure 9-5 World Lean Timeline	90
Figure 10-1 Pre-TPM Checklist	91
Figure 10-2 OEE-Overall Equipment Effectiveness (%)	92
Figure 10-3 7 Steps of Autonomous Maintenance	93
Figure 10-4 SMED Caption	94
Figure 10-5 Flow Modification	95
Figure 11-1 - Graphical Elimination of Waste	96
Figure 11-2 Graphical Interpretation of Lean	97
Figure 11-3 Overview of 7 Wastes	98
Figure 12-1 – Colorized Top-Down View of Proposed Layout	99
Figure 12-2 – Detailed CAD Drawing of Proposed Layout	100

Acknowledgement

We would like to thank Professor Dr. Mustapha Fofana, Worcester Polytechnic Institute, the WPI Mechanical Engineering Department, Ed Hallenbeck, Andrew Cervoni, Spence Engineering Co. and everyone at the company for their guidance and contributions throughout the course of this project.

Chapter 1: The Role of Lean Manufacturing System Design

1. Introduction

Lean Manufacturing System Design offers a unified framework to locate and interpret the most imaginable techniques, tools and engineering design for customer pull manufacturing in small or large scale industry. The goals in modern industry are to reduce waste of all kinds, vulnerabilities, disruptions and uncertainties while attaining high quality product tolerances and rewards. These are the important factors that reduce operational costs and warranty maintenance services and maximize return on investment. They foster employee empowerment through teamwork to enhance planning, processes, procedures, practices and performance in customer pull manufacturing industry. The momentum and skills of workers can be continuously improved to adapt to the cellular demands and flexibilities in the customer pull manufacturing systems. Spence Engineering Co., part of the Flow Technologies Division of CIRCOR International Inc., is an industry leader in the steam equipment regulation field. An ISO 9001 certified company; it is a custom manufacturer of steam specialty & fluid control devices. Spence supplies products to a vast array of customers ranging from educational establishments such as schools and colleges to industrial and commercial markets among others. Spence moved into its current Walden, NY manufacturing facility in 1967. Over the last few decades, the need to improve manufacturing practices has arisen. Practices that worked in the past may not fit into the current schemes and desires of the company or customer expectations. Spence Engineering is now going through such a transition. Manufacturing industries are evaluating, validating and analyzing models of lean system design that can coordinate the flow of manufacturing

information, material handling, selection of manufacturing processes, machine-tools, part programming NC codes and the effective utilization of skilled workers.

CICOR Spence Engineering is looking to restructure how they handle their product value streams so that they may improve and optimize their current product lines as well as create more floor space to their facilities. This effort is intended to increase growth in return of investment and incorporate new technologies of numerically computer controlled machining operations. This optimization process requires extensive planning, elimination of non-value manufacturing activities and participation from all aspects of the company. The project objectives aim at reconfiguring the current manufacturing floor space facilities, which includes the machine shop, the assembly benches, storage areas and the shipping and receiving docks. The reconfiguration of the Spence machine shop floor is aimed at minimizing machine set-up time, maintaining consistency in desired takt times and improving material handling efficiency. This Major Qualifying Project attempts at proving a comprehensive groundwork for the development of resilient and adaptable lean system design at CICOR Spence Engineering. This attempt is made primarily by spending seven weeks at Spence Engineering facilities and conducting extensive analysis of machine pairings, part routings, job-set up documentations and tool organization systems. The remaining part of the report is categorized as follows. In Chapter 2, the manufacturing evolution of CICOR Spence Engineering is presented. We discuss some important topics, namely, Spence Engineering products, processes, facilities, customers and organizational structure. Chapter 3 contains the new lean system design that is based upon the reduction of waste, vulnerabilities and uncertainties in function setup processes. In this lean system design, internal and external setup functions are minimized to attain desired manufacturing takt times and high quality. Internal setup functions or operations are activities that

must be carried out while the machine or manufacturing process is halted. Product pull authorization, material removal rates and the functions of the setup process are completely stopped. External setup operations on the other hand, are activities that can be performed while the machining or manufacturing process is still running. Tools, techniques, specifications and prepare values for the cutting conditions in terms of the requirements of part geometric dimensions and tolerances can be simultaneously located during part machining or manufacturing operation. Setup operation checklist, performing function setups, transporting of dies, streamlining material handling, making repairs, assigning the right skilled worker to the right manufacturing job and customer pull authorization can all take place without stopping the machining or manufacturing operation. In Chapter 4, we present the conclusion of the work and its future recommendation for extended improvement. Benchmarking indicators are established to quantify the effectiveness and operational performance improvement of CICOR Spence Engineering in the new lean manufacturing system design. The effort by the MQP team to eliminate waste, vulnerabilities, disruptions and uncertainties will improve the setup functions, takt times and continuous production of high quality product.

Chapter 2: The Manufacturing Evolution of CIRCOR Spence Engineering

2. Introduction

Spence Engineering was first founded in 1926 by Paulsen Spence. They have been



Figure 0-2 Original Spence Logo

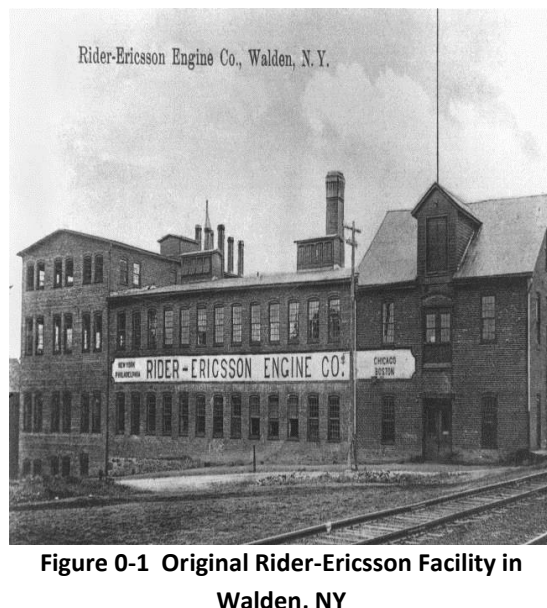


Figure 0-1 Original Rider-Ericsson Facility in
Walden, NY

designing and manufacturing steam pressure regulators since the company's conception.

In Figure 2-1 you may see the Spence Regulators logo, also in Figure 2-2 you can see the original facility. Spence Engineering started when Mr. Spence created the first type ED pilot-operated pressure regulator. This Spence regulator was a revolution in that it was the first ever pilot-operated pressure regulator. Compared to the regulators of the time, the pilot-operated regulator system greatly increased accuracy, speed, performance, and durability. The patent for the ED pilot regulator can be found in Appendix A. Shortly after Spence patented his creation, he met with the Rider-Ericsson Company, who agreed to share their facility in order to manufacture and sell the Spence regulator. In the following years Spence's creation became the standard for all steam regulators; to this day the pilot driven regulator is one of the most accurate methods of HVAC and process control available.

By the 1930's Spence had expanded their offerings to include regulators for pressure, temperature, backpressure control and more. Due to Spence's revolutionary products, sales during World War II were restricted to only the U.S. government, as the products were vital to

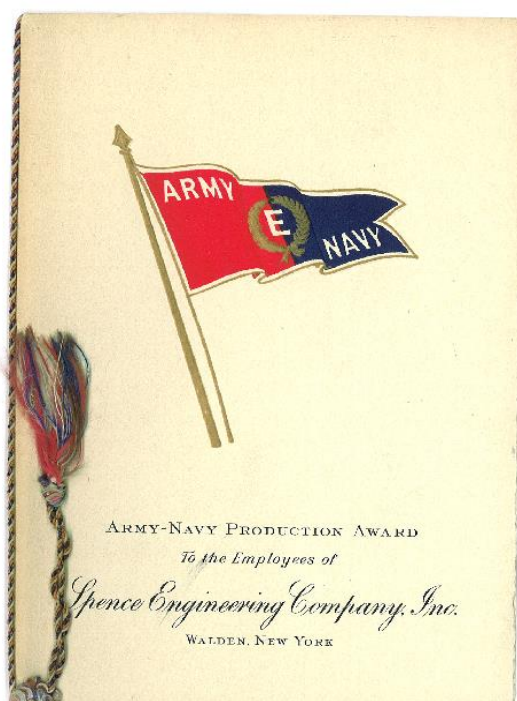


Figure 0-3 Army-Navy "E" award

the manufacturing of essential war materials. Due to all of this demand, Spence Engineering ended up receiving the coveted Army-Navy “E” award for production efficiency. In Figure 2-3 you may see the award. Spence continued to expand as a company and by 1960 Spence owned half the market for pilot-operated steam regulators. Due to the company’s ever growing needs, the Spence manufacturing facility needed to move in order to allow for the company to continue its expansion independently. Thus in 1967, Spence moved its manufacturing facility to its present day location in Walden, NY, with a space originally spanning 79,000 sq. ft. Later in 1984, Spence was sold to Watts Industries, while still retaining its name and products.

Even after this acquisition, Spence continued to grow in the years up to 1998; Spence acquired the Nicholson steam trap lines, the safety relief valves of Watts, and the series 2000 line from Ashcroft, as well as double their overall sales. In Figures 2-4 you may see the logos. In 1999 Spence received certifications as a manufacturer of fluid control and steam specialty devices and was later acquired in the same year by CIRCOR International after they bought out the HVAC, Oil & Gas, and Instrumentation divisions of Watts Industries. The Circor family of companies can be found in Appendix A. A year later Spence also acquired the RXSO Rockwood line of cryogenic safety relief valves. In 2005, due to Circor’s presence as a lean company, Spence also adopted the lean manufacturing practices of Circor within its own facility (*Spence Engineering*).



Figure 0-4 (top) Watts logo, (bottom) Nicholson logo

2.1 The Engineering Realization of Lean Manufacturing

Lean manufacturing itself is based around the mentality that using resources for any goal other than the creation of value for the customer are to be considered wasteful and need to be removed. From this point of view, value is defined as services or products that a customer would be willing to pay for. An example, as seen in Figure 2-5, of a service that would be considered wasteful is machine setup for any part making job, as the act doesn't directly impact the product,



Figure 0-5 Example of proper workplace flow in a Ford Facility

or moving the product from one end of the facility to the other. A common example for the machine shop within Spence is “The only time value is made, is when we are making chips”. That is because the only action that is truly impacting the consumer during the machining process is when Spence is cutting into metal to create and define the products the customer asks

for. Other value-added-work examples within Spence's other divisions include the assembling of parts to create

the full product, and when the finished parts are painted.

Many view lean manufacturing first started with Henry Ford in the early 1900's with his concept of waste. In short, his main reasoning for waste in manufacturing stemmed from poor workplace arrangement, which has become a major focus in modern day lean practices. Ford realized how easy it is to overlook this waste in work. He described in "My Life and Work" how a farmer would carry water back and forth, climb the same ladder a "dozen times" and instead of improving the movement of the work, will instead hire someone. He saw this wasted potential, saw that an improvement does not have to necessarily be an expense. While Ford got the lean revolution going, his philosophy had some major flaws. His methods worked solely in a steady state environment, when the entirety of the production facility was working to plan. His ideology didn't take into account the ever dynamic nature of a normal manufacturing facility. Ford's system had difficulty sustaining whenever a new product was introduced to the system, a good example of this is the introduction of the follow up to the Model T and Ford's decline afterwards. Figure 2-6 shows this model. Ford's other major flaw was his inability to incorporate "pull

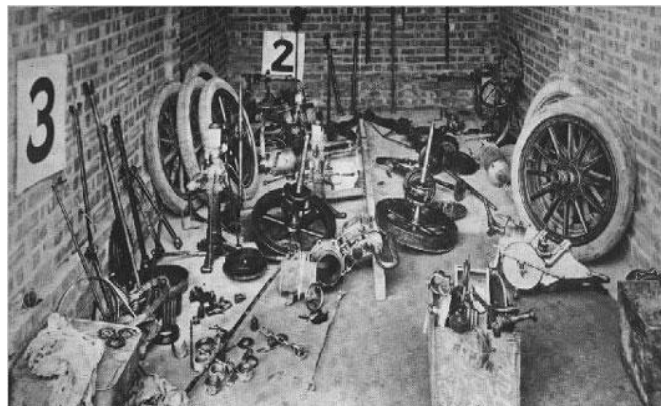


Figure 0-6 Model T interchangeable Parts

production”. This is where products are manufactured to customer demand so that there aren’t any products left in storage to wait. This is essential to lean manufacturing as stored products are considered wasteful and a liability. Because Ford never incorporated pull manufacturing, he suffered greatly from over-production.

One of Ford’s greatest contributions to lean philosophy has to be the concept of Design for Manufacture, also known as DFM. The concept of DFM is based on the basic principle of designing any and all parts to be easily manufactured. This also is the basis of creation of interchangeable parts and mass production. Ford developed the standardization of parts through the use of manufacturing tolerances. These tolerances represented the upper and lower dimensional limits of manufactured parts. If a part was manufactured outside of the limits the part no longer would be able to fit inside of the assembled system, thus making it unusable in a mass produced system.

The creation of these strict guidelines for manufacturing parts by Ford allowed the creation of the production line and the elimination of fitters. Fitters were responsible for shaping and fitting vehicle components so that they make actually work in the assembly. With Ford’s creation of DFM, fitters were no longer needed since if the parts were made within the tolerances they were able to fit into the assembly without any need of reshaping. It is believed that due to this Ford reduced manufacturing efforts by 60-90% (*Hounshell*).

While Ford may have gotten the lean ideology started, it was Kiichiro Toyoda, founder of the Toyota Motor Corporation, who developed the full ideology that would go on to become lean manufacturing. His first step to the development of lean, was when Toyota won its first truck contract with the Japanese government, his current manufacturing process had problems, so he

developed the famous Kaizen improvement teams to fix the problems (*Ōno*). Kaizen, which in Japanese means “improvement” or “change for the better” refers in the practical sense to activities used to improve all aspects of a company or facility. The activities will consist of members from all aspects of the company, from CEOs to machinists.

The demand for mass produced goods was minimal in post war Japan. This meant that traditional mass production would be a failure for Toyota. If he planned to be successful he needed to create a new way to manufacture in real-time demand scenarios and reduce wasting of



Figure 0-7 Example of a "5s" workplace

potential at the same time. 5s workplace can be seen in Figure 2-7. It was there that he realized that the scheduling of work should not be driven by sales and production targets, but instead by actual sales and demand. Parts produced should be looked as disposable and should have a shelf

life, not allowed to stay in storage for too long or else it would be considered a loss. This was a huge realization, as the majority of current manufacturing facilities were producing parts to meet goals and then just having the products sit in storage, creating waste. Toyota's change in how manufacturing was previously exercised would eliminate the danger of over production (*Liker*).

It was at an American supermarket where Toyota found his inspiration to solve this problem (*Ōno*). He noticed that supermarkets will only stock shelves to the customer demand. They will only order enough to sell, and then produce or order more because any unsold merchandise is waste or at the very least a cost for storage. Toyota realized that the same should apply to manufacturing, in that products should be created not for quotas, but instead for true existing sales. Products are made and then instantly shipped out to the customer. This fundamental principle became the core to modern day lean practices.

The history of lean manufacturing can be traced back almost 100 years in some guises. Here is an overview.

Taiichi Ohno is regarded as the founder of the Toyota Production System (TPS) which was developed from 1950 following an excursion to the Rouge Ford plant in the US by Eiji Toyoda, a young engineer who reported his findings on the Ford system back to Ohno.

In the English translation of his book 'TPS – beyond large scale production' Ohno (1988) describes how TPS evolved out of need, as the market place in post war Japan required small quantities of cars to be produced in many varieties. This was very different to the Ford principle of mass-producing the same Automobiles in large production runs. In the Venetian Arsenal, seen in Figure 2-8, we see the creation.



Figure 0-8 Venetian Arsenal

Although TPS began in 1950, it was not until the 1973 oil crisis that other Japanese firms began to take notice, and since this time the system has been studied, copied and implemented across many industries. Marc Brunel seen in Figure 2-9, is another example of the important characters.



Figure 0-9 Marc Brunel

Womack, Jones and Roos (1990) coined the phrase ‘Lean Manufacturing’ to describe TPS when they printed the results of a five-year study into the automotive industry in the book ‘The

Machine That Changed The World'. This gives a pretty good insight into The History Of Lean Manufacturing. Seen in Figure 2-10, is an by parts example.



Figure 0-10 Colt's Armory, Hartford, CT

Even with the massive amount of research that has taken place into the Toyota Production System, fifty one years after it was born, Slack et al (2001, p481) still refer to Lean Manufacturing as a 'radical departure from traditional operations practice'.

Ohno (1998) describes the most important objective of the TPS as increasing production efficiency through consistently and thoroughly eliminating waste.

The Seven Wastes Commonly found in physical production (Womack and Jones 2003, pp 351 – 352)

Ohno (1988) describes the four key elements of a TPS as: Just-In-Time (JIT), Jidoka, Standardised Work and Kaizen. Sample Ford plant seen in Figure 2-11.



Figure 0-11 Ford Plant

The makeup of each of these elements is covered below

In general terms the key elements of Lean Manufacturing work together to continually improve production processes. Put simply, waste elimination is accomplished through Just In Time and Jidoka, maintained through Standardized work, and improved through Kaizen.

Just In Time (JIT) -

Producing what is needed, when it is needed, in exactly the amount needed. (Using pull systems (Kanban), continuous flow processing, and synchronizing the production speed)

Jidoka -

The ability of production to be stopped in the eventuality of a problem, either by the machines themselves or people. (Using 'stop systems' and error proofing).

Standardized work -

Standardize procedures concentrating on the most efficient human movements and work sequence for each process.

(Using synchronous production speeds, working sequence and standard in process stock)

Kaizen Never ending job design through continuous improvement (Using a basis of standardized work).

In summary the principles from the history of lean Manufacturing are to reduce waste through the application of a number of process improvement tools.

Womack et al (2003) define waste as any activity that consumes resource but adds no value as specified by the customer.

In order for us to understand the waste within manufacturing activities Ohno (1988) broke waste up into seven elements. Seen in Figure 2-12 is Kanban and supermarkets.

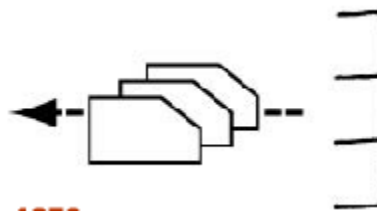


Figure 0-12 Kanban and Supermarkets

These elements are: Overproduction, Over-processing, Waiting, Transport, Inventory, Motion, and Defects and they are defined from the history of lean manufacturing below:

Overproduction - producing things ahead of demand

Waiting – inability to move to the next processing step

Transport – unnecessary movement of materials between processes

Over processing – inappropriate processing of parts, due to poor tool and or product design

Inventory – storing more parts than the absolute minimum

Movement – unnecessary movement of people during the course of their work.

Defects – production of defective parts

Understanding the Application of Flow processing techniques

Flow production is based on the Just in Time methodologies that fall within a ‘Lean’ production system. Womack et al (2003) contend that the concept of making products flow is almost counterintuitive and difficult for many people to conceptualize let alone implement.

Flow means producing without (or with minimal) batches, waiting, or wasted motion, in other words flow means that each individual product keeps moving either in the literal sense or in the sense of being continuously worked on.

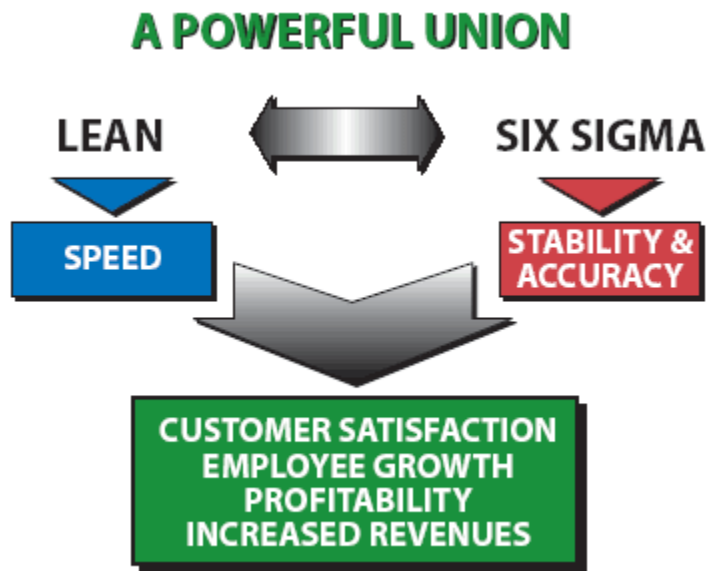


Figure 0-13 Powerful Union

The concept of flow has origins that predate TPS. This as seen in Figure 2-13, made for an important role.

Henry Ford utilized scientific management theory to implement production lines and one-piece production in 1910.

Ford identified that there were two basic ways to build an automobile: one was to keep the automobiles stationary whilst moving the assembly workers around; the other was to keep the assembly workers stationary whilst the automobiles where moved around.

Keniche Sekine (1990, pp3-4) former head of the TPS consulting group describes the situation when Ford discovered the benefit of moving the automobiles around:

Recognizing how bulky and heavy automobiles were, Ford initially thought it better to follow the first concept (keeping cars stationary).

However, one day while looking for ways to eliminate waste from assembly processes, Ford noticed the following:

- Waste in the scattered movement of workers

- Waste in searching for, comparing and finding objects

- Waste in conveying objects

After noticing these types of waste, Ford thought long and hard about how he could eliminate them.

Finally, he hit upon the idea of mounting cars on a row of cars that could be pulled along by a rope and winch.

Right away he issued the following instruction to his employees:

1. Set up a large winch and a large thick rope to pull the automobiles along during assembly.

2. Since the factory was about 80m long, divide the assembly line into 15 one hour processes. This would allow the rope to pull all of the automobiles to the next process once per hour.

3. Distribute the assembly parts to their corresponding processes before they are needed.

4. Assign three or four workers to each process and work out the balance of labor by observing the assembly line.”

The experiment proved a big success. Sekine (1990) reports that assembly time per vehicle was reduced from 13 hours to just 5 hours from following the preceding 4 steps.

Ford had established a simple methodology for creating production flow, and almost 100 years later these four steps are evident in conventional techniques used to create production flow.

These techniques are detailed below

Production flow is a worthy prize for any manufacturer and to achieve it a number of things need to be in place.

Broadly speaking Womack et.al (2003) identifies the pre- requisites to achieve flow as:-

- A clear understanding of your customer requirement so that the production process can be organized to specifically achieve them.
- Production team with responsibility for adding value to the same product should be co-located, and move away from traditional production silos.
- Production equipment should be fit for purpose and well maintained to allow operation with minimal waste.
- Production processes should be standardized to ensure even, consistent paced work without production operators becoming overburdened or operating in conditions of waste.
- Production employees should attempt to identify and eliminate all waste in production.
- Pull systems should be introduced to ensure that process only produces a good that the subsequent process needs.
- Visual management systems should be implemented so that production process abnormalities and the consequent countermeasure can be easily identified.

Additionally Muhlemann, Oakland & Lockyer (1992) identify the further requirements of:

- Constant demand is required as flow systems are designed to achieve a specified output, if the output changes the lay out of the system will need to be changed in order to avoid the cost of inventory, or failure to meet customer requirements.
- Standardized tasks need to be present to ensure that process variability is minimized and the production line can meet customer demand with minimum levels of waste.
- Material inputs to the system must be on time and to the required quality, as disruption will cause the system to fail.

Flow allows the entire production process to be regulated by the natural laws of supply and demand.

It works by customer demand stimulating the production of a stock-keeping unit.

In turn the production of a stock-keeping unit stimulates the production and delivery of all the required components...and so on.

The result is that the right parts and materials are produced at the right time and delivered exactly when they are required; in the exact amounts they are needed. Production is 'pulled' by the customer rather than being 'pushed' by the capabilities (or limitations) of the production system itself.

Traditionally the physical manifestation of flow production process is the moving production line.

However using a technique called 'line balancing' we can get the benefits of a flow line in a fixed assembly position. Sekine (1992) terms fixed assembly manufacture 'gypsy production' as the product remains in one place whilst workers move around it.

Line balancing, seen in Figure 2-14, means adjusting the spread of work evenly between people to the rate of customer demand.

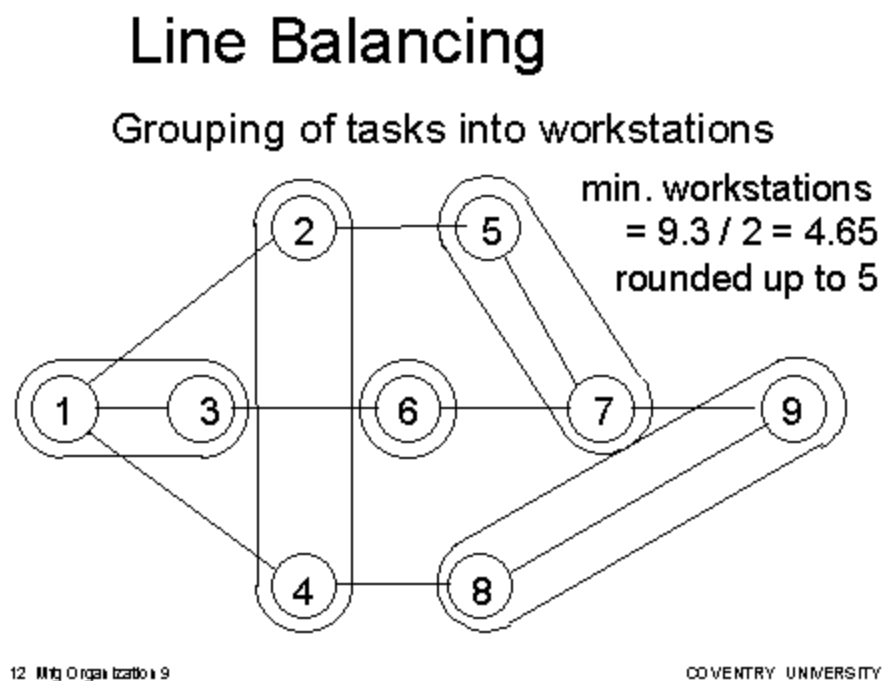


Figure 0-14 Line Balancing

Although there are instances of rigorous process thinking in manufacturing all the way back to the Arsenal in Venice in the 1450s, the first person to truly integrate an entire production process was Henry Ford. At Highland Park, MI, in 1913 he married consistently interchangeable parts with standard work and moving conveyance to create what he called flow production. The public grasped this in the dramatic form of the moving assembly line, but from the standpoint of the manufacturing engineer the breakthroughs actually went much further.

Ford lined up fabrication steps in process sequence wherever possible using special-purpose machines and go/no-go gauges to fabricate and assemble the components going into the vehicle within a few minutes, and deliver perfectly fitting components directly to line-side. This was a truly revolutionary break from the shop practices of the American System that consisted of general-purpose machines grouped by process, which made parts that eventually found their way into finished products after a good bit of tinkering (fitting) in subassembly and final assembly.

The problem with Ford's system was not the flow: He was able to turn the inventories of the entire company every few days. Rather it was his inability to provide variety. The Model T was not just limited to one color. It was also limited to one specification so that all Model T chassis were essentially identical up through the end of production in 1926. (The customer did have a choice of four or five body styles, a drop-on feature from outside suppliers added at the very end of the production line.) Indeed, it appears that practically every machine in the Ford Motor Company worked on a single part number, and there were essentially no changeovers.

In Appendix D you may find additional pictures that will aid in the understanding of the history, and implementation. In Figure 2-15, is one of the first lean productions.



Figure 0-15 Lean Start

When the world wanted variety, including model cycles shorter than the 19 years for the Model T, Ford seemed to lose his way. Other automakers responded to the need for many models, each with many options, but with production systems whose design and fabrication steps regressed toward process areas with much longer throughput times. Over time they populated their fabrication shops with larger and larger machines that ran faster and faster, apparently lowering costs per process step, but continually increasing throughput times and inventories except in the rare case—like engine machining lines—where all of the process steps could be linked and automated. Even worse, the time lags between process steps and the complex part routings required ever more sophisticated information management systems culminating in computerized Materials Requirements Planning (MRP) systems.



Figure 0-16 Kiichiro Toyoda

As Kiichiro Toyoda, seen in Figure 2-16, Taiichi Ohno, and others at Toyota looked at this situation in the 1930s, and more intensely just after World War II, it occurred to them that a series of simple innovations might make it more possible to provide both continuity in process flow and a wide variety in product offerings. They therefore revisited Ford's original thinking, and invented the Toyota Production System.

This system in essence shifted the focus of the manufacturing engineer from individual machines and their utilization, to the flow of the product through the total process. Toyota concluded that by right-sizing machines for the actual volume needed, introducing self-monitoring machines to ensure quality, lining the machines up in process sequence, pioneering quick setups so each machine could make small volumes of many part numbers, and having each process step notify the previous step of its current needs for materials, it would be possible to obtain low cost, high variety, high quality, and very rapid throughput times to respond to changing customer desires. Also, information management could be made much simpler and more accurate.

The thought process of lean was thoroughly described in the book *The Machine That Changed the World* (1990) by James P. Womack, Daniel Roos, and Daniel T. Jones. In a subsequent volume, *Lean Thinking* (1996), James P. Womack and Daniel T. Jones distilled these lean principles even further to five:

- Specify the value desired by the customer
- Identify the value stream for each product providing that value and challenge all of the wasted steps (generally nine out of ten) currently necessary to provide it
- Make the product flow continuously through the remaining value-added steps
- Introduce pull between all steps where continuous flow is possible
- Manage toward perfection so that the number of steps and the amount of time and information needed to serve the customer continually falls

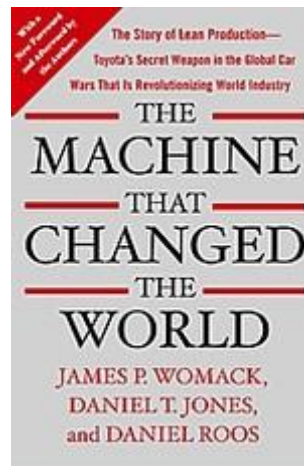


Figure 0-17 Lean Manufacturing Book Created

As these words are written, sample book seen in Figure 2-17, Toyota, the leading lean exemplar in the world, stands poised to become the largest automaker in the world in terms of overall sales. Its dominant success in everything from rising sales and market shares in every global market, not to mention a clear lead in hybrid technology, stands as the strongest proof of the power of lean enterprise.

This continued success has over the past two decades created an enormous demand for greater knowledge about lean thinking. There are literally hundreds of books and papers, not to mention thousands of media articles exploring the subject, and numerous other resources available to this growing audience.

As lean thinking continues to spread to every country in the world, leaders are also adapting the tools and principles beyond manufacturing, to logistics and distribution, services, retail, healthcare, construction, maintenance, and even government. Indeed, lean consciousness and methods are only beginning to take root among senior managers and leaders in all sectors today.

2.2 Tools, Techniques and Technology for Eliminating Non-value Added Functions

As lean manufacturing continued to grow and evolve around its central themes, it became a manufacturing philosophy as well as a toolbox. While the tools vary greatly, they all revolve around the basic principle of reducing waste. Some of these tools include, just-in-time, First-in-first-out, and the 5s strategy. Just-in-time (JIT) relates to relying on cues from one part of the manufacturing process to signal the beginning of another part of the same or a different process. This is done to have all parts for an assembly ready at the same time and thus reduce over-stock inventory costs and wastes. First-in-first-out is the basic principle that the first part in should be the first part out, thus keeping all manufacturing in a specific order at all times (*Wilson*). The 5s methodology is the guideline for proper workplace organization. The 5s' in the system refers to: sorting, straightening, and sweeping, standardizing, and finally sustaining the practice (*Plant*). Many more lean tools have been created, but this sampling gives a good view on some of the more important details that lean manufacturing looks to incorporate and improve.

In the following pages, the ideology behind lean thinking and its methods and tools have been discussed extensively. Drawing from the previous sections which have introduced lean manufacturing and its basic principles, we will show how lean can be implemented in a manufacturing environment.

Total Productive Maintenance (TPM) seeks to engage all levels and functions in an organization to maximize the overall effectiveness of production equipment (Campbell and Dixon). To initiate a facility's TPM effort as part of the LEAN Roll Out Strategy, TPM training needs to be provided. This develops a common level of knowledge on what it is and how to do it. Other means of implementing TPM can be by discussing the facility's existing Maintenance, Preventive Maintenance, and Total Productive Maintenance environments and plans, ideas, and directions for future improvements. This can be achieved by developing and discussing the facility's TPM objectives that will drive the company to a globally competitive LEAN TPM level. The objectives of the plant's TPM roll-out is three fold.

- A. Creation of a TPM Plan (PLIP) utilizing "TPM Recipe" including the various Steps of Autonomous Maintenance. This involves both Existing equipment and planned equipment.
- B. Development of company formats for the TPM checklists and audits. This has to be applied to the LEAN target area(s).
- C. Implementation and driving the improvement of TPM Measurable.

However, before an effort towards TPM can be made, a thorough Pre-TPM Conditions checklist must be completed that already exist at the company. (Appendix D)

The principle characteristics of a TPM system are (Leflar):

1. Operators perform Preventive Maintenance functions they have been trained to perform - that do not require the capabilities of a skilled tradesman.
2. Skilled maintenance personnel train the above and develop “one-point lessons”.
3. Maintenance department moves from a “fire-fighting” mode to a prevention mode.

A definition of TPM contains the following five points:

1. A philosophy and system which aims at getting the most effective use of equipment (i.e., overall equipment effectiveness).
2. It establishes a total (companywide) PM system covering the entire life of the equipment by using a proactive approach to detect and repair a machine problem before it causes an interruption in the production process.
3. It requires the participation of equipment designers, equipment operators, and maintenance department workers.
4. It involves every employee from top management down.
5. It promotes and implements PM based on autonomous, small-group activities using routine cleaning schedules to examine equipment thoroughly.

The concept of TPM stems from the following five pillars:

1. Improvement activities designed to increase equipment effectiveness; this can be accomplished mainly by eliminating the big losses.
2. An autonomous maintenance program to be performed by equipment operators. This is established as operators are trained to know their equipment.
3. A planned maintenance system (including Preventive and Predictive), including spare parts and tool crib 5-S.

4. Training to improve operation and maintenance skills. This raises the skill levels of equipment operators and maintenance workers
5. A system for Maintenance Prevention design and early equipment management. This helps create equipment that requires less maintenance and gets new equipment operating normally in less time.

Manufacturing processes are becoming more synchronized. Processes in total system are dependent upon each other. Equipment available time (uptime) is critical. Equipment available time (uptime) is critical. JIT requires equipment to produce the correct product when required in quantities required. Reliability is paramount. Life Cycle Costs need to be reduced. More effective use of human resources has to be carried out. All these factors ultimately shape the necessity for Total Productive Maintenance.

Apart from the aforementioned factors, TPM when practiced correctly also focuses management (maintenance and improvement), forms a basis for training, audit and diagnosis. It also takes into account Controls variability and eliminates Safety hazards and accidents. Finally, it improves company image and customer satisfaction.

TPM was initially practiced as means to identify and eliminate the six big losses namely:

1. Unexpected breakdowns.
2. Set-up and adjustments (Changeover).
3. Minor stoppages or idling.
4. Actual operating speed versus designed speed.

5. Defects and / or reworking of defects.
6. Reduced yield between start of production and stable production.

The losses can be grouped based on the nature of causes and production impacts. Downtime losses are a major group. This includes Breakdown losses and Set-up and Adjustment losses. Breakdown losses are defined as Sudden, dramatic or unexpected equipment failures that result in loss of productivity. Contributing factors include driven system failures, electrical system failures and structural fatigues. Set-up and Adjustment losses are defined as Downtime and defective product that occurs when production of one part ends and the equipment is set-up/adjusted to meet the requirements of another part. Degree of loss depends on Process standards, Maintenance level of equipment, Maintenance level of tooling, Operator skill level.

The second group of losses can be classified as Speed Losses. This includes Idling & Minor Stoppages and Reduced Speed Losses. In the former, Production is interrupted by a temporary malfunction or when the machine is idling. Contributing factors include defective products that shut line down, Disruption of production flow, Mis-location of part, Temporary equipment malfunction. The latter refers to the difference between equipment design speed and the actual operating speed. Contributing factors for this include mechanical problems, poor quality, fear of abusing or overtaxing equipment and Operator training.

The third and final grouping is named Defect Losses. It includes both Process Defects (Scrap and Rework) and Start Up Losses. The former means Losses in quality caused by malfunctioning equipment or tooling. Degree of loss depends on Maintenance level of equipment, Maintenance level of tooling and Operator skill level. The latter yield losses that occur during the early stages of production, from machine start-up to stabilization. Degree of loss

depends on Maintenance level of equipment, Maintenance level of tooling, Operator skill level and Standardization level.

The following points detail out how a TPM can be performed. It is fondly known in Lean circles as “The Recipe”.

1. Develop the Infrastructure - Roles and Responsibilities, Maintenance System and Performance Feedback System
2. Gather and Review Data - O.E.E. (Appendix D), % Work Orders Planned vs. Total and % PM Work Orders completed on time
3. Establish / Update Maintenance requirements for both existing and planned machines- Determine Preventive (Equipment specs, Experience, Other) and Determine Predictive (Meaningful tools)
4. Develop standards and create Checklists - Item vs. Frequency vs. Specs vs. “record the data” and Operators vs. Maintenance Tech
5. Training (What/Why/How), especially Safety - Detailed module(s) and One-Point Lessons
6. Perform TPM checks initially (trial) and ongoing - Use OEE / Measurable feedback to continuously enhance system
7. Make machines better than new - Target a Machine, Use “7 Steps of Autonomous Maintenance” (Appendix D) and Cascade to other machines

The following sections will analyze a few key concepts of Lean Manufacturing. Figure 2-18 represents these.

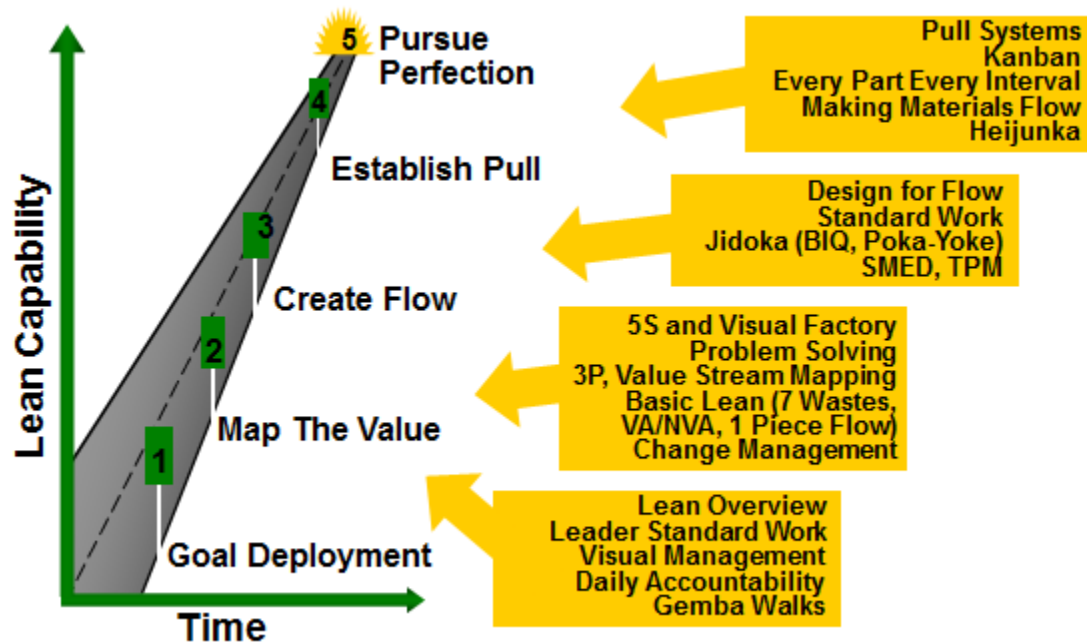


Figure 0-18 Lean Tools and Concepts

An important aspect of a Lean transformation is Leader Standard Work. This is essential because it establishes discipline by standardizing the daily management routines. It also ensures a focus on process in a Lean environment by “doing it” rather than “getting it”. The objectives are - Leader standard work at the plant and Division level, Leadership team training in leader standard work and to ‘Learn and Do’. Leader standard work can be applied to Lean Leadership training and Lean roll-out.

Visual Management (VM) is another key aspect of Lean. It is important because it strives to empower employees by visually sharing information regarding current situation and improvement opportunities so everyone can help drive continuous improvement. The objective

are - To have each person involved in VM to understand what, why and how it is done and begin to consistently practice how it is done in their area. VM can be done as a standalone or in a direct interface with 5S and Lean Management. It can also be integrated into any Lean training. Similarly, VM in System Training can get leaders to the Shop Floor/Gemba to start measuring with a common set of metrics on a real time basis. The objectives are - Vision boards at the cell level and area level and Leadership Team trained in visual management system.

Daily Accountability is necessary in a Lean setting. It simply states “Go to the Shop Floor/Gemba and review yesterday, today, and tomorrow to drive accountability in the management team during the lean transformation” Its objectives are - Leadership team training on the accountability process.

Five S or 5S strives to create a disciplined, high performance workplace in which abnormalities are quickly exposed and addressed. It goes hand-in-hand with the concept of Problem Solving which ensures that problems are solved at the appropriate layers of the organization. In a Lean environment recurring problems are a major sin. It is also vital to involve all employees in the problem solving process.

Value Stream Mapping (VSM) identifies the value-add and waste in a Value Stream to improve the big picture, not just individual processes. It relies on creation of a Value Stream Map that includes the Current State Map, Future State Map and Value Stream Plan. It also aims to develop the ability to “see the flow” and identify “flow interrupters” (wastes). It also teaches how and why VSM is a key lean tool for management planning and decisions.

The following paragraphs talks about one of the most important Lean Goals, Setup Reduction (SMED) and describes the methodology to achieve these goals. We will start with

explaining the concepts and principles of Single Minute Exchange of Dies (SMED) and the four step method for setup reduction. Finally, the preparation necessary to undertake setup reduction is discussed. Set-up time is the length of time from the last good product of a production run to the first good product(s) of the next production run. It is not just the time associated with working on the machine but the elapsed time between the last good piece and the first good piece of the next product.

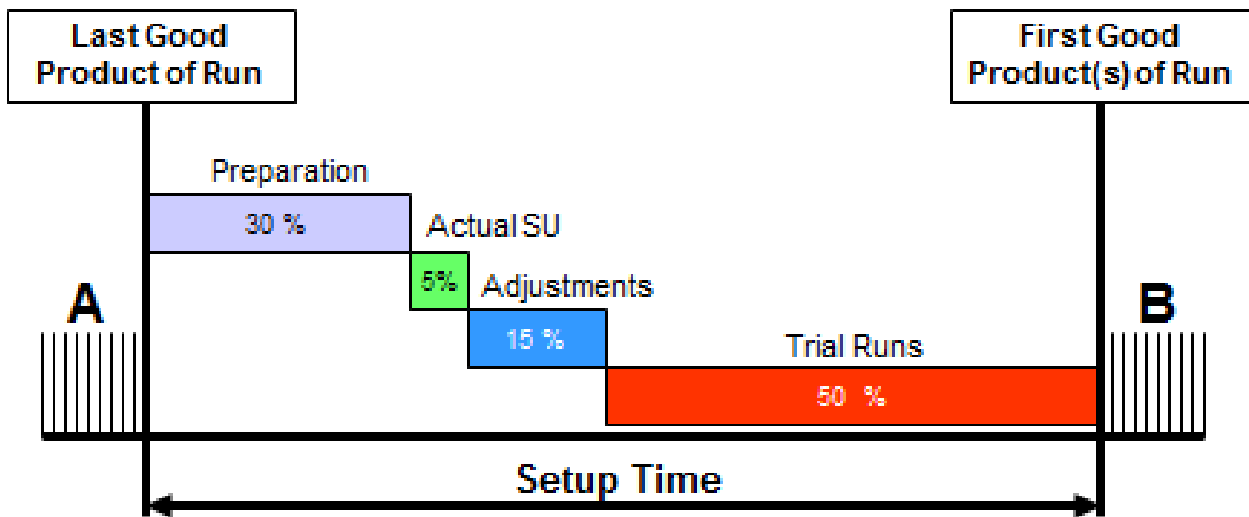


Figure 0-19 Set-up Time

Benefits of Set-up Reduction are manifold. As seen in Figure 2-19, the importance is highlighted. The following two figures form a comprehensive “benefit-tree” for SMED. The key here is to point out that the reason for setup reduction is to allow us to do more changeovers, not to increase productivity by decreasing downtime. We get a huge responsiveness benefit by being able to reduce lot size and run what we really need. Typically we try to group runs of the same (or similar) product together to maximize efficiency, but all we are really doing is building more

than we need of that product and neglecting to run something else that we need. By reducing setup time we can change over more often and run the parts we need, thus reducing inventory.

We also reduce our quality risk by increasing the cycles of product and reducing the time it takes to process them through. We can identify a problem quickly, before we run thousands of parts. It is also useful to point out that, like everything in life, practice makes perfect. The more setup iterations we go through, the better we will become at performing them. This should lead to improved quality and far less searching for answers; we are more likely to remember what it takes to create high quality parts. In Figure 2-20, we see the highlights of the reduction.

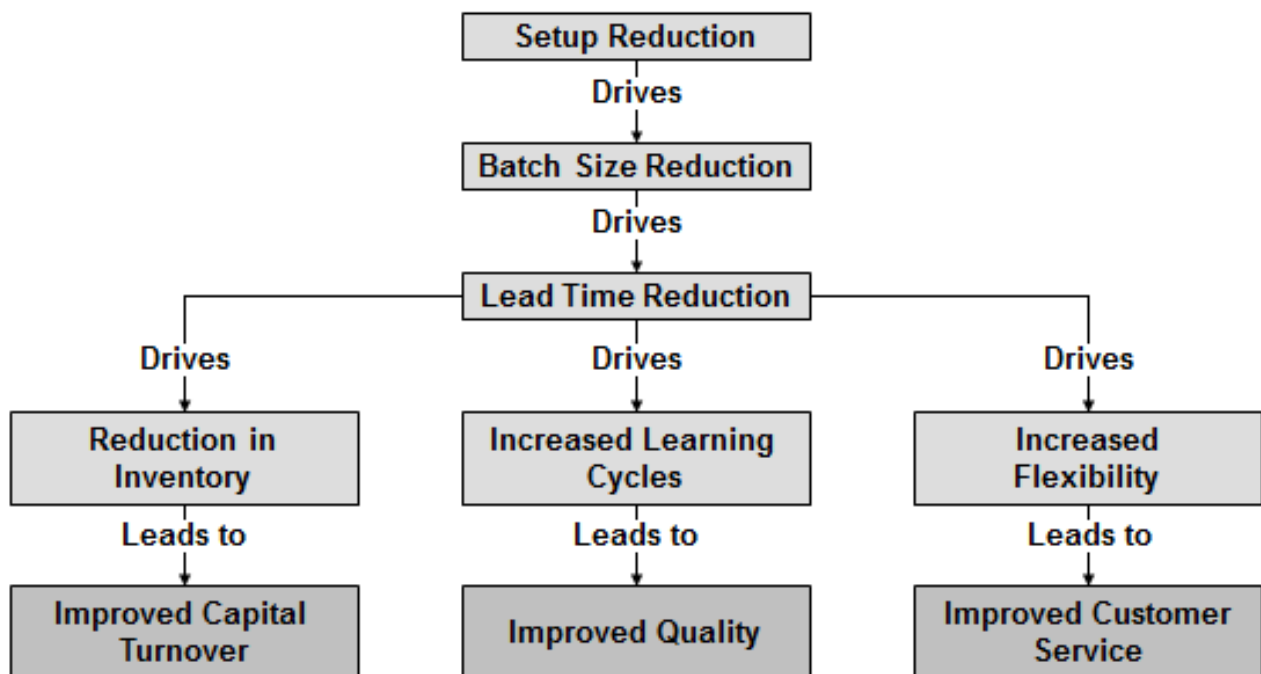


Figure 0-20 Benefits of Set-up Reduction

As we lower the water level (inventory), we will expose problems in the process that were previously hidden. When talking about service to our customers and lead time, minimal set-up time are key to improvement. SMED is the lean tool that we use here.

Tools used for SMED -

1. Setup Reduction
2. Variation Analysis
3. 5S (Workplace Organization)
4. Adjustment Eliminators
5. Standard Work

All of the items listed here are applied during a SMED event. Typically the biggest chunks of time revolve around good preparation and the elimination of the trial and error method of adjusting. It is important to remember that we really want to put the die or fixture on the machine and walk away, knowing that the parts will be good on the very first run.

Following is a list of advantages of Rapid Set-up over Typical Set-up -

1. Cut scrap and rework risk
2. Cut inventory investment
3. Able to introduce quality improvements more quickly (more cycles of learning)
4. Able to change the schedule more often to meet changing customer demand
5. Able to introduce design changes more quickly
6. Increase available floor space

The SMED Roadmap can be seen in a pictorial form in Appendix D. A start for SMED transformation should begin with SMED Team Selection. It should consist of a process owner (an Individual from the plant who is responsible for day to day manufacturing operations), an Engineer (that understands the equipment and processes in the value stream), an Operator (an associate who typically performs the set-up and who is not shy in expressing opinions), an experienced toolmaker (who is familiar with the process and can help make modifications if necessary), and Top Management (an individual who will work with the team and can use this experience to promote lean throughout the facility).

After the SMED team selection, a 4-Step Method is followed rigorously:

Step 1: Videotaping and document setup and separation of elements into internal or external

Step 2: Elimination of obvious wastes and conversion of internal to external

Step 3: Streamlining of internal and external elements

Step 4: Elimination of adjustments internal to the setup

The following picture guideline may be used to understand the flow of the 4 - Steps better. These are visualized in Figure 2-21.

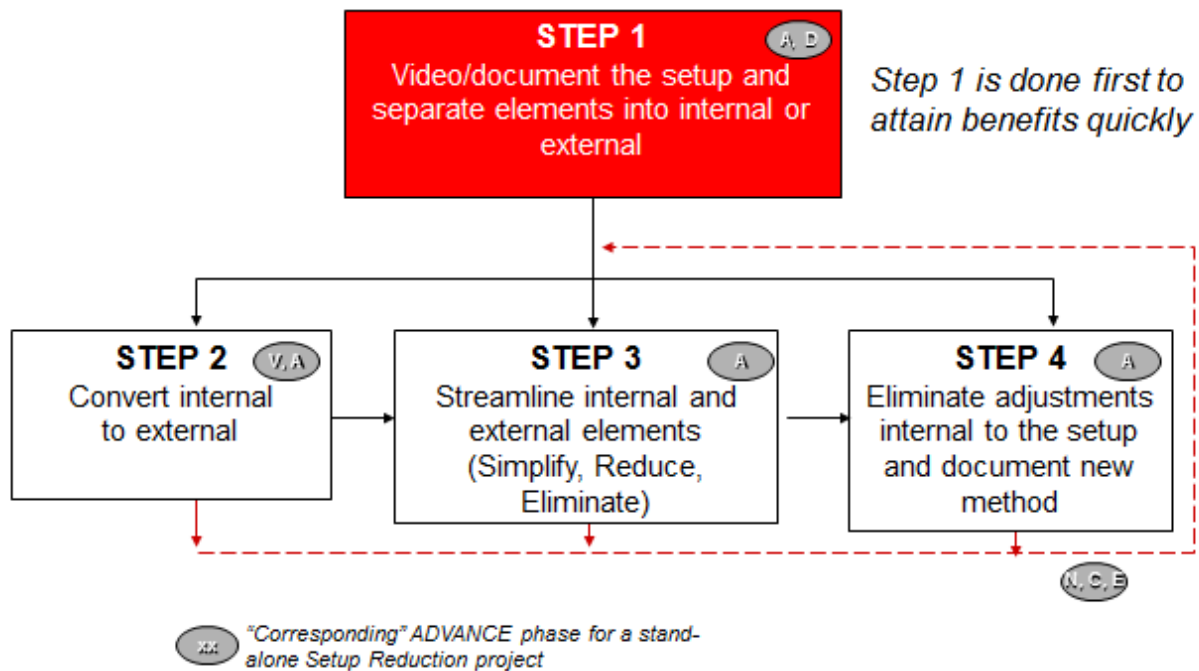


Figure 0-21 Four-Step to achieve SMED

In the following sections, the 4-Steps have been explained in details. Step 1 includes Internal and External Set-up. Internal setup is an activity that must be performed while the equipment is down. This includes Changing dies / fixtures and changing tooling. External setup is an activity that could be performed while the equipment is producing parts such as Retrieving tools and hardware or Loading programs.

Step 2 is conversion of Internal to External Set-up. This includes conversion of any internal setup elements to external setup elements. This also allows for re-examination of internal elements from step 1 and verifying that they are actually internal. This uses several tools such as

- Organization
- Checklists

- Setup carts
- Shadow boards
- Work instructions

Vast amounts of setup time are lost due to searching for setup hardware (Tools Fixtures, Nuts and bolts, Clamping devices and Measuring devices) and setup information (Data -tool and machine settings, Procedures).

Step 3 is the streamlining of Internal and External Events. A few techniques for doing this are listed below -

- Eliminate waste due to excess motion
- Nut/bolt improvement methods (Reduce/eliminate Need for Hand Tools, Reduce/eliminate Nuts and Bolts, Hex Nuts, Etc.)
- Replace with Quick Fastening/Releasing Devices (Single Motion Securing, U-slot Method, Pear Shaped Hole Method, Clamps)
- Use only 1 type / size of fastener

Step 4 asks for Elimination of Adjustments internal to the Set-up. Basically, it strives to change the Set-up from an “art” to a “science”. Elimination should also not be confused with reduction in time required to perform adjustments. Tools for Step 4 are:

- Abandon reliance on intuition for settings
- Settings as a result of intuition are inexact and do not provide the required precision as constant value settings
- Convert intuition to Fact

- As long as settings are made based on intuition, there is no way to avoid adjustments and test runs

This way, the 4-Step methodology can help SMED a manufacturing facility.

The following sections rely on the Lean overview and re-introduce several key concepts. 5S is a process and method for creating and maintaining an organized, clean, high performance work place (Hirano and Hiroyuki). Standard Work/Design for Flow is a Process to Create Standard Operations which is a Prescribed Sequence of Steps by Operator Balanced to the Customer Demand. Its goals are to minimize variation in Output, Quality, WIP and Cost. It has several benefits such as exposing and eliminating wastes. It provides the Method by which a Cell is managed. This facilitates Continuous Flow.

Appendix D shows Flow Modifications and change from Islands to Symptoms. This is the fundamental idea behind Single Piece Flow.

Another extremely important Lean tool is Production Preparation Process (3P) (Vaughn et al). 3P is basically a method for designing products and processes that better meet customer's needs with improved safety, quality, and delivery and at a lower total cost. Figure below shows why modern-day manufacturing facilities need to implement 3P.

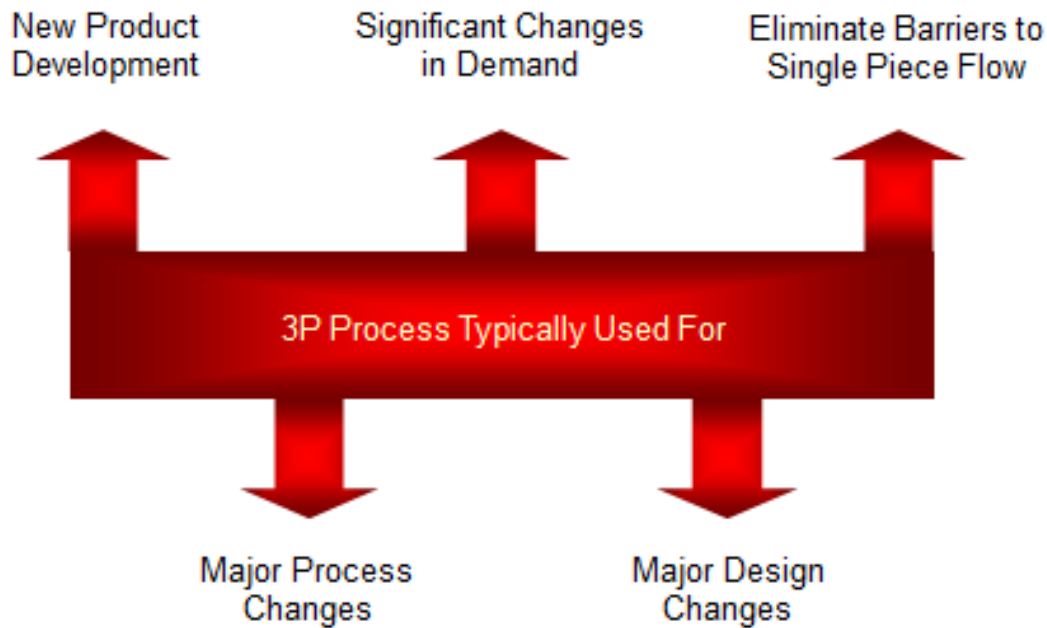


Figure 0-22 3P benefits

The next couple of sections have been dedicated to examining Failure Mode and Effect Analysis (FMEA). Example seen in Figure 2-23. FMEA is a one of the earliest Lean Tools. It was first used in the 1960's in the Aerospace industry during the Apollo missions. Later, the automotive industry saw the advantages of using this tool to reduce risks related to poor quality.

Failure mode is defined as the way in which the component, subassembly, product, input, or process could fail to perform its intended function. Failure modes may be the result of upstream operations or may cause downstream operations to fail. Failure Modes and Effects Analysis is a methodology to evaluate failure modes and their effects in designs and in processes. Benefits of FMEA have been listed below:

- Facilitates process improvement
- Identifies and eliminates concerns early in the development of a process or design
- Improves internal and external customer satisfaction

- Focuses on prevention
- FMEA may be a customer requirement
- FMEA may be required by an applicable Quality System Standard

2.3 Elimination of Non-Value Added Functions in Manufacturing Machining Process

One major tool of lean that Spence in particular has been implementing for this project is 3P. 3P stands for Production Preparation Process. It's defined as a "method for designing products and processes that better meet customers' needs with improved safety, quality, and delivery and at lower total cost." The main time to utilize 3P is during a massive change within a manufacturing facility and to ensure that these changes stay in line with lean thinking. This includes new product developments, major design or process changes, and significant changes in demand (*Butler*). 3P requires significant preparation and planning in the form of a Kaizen so that, as with all things lean, everything is implemented correctly the first time.

2.4 The Seven Types of Non-value Added Functions and Their Recognition

Within the realm of lean manufacturing, waste is referred to as "muda". Muda is a Japanese word meaning "futility; uselessness; idleness; superfluity; waste; wastage; wastefulness"(Kenkyusha). The basis to lean is the removal of wasted potential on the manufacturing floor. In an ideal manufacturing system, all waste is removed and all processes

within the system work at 100% efficiency. Sadly, this is not possible within a real system, but steps can be taken to optimize a facility to reduce waste to negligible levels.

Lean manufacturing itself is based around the mentality that using resources for any goal other than the creation of value for the customer are to be considered wasteful and need to be



removed. Sample waste outline in Figure 2-23. From this point of view, value is defined as services or products that a customer would be willing to pay for. An example of a service that would be considered wasteful is machine setup for any part making job, as the act doesn't directly impact the product, or moving the product from one end of the facility to the other. A common example for the machine shop within Spence is "The only time value is made, is when we are making chips". That is because the only action that is truly impacting the consumer during the machining process is when Spence is cutting into metal to create and define the products the customer asks for. Other value-added-work examples within Spence's other divisions includes the assembling of parts to create the full product, and when the finished parts are painted. But what about this wasted potential? What is considered waste? What kinds of waste are there? The Toyota Production System, the foundation to lean, outlines seven unique forms of waste (Hines). These seven wastes were identified by Shigeo Shingo as part of the Toyota Production System. Those wastes are Transportation, Inventory, Motion, Wait, Over-

processing, Over-Production, Defect (Ohno). A chart displaying the breakdown of each waste can be found in Appendix F. The identification of the waste is just as important as eliminating it. A graphical interpretation of an eliminating waste the lean way can be found in Appendix F.

2.4.2 Transportation

Sample transportation overview is shown in Figure 2-24

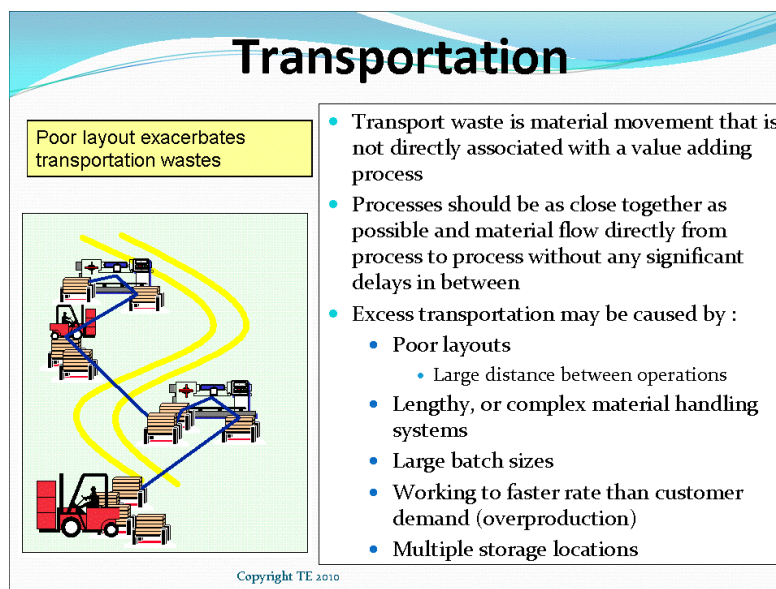


Figure 0-24 - Transportation Waste Overview

Transportation while necessary is a waste to the manufacturing process. Transportation can include the movement of material from one end of the facility to the other. It can be in the form of fork trucks, conveyor systems, or even simply manual movement by hand. Regardless of the movement, all transportation possesses wasted potential and time. The act itself is not a value-added procedure. While it may bring the product to areas where value may be added, the process itself does nothing to enhance its value. In actuality, the transportation of product brings the risk of damage, loss, delay, and etc. As the distance that the product must be transported

increases, the risk of damage increases. Excessive transportation is not isolated to physical product. This waste is also seen in people and information (Hines). Particularly in information we can observe the risk involved in excessively long and complicated transportation. As information is passed along a natural degradation can be seen. The more people and places information passes the greater chance of the information being misinterpreted and damaged, thus changing it from its original intend forever. A change such as this can be particularly risky as a miscommunication in manufacturing can cause huge errors to happen.

2.4.3 Inventory

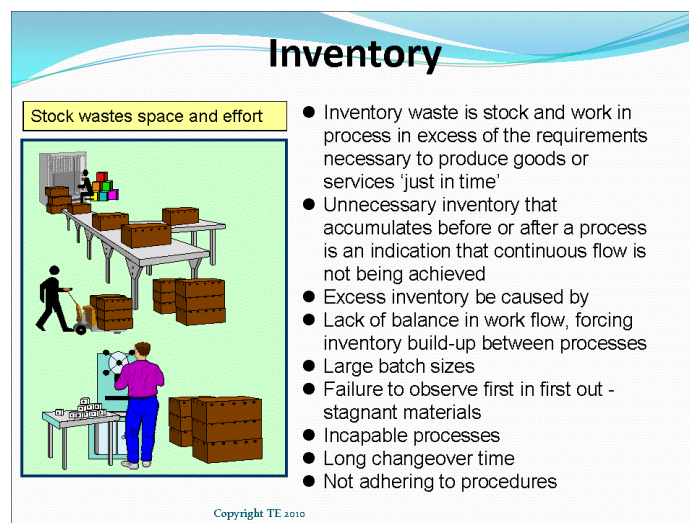


Figure 0-25 - Inventory Waste Overview

Inventory is necessary as making parts on a per order basis can be expensive and difficult to manage. An overview is shown in Figure 2-26. But an excessive inventory can lead to great risk and cost (Hines). Any raw material, Work in Process (WIP) or finished goods which are being stored i.e. no longer having value added to them, thus making inventory a non-value process and classifies it as waste. When merchandise is in storage, its risk for damage and loss increases as time progresses. The longer that the item is held in the company without any worth enhancing measures are done to it, it simply burns money. A large inventory, as seen in Figure 2-25, also takes up valuable facility space unnecessarily. This space can be used to enhance the company's business through a multitude of means. New value streams could be added, new value-adding processes could be based within the space of the current inventory area. The dead



Figure 0-26 - Example of Excessive Inventory

space of inventory has some of the greatest potential as the space it inhabits can be remodeled for anything else. As excess inventory is reduced, the potential for expansion increases, while risk is reduced with the inventory.

2.4.4 Over Production

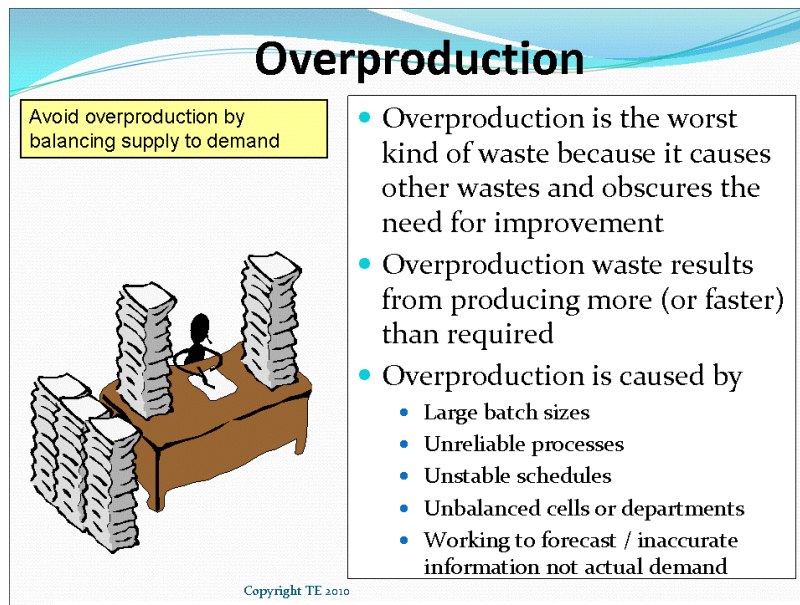


Figure 0-27 - Over Production Overview

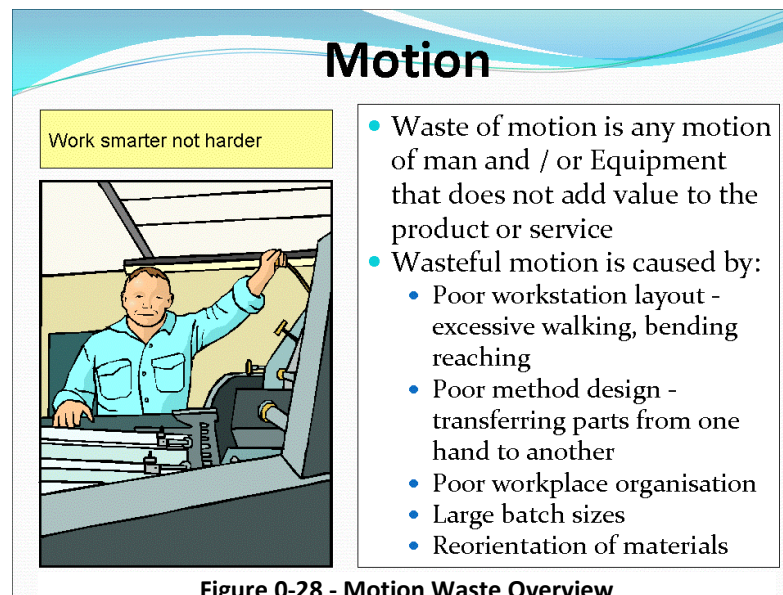
Over production, as seen in Figure 2-27, ties in closely to excessive inventory levels. Over production happens when goods are produced too quickly or in too large of batches. It results in poor flow of goods or information and excessive inventory (Hines). Over production is a major form of waste and one of the main items lean manufacturing tries to combat. When producing not to customer demand, you are taking a massive gamble and utilizing valuable resources to produce items that have no definitive sale. The potential for profit is decreased as these items then go into inventory indefinitely. Over production feeds the waste that is inventory, it is one of the major contributors to excessive inventory. Over production is in many eyes viewed as the worst of the seven types of wastes as it has the potential to hide other waste.

The over production of items has been ingrained into American manufacturing over the years. This is due to large batch production being the norm in the past. There is also a general

distrust of suppliers of materials, so many companies will purchase more material than they need and sooner than they need it, which results in over production (Seven Wastes).

2.4.5 Motion

Motion, as seen in Figure 2-28, waste encompasses all motions done that add no value.



Motion waste is usually associated with poor work efficiency. An example is of brick layers who have to pick up a brick from ground level to the level they must lay the brick. It has been seen that bringing said brick up to the level of the worker will have efficiency increase significantly. If workers are spending time lifting, searching, retrieving, rather than cutting and assembling, efficiency is greatly lowered (Seven Wastes).

The cause of motion waste is usually due to poor cell layout. Having the necessary items to build and assemble being scattered about one's cell or worse, outside of one's cell, brings the need for the worker to move around unnecessarily. The old mantra of "work smarter, not harder"

is the basis for motion waste. By working smarter, one would not need to move around so much and expend the extra energy to complete a simple task.

Motion waste can be reduced by create better cell organization and flow. With increased organization, workers won't have to search and hunt for the necessary tools and parts to complete their job. And improved flow will make the actions necessary to the job quicker and easier, thus increasing efficiency and greatly reducing motion waste.

2.4.6 Waiting

Waiting, as seen in Figure 2-29, is one of the most basic of the seven wastes. Waiting is the act of doing nothing or working slowly, while waiting for a previous process to finish. Waiting can have serious financial impacts as employees are being paid to do nothing that adds value or

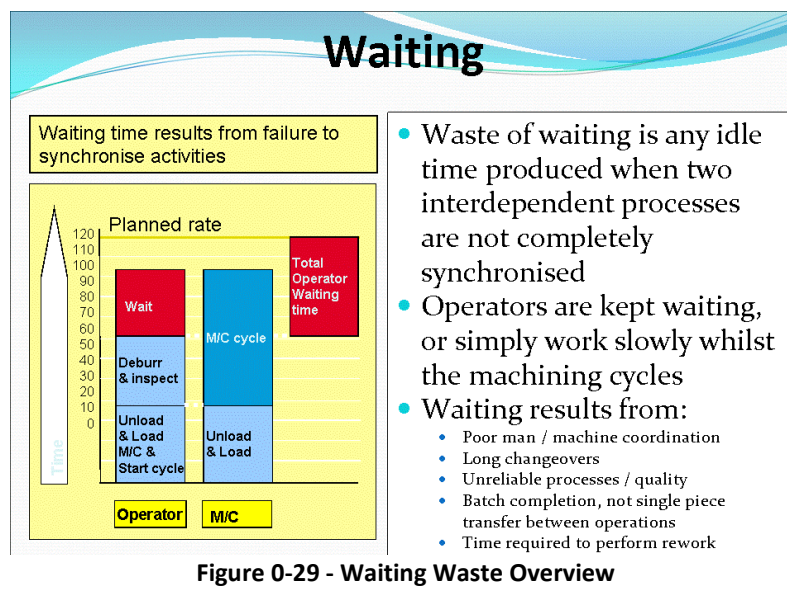


Figure 0-29 - Waiting Waste Overview

reduces a potential waste in the facility. Waiting is not something that your customer is going to want to pay for, the cost of the time spent waiting will come direct from your profit, for every penny you can save it is a penny put straight back into your profit. Often the time spent waiting

is made up later during overtime at a premium rate, good for your employees but not so good for your profit. (Seven Wastes).

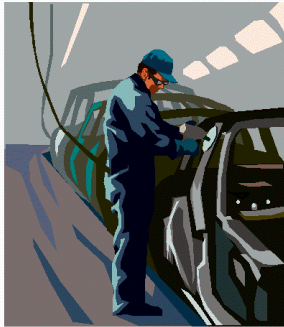
Unbalanced processes are a cause of waiting. If one process takes longer than the next then workers and operators will be idle. Unreliable processes also are causes for waiting. If a process is known to break down or have variable times, then waiting will occur and cause time to be wasted. Lack of information can also cause waiting, either through unclear or missing information to conduct an operation or even through waiting to know which product is required to be run next (Seven Wastes).

Waiting waste can be reduced by balancing takt time and matching cycle times so that while one operation is happening another may be completed. Also improving machine reliability and quality will help stabilize time and thus be able to track time better and reduce wait.

2.4.7 Over Process

Over-processing

Clear, standardised instructions
avoid over-processing



- Over processing is putting more into the product than is valued by the customer,
 - painting of unseen areas
 - unnecessarily tight tolerances
 - cleaning and polishing beyond the level required
- The goal is to do only the level of processing to match that which is useful and necessary
- Over-processing is caused by:
 - No standardisation of best techniques
 - Unclear specification / quality acceptance standards

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Figure 0-30 - Over Process Waste Overview

Over process, as seen in Figure 2-30, is a one of the main seven wastes of lean manufacturing. Over process refers to the adding of value to a product that the customer doesn't actually require. An example of this is painting a part that will never be seen or will not be exposed to corrosion (Seven Wastes). By adding work that is not required, over processing costs you money with regards to the time of your staff, the materials used and the wear on your equipment. These costs can amount to a considerable sum over a period of time; they will also reduce your efficiencies as the operators that are over processing could be performing other value adding tasks that the customer is willing to pay you for (Seven Wastes).

Over process waste is usually due to poor or unclear standards and specifications. Operator will not know what actually adds value to a product, so they may over process a part in order to be sure everything necessary is completed. Another issue is the one of non-standardized working practices; unless you have standardized working then you will have differences in methods between different shifts and different people. The most common issue is to do with design, often designers specify tolerances that require precision machining when in reality looser tolerances that could be produced by significantly less expensive methods could be employed (Seven Wastes). This goes to show that over process waste can come from a variety of sources, mainly due to workers who only want to make sure that their work is complete.

2.4.8 Defect

The final waste of the main seven wastes is Defect Waste, as seen in Figure 2-31. It is the waste that is most clearly illustrated. A defect is when a product or service deviates in a negative

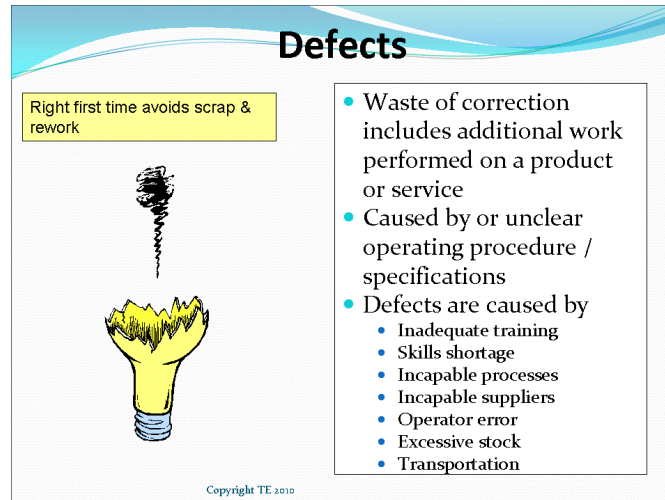


Figure 0-31 - Defect Waste Overview

fashion from what the customer specified.

The cause of defects can stem from many different places. Many are avoidable, while some are not. Many times defects are caused by incorrect methods due to non-standard operations. An example is the same process done multiple times in different ways across different shifts. Defects can also occur from poor planning in terms of design of the actual product and not keeping in mind the assembly of said product. Defects also arise if we reward the fastest part producers, or punish people who don't make their "numbers" (Seven Wastes). Such pressure for quantity over quality will eventually result in defects.

Finding the source of defects can be difficult, but to truly be a lean manufacturing facility it is necessary. This is due to defects are one of the most needed wastes to completely eliminate.

As defects directly result in lost product and profit. There are no salvaging defects, if they happen often, profits will fall greatly.

2.5 Unofficial Wastes of Lean

While the seven wastes are the main wastes involved in lean manufacturing, through the years several other wastes have come to be. The two we would like to discuss are resources and creativity (Seven Wastes). Both these wastes should not be overlooked because they both have massive factors to overall efficiency of a facility.

2.5.2 Resources

Resource waste is includes heat, light, etc. in a non-useful way. This is a massive waste is a large amount of facilities. A very good example of this is lighting an entire facility when only half of it is in use at the time. Because the light is not being utilized, it is simply wasting money on lighting an unused area and thus wasting money.

This particular waste can be fixed rather easily. By utilizing different types of personnel sensors throughout one's facility, one may be able to distribute resources only to areas that require them. A perfect example of this would be motion sensing lights. This way lights are only activated when personnel are in that select area. Once workers are no longer in that area, the lights shut off and the resource is saved. This saved resource then in turns save money for the company.

2.5.3 Creativity

The final unofficial waste is creativity, seen in Figure 2-32. This waste involves the

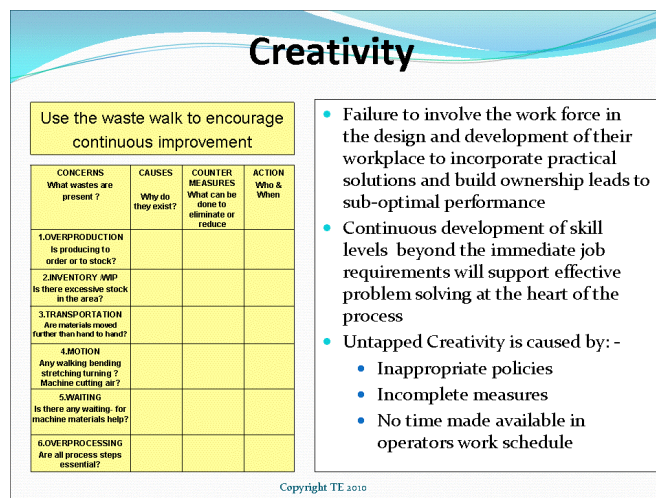


Figure 0-32 - Creativity Waste Overview

failure to make good use of all of your employees. They are the most valuable resources in terms of keeping the company running smoothly. Without the involvement and loyalty of all of your employees your company will fail to compete as effectively as it could do with their help. In today's global marketplace we need every advantage that we can get to maintain and improve our businesses (Seven Wastes).

Creativity can be wasted by not utilizing the individual strengths. By simply having employees blindly follow instructions and managers blindly managing, you can never learn about your company's hidden potential that is one's employees. This problem may be overcome by allowing all employees test their skills by problem solving. Seeing who is good at what. By creating team work, you will be able to observe your employee's strengths and see what roles they naturally migrate to.

Chapter 3: CIRCOR Lean Manufacturing System Dynamics

3. Introduction

During this section, the system of methods utilized to successfully complete this project was established. As the flow chart in Figure 3.1 demonstrates, a plan was followed. Initially, the Pre-Qualifying Project (PQP) provided time for the group to be well prepared to address possible solutions and future obstacles. Once at the company, the work done to address the problems presented was discussed with the sponsor company in order to be pointed in the right direction in terms of solutions.

Based on the instructions provided by Spence Engineering Co., the group worked on the tasks assigned to make progress towards the desired goal. By this time the group was able to get caught up on what previous summer students had done, along with how the machine shop operated at that moment. Furthermore, it was necessary to plan a visit to the company in order to have an insight on how the machines themselves operated, and how the plant looked in person rather than on paper. There was constant communication with Spence during these seven weeks, along with weekly meetings in order to interchange ideas, and for progress reports.

After completing the machine sort and then being able to view the machines and plant in person the group smoothly proceeded to the next steps. The prints were sorted by regulator vs. non regulator and by features with a future state layout of the machine shop in mind. The machine capacity analysis was then begun in preparation for the Major Qualifying Project on site at Walden, NY. A PQP flow chart is shown in figure 3.1, along with a Gantt chart of the project in Figure 3.2.

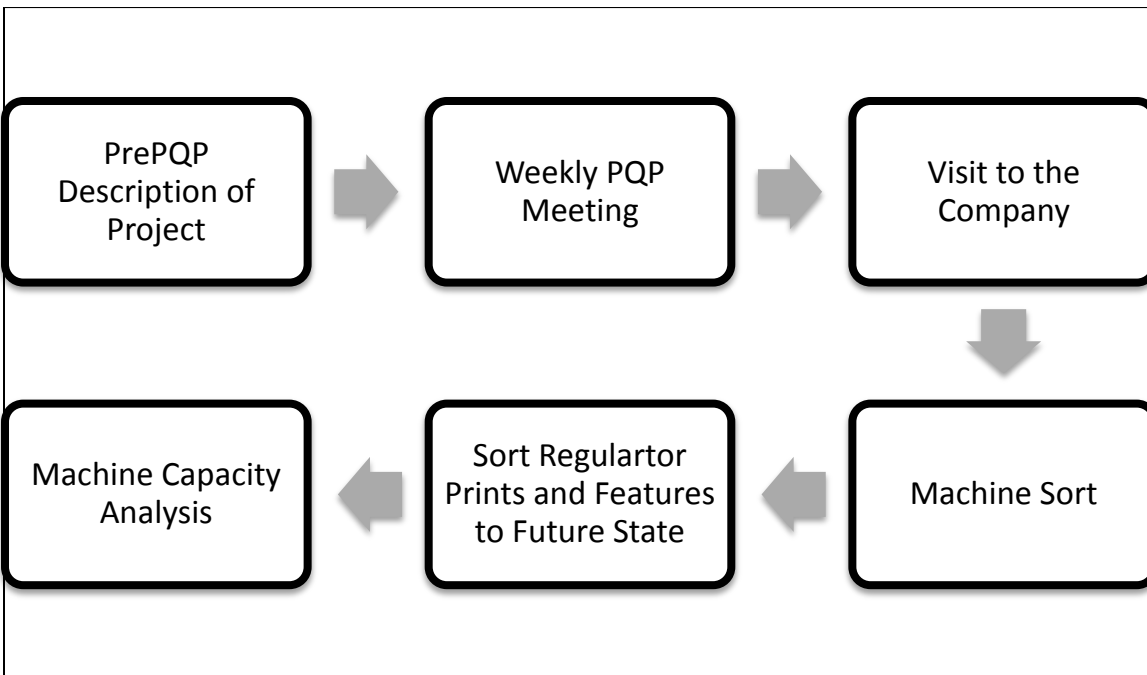


Figure 3-1 PQP Flowchart

CIRCOR ACTION PLAN								
Improvement Priority		Mgmt. Owner:						
Drive CBS to Implement Spence Value Stream Regulator Model Line		Andrew Cervoni						
Linked TTI	1 - Improve Regulator LT on runner product from 12.7 days to 5 days LT by 10Y12013 2 - Improve OTD % measured at time of miss to original ship date on regulator runner product from 63.6% to 95% by 10Y12013 3 - Improve gross margin on regulator product from 40.7% to 42.9% full year by 12/31/2013		Support Team:		Ed Hallenbeck	Tim Quinn	Tony Snyder	
Current Situation Summary:		VSM			ME		CIM	
Work pieces assigned to machines based on machine availability instead of facilitating changeover reduction and value stream alignment								
#	Action Step/ Kaizen Events	Owner(s)	WK 1 (1/13-19)	WK 2 (1/20-26)	WK 3 (1/27-2/2)	WK 4 (2/3-9)	WK 5 (2/10-16)	WK 6 (2/17-23)
1	Visit WPI, Assign hw.	AC, EH, TO	□					
2	Collect visitor's packages, Schedule student on site visit	AC, EH	○	□				
3	Students visit Spence facility, present 140127 assignment results, learn machine tools	Andrew	○	□				
4	Machine sort by capability & size, identify Regulator machines	Team		○	□			
5	Sort Regulator prints by features & size w/ respect to future machine center	Team		○	○	□		
6	Machine capacity analysis	Team				○	□	
7	Check and adjust routings based on machine capacity analysis	Andrew					○	□
8	Develop tool packs	Team					○	○
□ = On Schedule ◻ = At Risk ◻ = Behind Schedule ○ = Start (lower case "M") ● = Activity in Month (lower case "L") ◊ = Milestone (lower case "U") ◻ = Completion (lower case "P")								
Note: Font Type Wingding for all symbols								

Figure 3-2 Project Gantt Chart

After completing the PQP, seven weeks were spent at Spence to complete the project. Immediately after arriving at Spence the group was part of a Kaizen event in order to apply the

analysis that was done during the PQP, to the ideas and proposals the rest of the company had been working on. The goal of the event was to create a pitch of the future or a proposed layout of the plant along with specifics and numerical data to back it up. After obtaining a proposed layout for the machine shop the group measured machines and cabinets in the shop and created a 3D model of the proposed plant layout. All data needed was then to be documented electronically for bookkeeping, and organization. After confirming that components were planned to be routed to most efficient machine tools for manufacturing in the future layout, the team documented these routings. A documentation system was set up for tools in work station as well as for job set ups. A sample flowchart for the MQP portion of the project is shown in Figure 3.3.

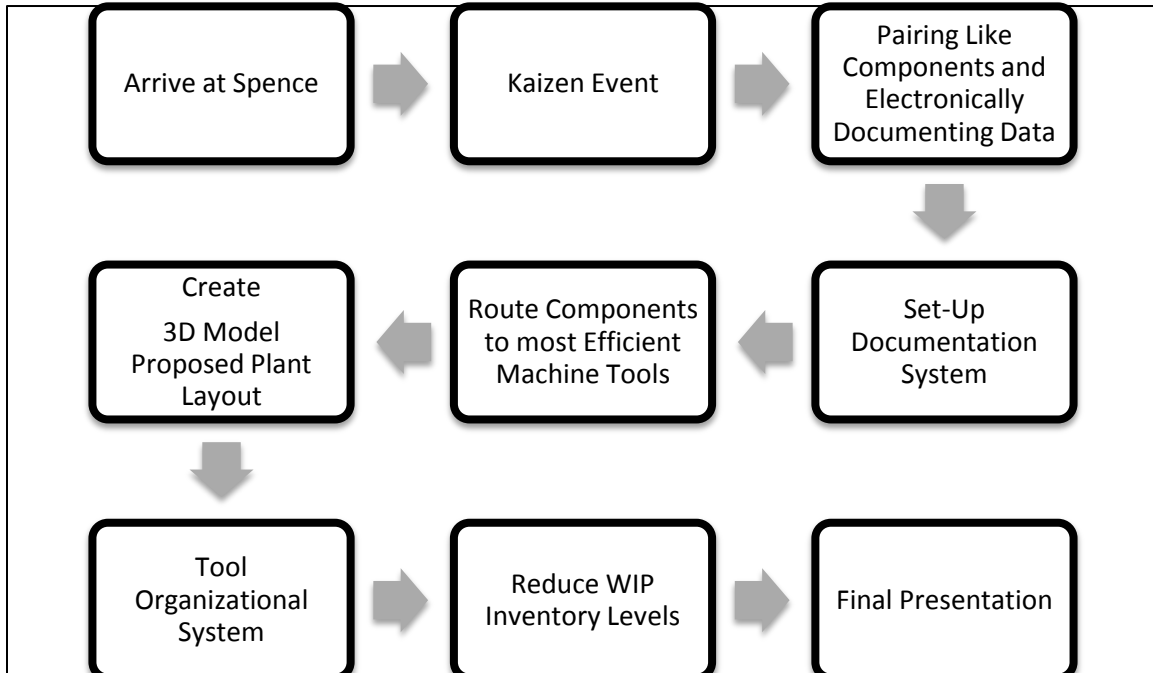


Figure 3-3 MQP Flowchart

3.1 Results

Throughout this project, the MQP group was able to learn a lot of things. It not only got to experience what the business culture was like, but was also able to master new technical skills. Aided with the communication and mentoring from the staff at Spence, the group refined its skills in order to provide the desired results. It toned its CAD skills and expanded the CAD software programs when taking ideas to computer. One of the abilities that it was able to improve the most was the ability to work with others and presenting ideas. This was done through various meetings, networking and presentations to shop floor employees as well as others.

As part of the nature of the project a lot of the education was geared towards lean manufacturing. From events like Kaizen, to daily learning about how to implement the project in lean ways, led to the broadening of wisdom in the area.

Throughout the progress of the project the group had to brainstorm constantly in the search for an innovative idea. As with most things in a group environment, ideas were flying along with counterproposals and a balance needed to be found such that every part of the group could be ok with the proposal. Every step had to be taken keeping in mind that nothing was set in stone other than the fact that the focus of the project was to lean out the plant in order to allow for expansion. A good example of this is the “final” proposed layout, shown in Figure 3-4, which is by no means final, but is a finalist.

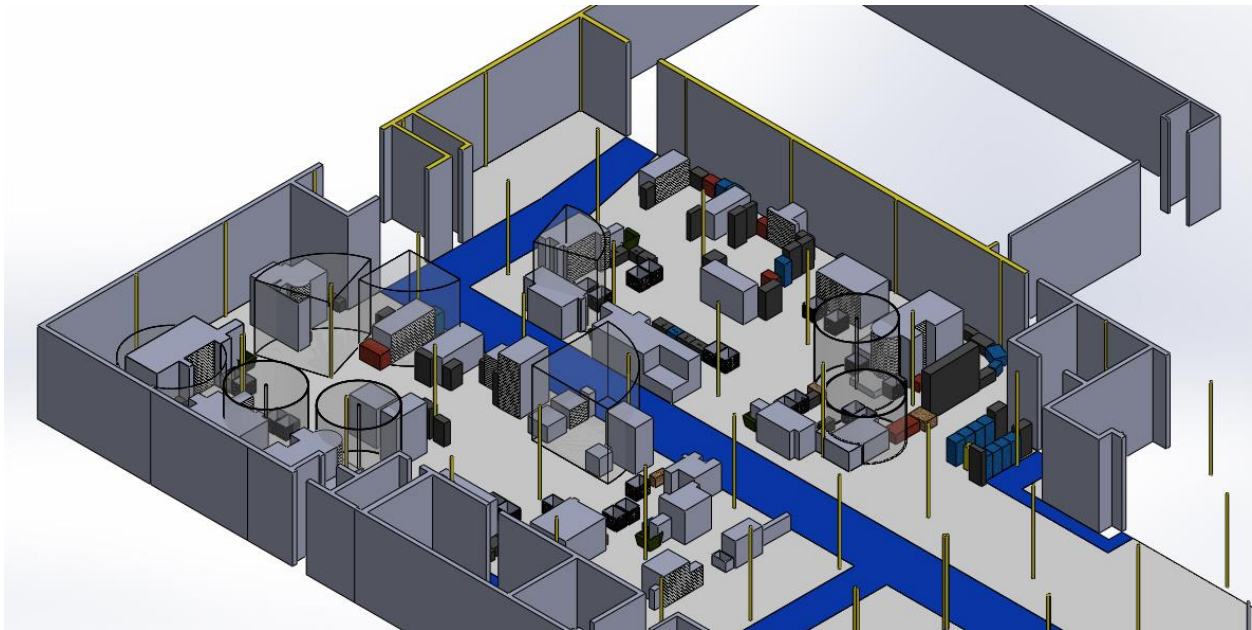


Figure 3-4 Proposed Machine Shop Layout 3D Model

Figure 3-4 is an isometric view of the proposed shop layout a Top down view of the machine shop can be found in Appendix G as well as a detailed machine drawing of the layout. The layout itself is divided into two super cells. The upper super cell holds the non-regulator line, while the lower super cell holds the regulator line. The proposed layout would break down the previous “silos” within the machine shop. What does this mean? It means there is less ability for operators to hide behind their machines. It also means that one lead man per cell may be able to stand in the center of the cell and exactly know how the operations are going and be able to visually see if there is any problem spots. The whole floor space is opened up to bring a sense of teamwork to the floor, and allow everyone to be responsible for their work.

Throughout the Kaizen event the 3P process was utilized to come up with proposed layout of the machine shop. The result of this was a proposal that would save around 12,000 sq. ft. of shop floor for expansion. This in itself is great for the company’s future as it opens doors for opportunities. In addition, after the use of the data acquired during the PQP for pairing of like

components, and routes, the flow throughout the plant is expected to greatly improve. The layout would not only save floor space, but it would also aid in improve flow through the plant. For example the current state for the D-Pilot is 9,126ft and the future state is predicted to be 7,421ft. In addition, the project aided in the achievement of opening up about 20,000 sq. ft. of floor space.

The WIP inventory levels are very important to the company. In a perfect world you want to have one piece flow. However, we do not live in a perfect world, so we have WIP inventory. This inventory is risk to the company; it takes away floor space for possible expansion of product line, the company risks not selling the parts they have in the inventory, and large batches mean that if there is an initial problem with a part, more will have to be scrapped. By reducing a key factor (set-up time) the WIP inventory can be greatly reduced. By reducing the set-up time it allows you to get closer to one-piece flow, and reduce the need to keep large inventory. This allows for great opportunity to grow.

After the documentation of data, and having a base for the layout a more detailed focus towards specific work center was applied. Inventory was noted and documented for work centers. Then, by taking the new part routings a new documentation was created to keep track of what additional tools would be required to perform these jobs on their new homes. With this the machines turrets were analyzed in order to reduce set up time. This on itself will be of great benefit to the manufacturing process. Once a set up was achieved with the desired goal it was documented. Also, a new set up sheet documentation was created to improve intuitivism on the set up sheets. Set-up sheet format was prepared keeping in mind two basic guidelines. First, any sheet must be intuitive for all machinists since the same part in the same machine could be run

by two different machinists. This was achieved by using one standard format with shop floor-wide color codes and simple one-dimensional flow through the entire sheet. For example, a 'comment' section was added to each field for tool-holding positions for further clarification in case a change is made at a later date or vital information is overlooked during the creation of part-specific set-up sheets. Secondly, the sheets were prepared with an idea to have flexibility for one or two lead operators to edit them on the fly. This was achieved with the addition of two 'hidden' extra sheets which contains a variety of options and acts as alternatives for their counterparts on the main set-up sheet itself, see Appendix C for an example set-up sheet. With this, the lead operators can go and select the precise option and switch out the faulty one and save it on the main server. In a matter of minutes, the entire shop floor and all the machinists now see the rectified version. Then a tool organization system was also set up in order to make things run smoother and allow for better tracking of tools. These processes were achieved with constant interaction with work center operators for proper feedback and corrections.

A lot of ideas that go into lean manufacturing are aimed at the changing of work-place culture. The proposed machine shop floor layout and the tool system organization combined with the new set-up sheet documentation will bring about a change in the Spence shop culture. There would be greater accountability. Instead of having silos of machine (and their operators) in small patches spread across the entire shop floor, the new layout ensures a more open and even machine spread. Communication between machinists would be enhanced and operators would gradually make the shop floor self-sustaining. The lead men in the Shop would have wide visibility and would be able to attend to issues with any work-center in less time than the current situation. Reliance on engineers and managers for simple tasks will slowly fade away and productivity would be increased.

As a result of the project a reduction in WIP inventory level was to be achieved. The current state routings were set up in an as available basis, if a machine had time available at that moment that's where the part would go. This set up left much to be desired. The result of our project was to establish a foundation for improvement, which was achieved by the sorting of machine and parts by like features, new floor layout, change in shop work culture, as well as document standardization. This foundation will give the machine shop the groundwork needed for it to be SMED (Single-Minute Exchange of Die). In the following pictures we can see examples of how the flow has improved in the proposed layout, Figure 3-5 and 3-6. In Appendix B more pictures can be found to better show the improvements from the current state.

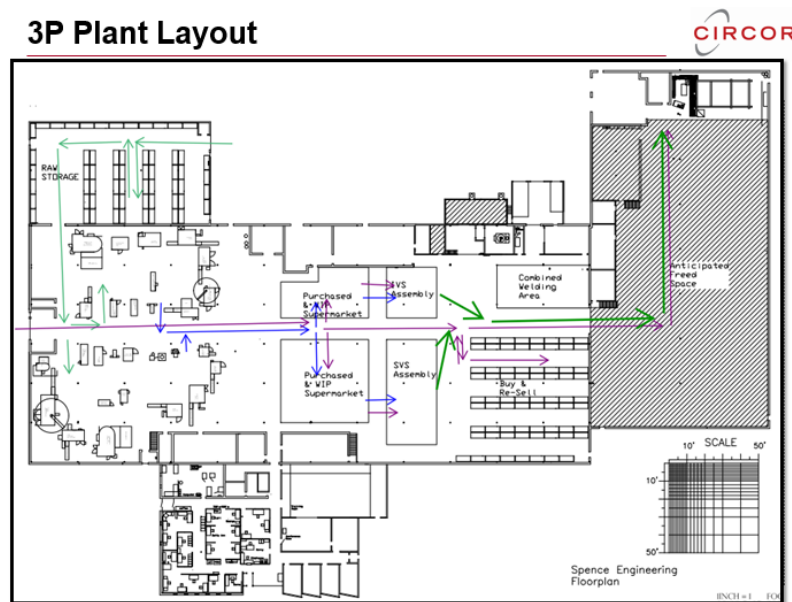


Figure 3-5 Plant Routings

PQPR – future state visual routing

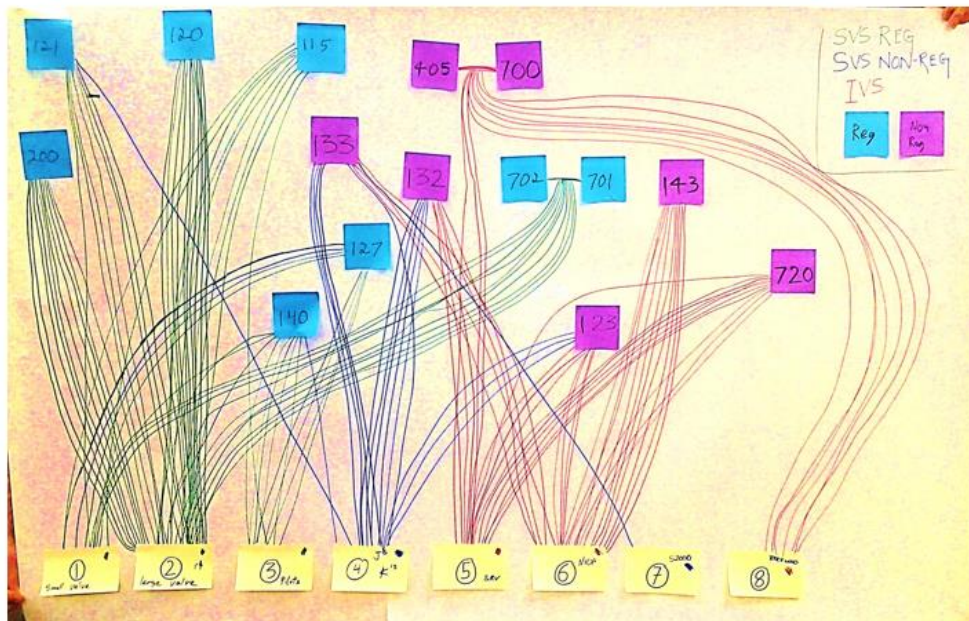


Figure 3-6 Future State Routings by Machine

CHAPTER 4: Conclusions

The project introduced the group members to the daily functioning of a manufacturing facility. This experience was crucial in understanding the importance of our results as compared to work done for academic purposes. This report and all its recommendations for future-state machine shop re-organization were derived from actual data obtained from the company. Likewise, the results can be directly applied when and as needed with minimal or no modifications required because of 'real-time' analysis by the MQP group members.

To demonstrate the movement of a part within our proposed system, we will be using a 8 inch pinion from the Morgan No-Twist mills. The part specifications were found in Mr. Dailida's Master Thesis. This part's specifications can be seen in Figure 4-1 (Dailida). The reasoning for these parts is so we can demonstrate with a tangle model how a part may flow through our proposed system.

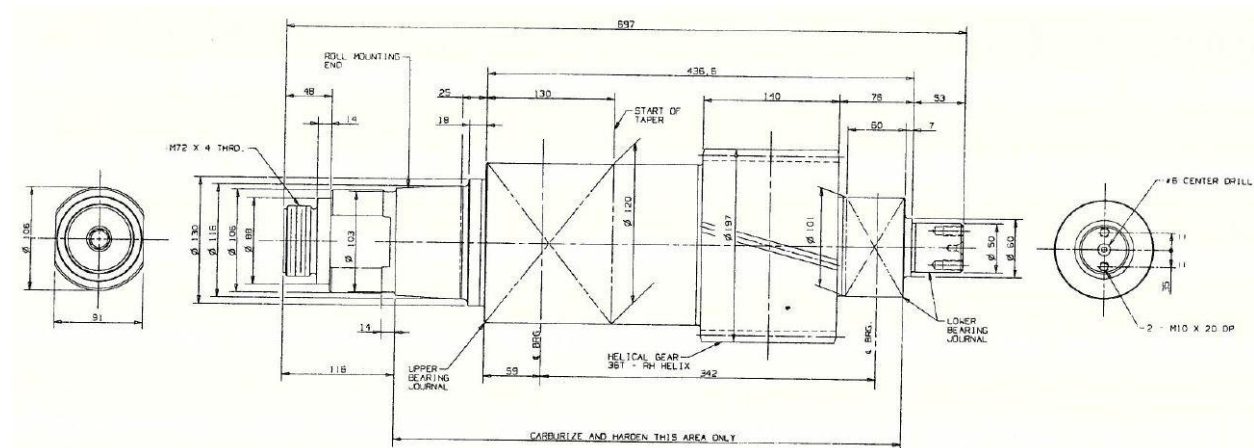


Figure 4-1 - Pinion Machine Drawing (Note: NOT SPENCE PART)

The part information is first brought to the operator along with the necessary raw material. In the example of the pinion the raw material would be 8" bar stock. This initial

information packet includes the the batch information, drawing, and other relevant starting information. Using the part number obtained from the initial packet the operator then pulls up the parts setup sheet. an example of a sheet up sheet can again be found in Appendix C Set- Up Sheets. By utilizing this standardized setup sheet the operator will then setup the CNC mill to the necessary specifications of the part in order to come off complete. In the example of the pinion, which due to its non-symmetrical geometry, would require a lathe that has live tooling capabilities. Due to the plans we setup, the lathe would already be configured with that this part in mind and thus have set turret positions for each tool type the pinion requires. Using the standardized setup sheet, the operator is easily and quickly able to setup the machine and then runs the programs. Once the program finishes, the part will then come off the machine complete and ready for assembly of the Morgan No-Twist mill. An image of this completed part may be found below in Figure 4-2.

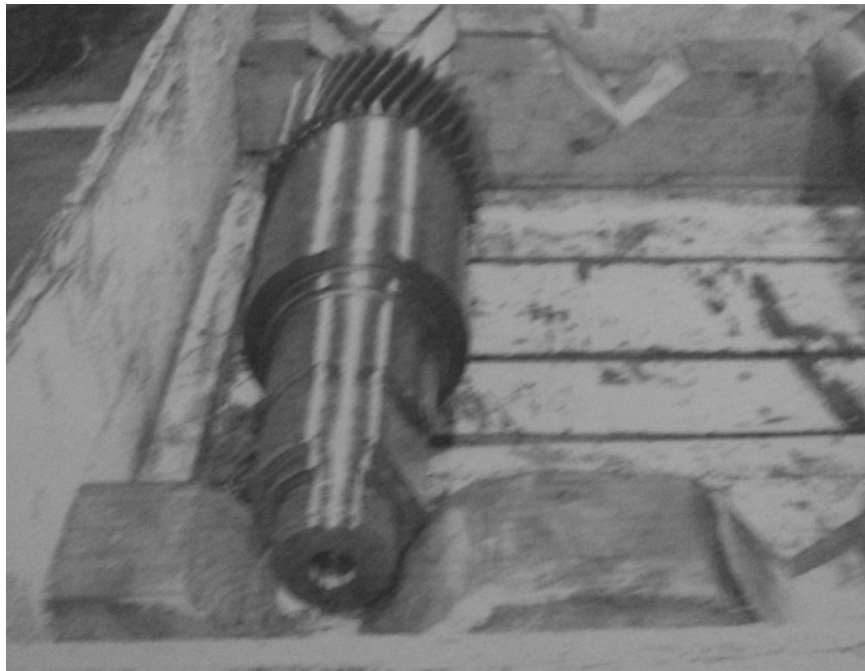


Figure 4-2 - Completed Pinion (Note: NOT SPENCE PART)

During the process if the machinist found any changes to the setup necessary to machine finished or to improve the efficiency of the machining, they will add changes on the fly to the online setup sheet. These changes will then be reflected shop-wide for this parts setup. Figure 4-3 demonstrates this process in a step-by-step fashion. This chart can be used as a general guide for both operators and managers so that they may see if the correct flow and process is happening. This allows for errors to be more quickly found within the process.

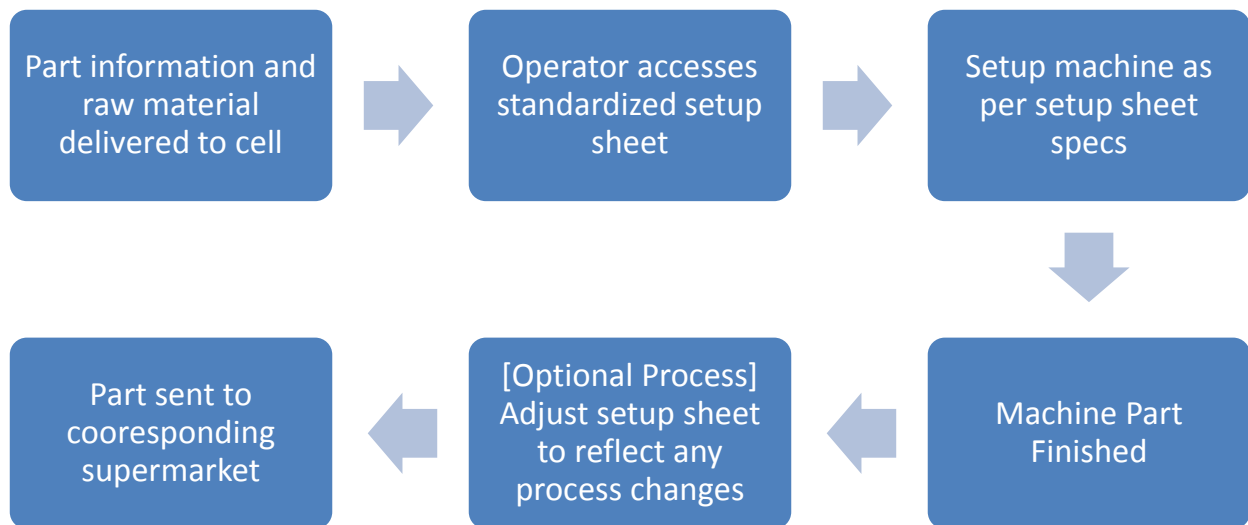


Figure 4-3 - Proposed System Check List

After our initial recommended system is fully implemented into Spence's machine shop, a further possible extended future state model would involve creating automated systems on the shop floor to enhance predictability and efficiency, while lowering risk. A simple mock work cell layout can be found within Figure 4-4 below.

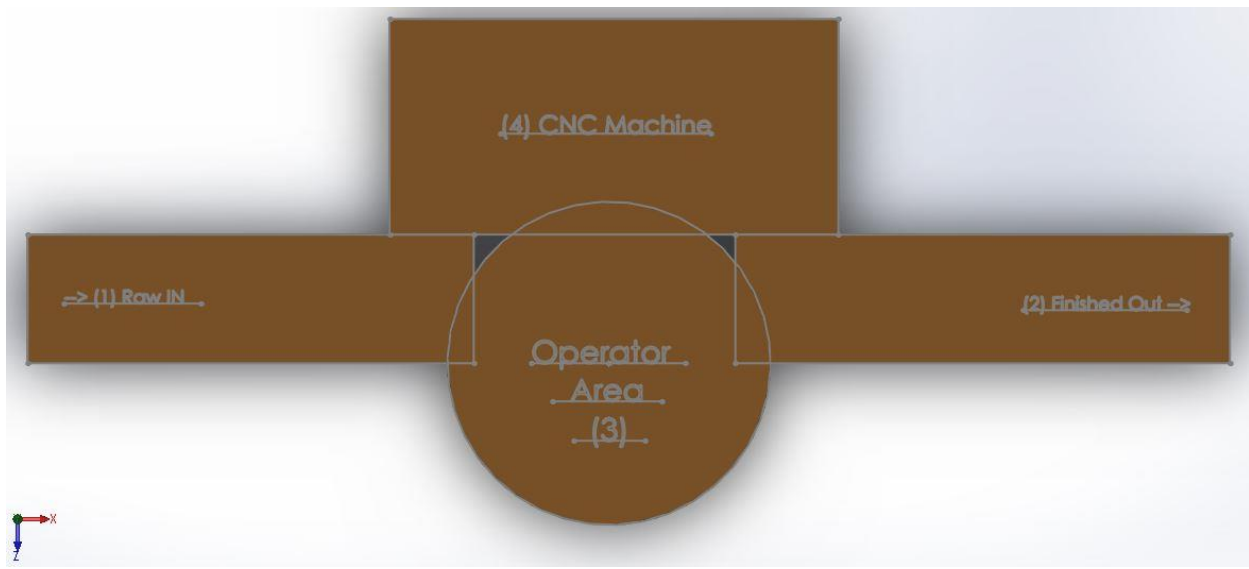


Figure 4-4 - Extended Future State Work Cell

Areas 1 and 2 represent conveyor systems; area 3 represents the maximum working zone, while area 4 shows the CNC machine of the work cell. The logic behind this that the raw material would be delivered to operator via conveyor system (Area 1) and then machined finished and then put onto the Area 2 conveyor system, which would then deliver it to assembly.

This proposed system would reduce the several key wastes. It would reduce wait as constant supply of material is being delivered to the operator. Additionally a second machine could be placed behind the operator and have the conveyor deliver material asynchronously to the cell. This way while the first machine is running, the operator may work on the second machine. This also makes the delivery of raw and finished parts more predictable and lowers the risk. It also would lower travel and movement waste. As the conveyor systems require smaller avenues of movement the necessary space to move raw and finished parts will be less and thus cell can be closer together. Due to everything being moved closer, travel waste will be lowered.

Movement waste is lowered as the conveyor system is within arm's reach for the operator meaning he won't be making any unnecessary movements.

As rewarding as the experience was, there were both constraints and shortcomings. Due to a short 7-week period for on-site project completion, detailed analysis of shop resources could not be done extensively. The group however does not foresee that to be a significant issue since the major elements have been thoroughly examined and similar principles can be extended on to the ones left out for this project. The availability of more digital resources rather than hand-written operator notes could also have helped in expedited planning and scrutiny. Seen in Figure 4-1, is a plot of the improvement in reduction of non-value added.

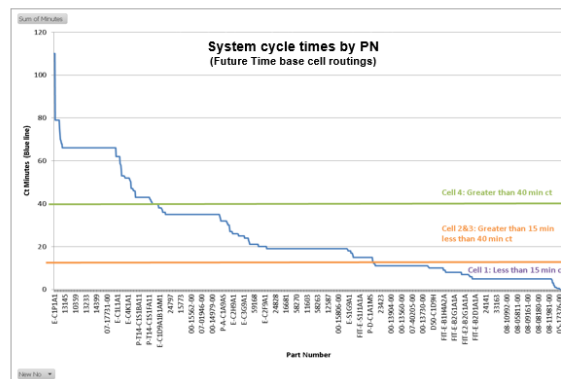


Figure 4-5 Improvement in Reduction of Non-Value Added

In conclusion, the MQP group from the very beginning strived to create an overall system which Spence could utilize as a foundation for future modifications in their shop floor. Although the group focused on singular issues and proposed resolutions, the main idea was to develop a framework in keeping with the company's growth plans. As seen in Figure 4-1, the improvements achieved.

Current state vs. Future State

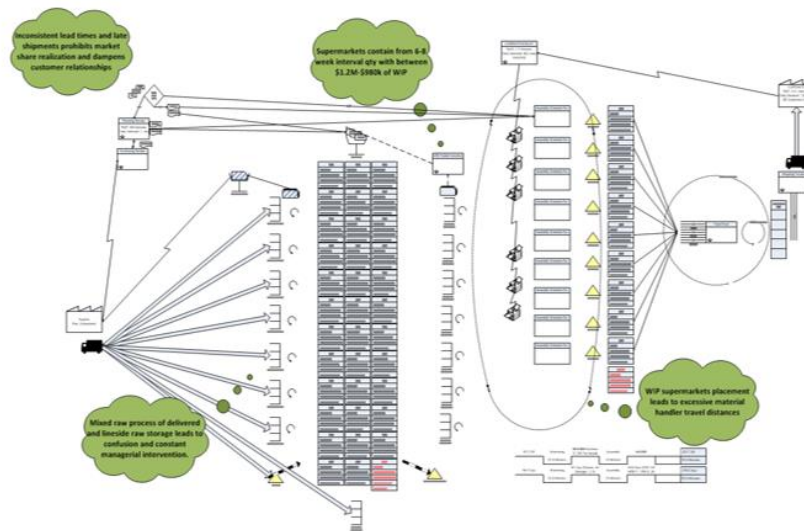


Figure 4-6 Current VS Future

The communication between the project members and Spence Engineering was fantastic and invaluable. Constant advice from the engineering team blended well with machine specific operator interactions to enhance the effectiveness of the recommendations proposed in this report.

The group is extremely pleased with the project results and hopes that Spence Engineering sees this as a joint venture with WPI in the coming years.

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Appendix A: Spence History

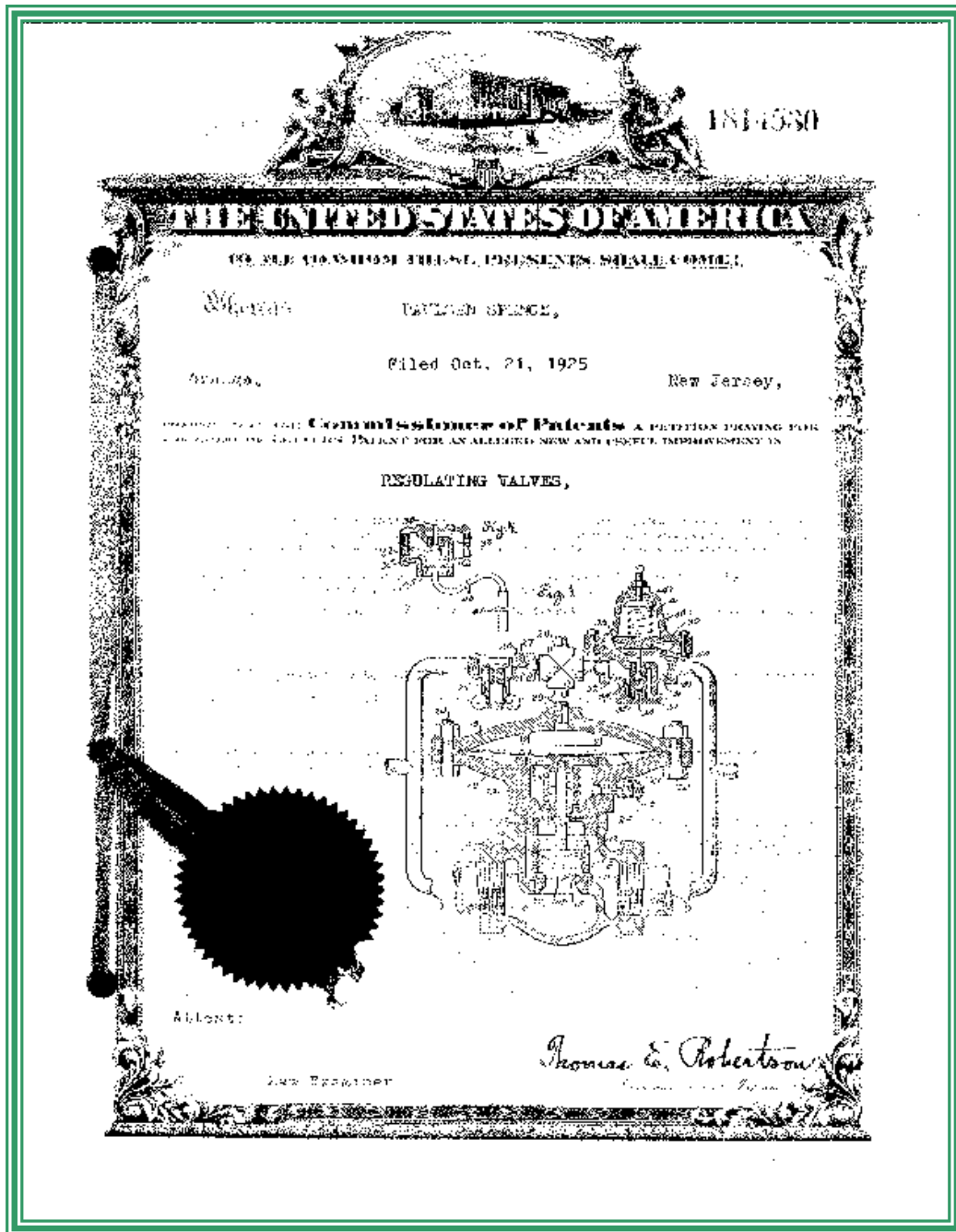


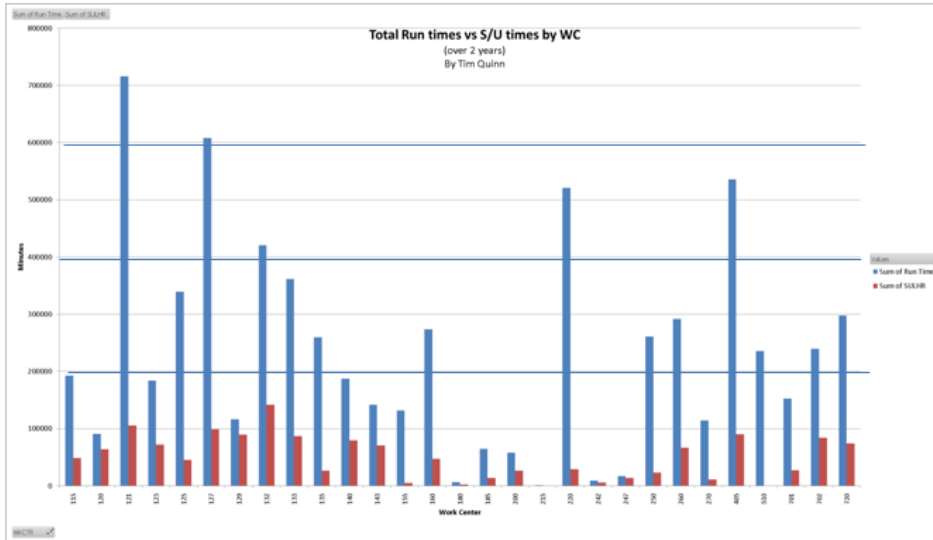
Figure 6-1 Paulsen Patent for ED pilot regulator



Figure 6-2 The CIRCOR family of Companies

Appendix B: Product Family Analysis

Step 2: Product Family Analysis

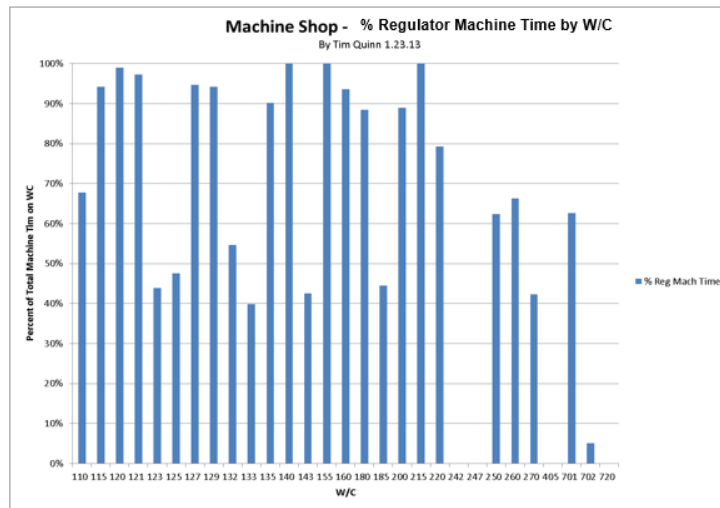


From File "Machine Shop Reg and All.xlsx" Tab "Run SU"
 This is for all parts in the machine shop NOT just regulator
 These are the preliminary steps of the PQPR

16

Figure 7-1 Product Family Analysis

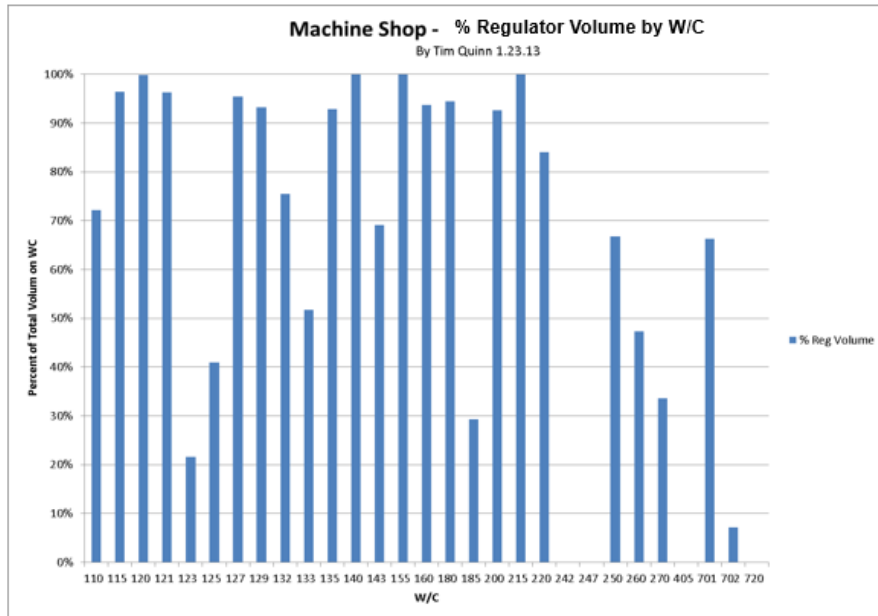
Step 2: Product Family Analysis



From File "Machine Shop Reg and All.xlsx" Tab "Reg by Time"
 These are the preliminary steps of the PQPR

Figure 7-2 Product Family Analysis

Step 2: Product Family Analysis



From File "Machine Shop Reg and All.xlsx" Tab "Reg by Volume"
These are the preliminary steps of the PQPR

Figure 7-3 Product Family Analysis Regulator Volume by W/C

Current state vs. Future State

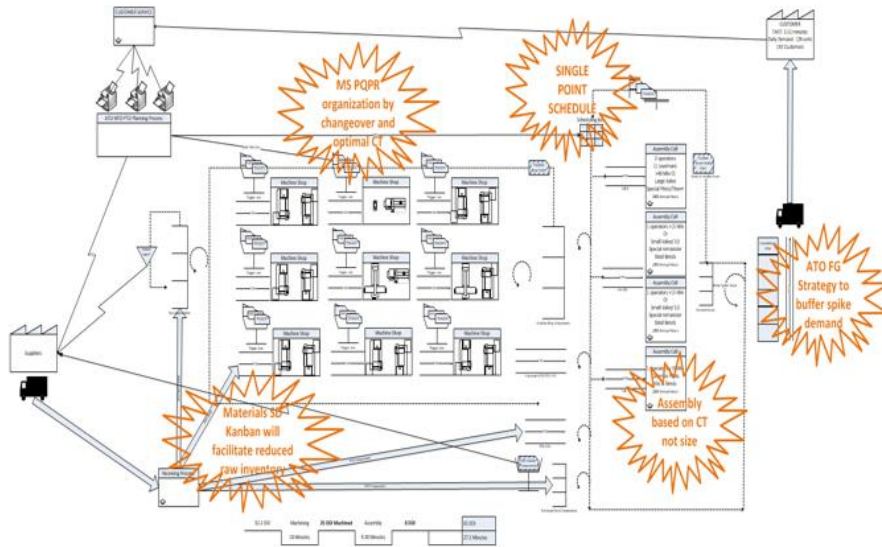


Figure 7-4 Current State vs. Future State

Current state

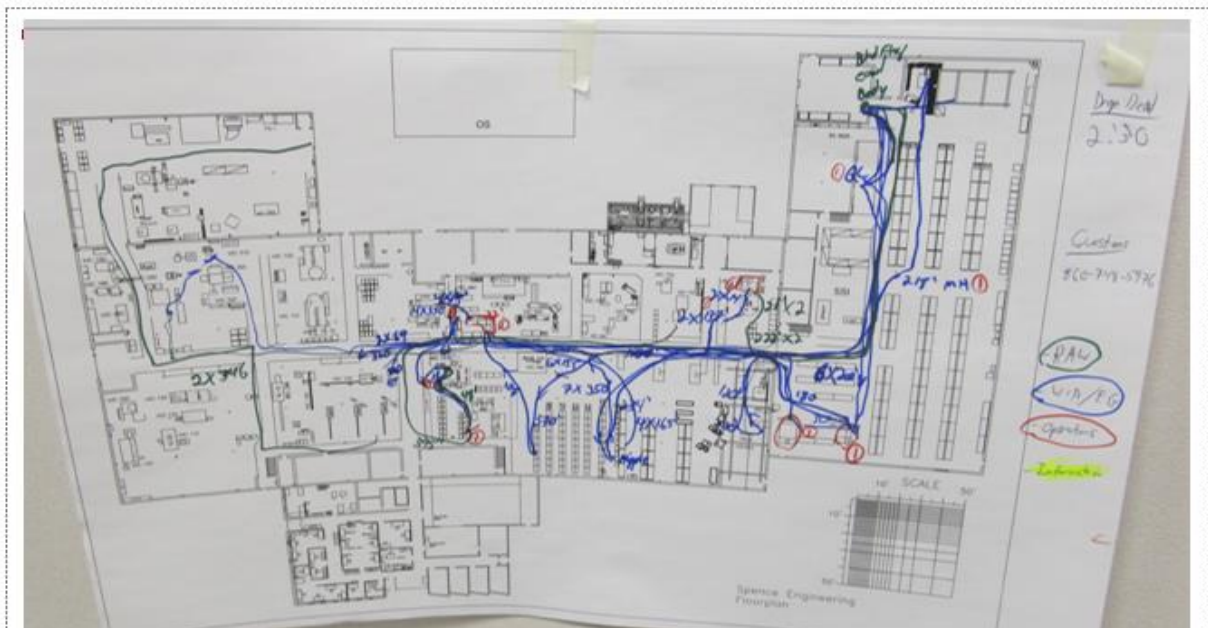


Figure 7-5 Current Plant Layout

V. Implementation Plan														
Action Step/Kaizen Events	Owner(s)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Steps 1-4 (Demand Profile, Product	TQ		○	●	□									
PQPR analysis for machine stop	AC				○	●	□							
Design and creation of assembly cell	TQ				○	●	□							
Plant 3P	EH						□							
Placement of assembly cells, super	EH							○	□					
Machine Moves	EH								○	□				
One point of schedule	TQ									□				
Internal at the pacemaker	TQ										□			
Pitch	TQ											□		
Bronze certification	TQEH												□	

Figure 7-6 Implementation Plan Going Forward

Appendix C: Set- Up Sheets

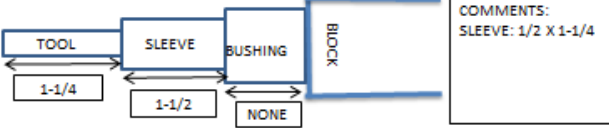
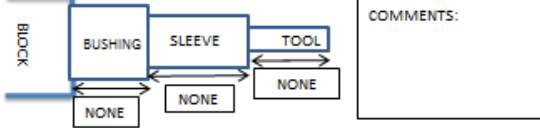
Figure 8-1 - Set-up Sheet for D-Pilot Body

CYCLE TIME	0:05:10	
SET UP TIME		
PARTS/HOUR	11	
PART NAME	D-PILOT BODY	
PRINT #	04-00630- 00	REV W
RAW MAT.	01-00630-00	
PROGRAM	0300	
REVISED	4/9/2013	

MAIN SPINDLE		SUB SPINDLE	
JAWS	029336-1	JAWS	SJ3-001
PRESSURE	280 psi (1.9 Mpa)	PRESSURE	200 psi (1.4 Mpa)

POSITION 1

4 STATION ID HOLDER

MAIN SPINDLE				SUB SPINDLE			
T0101				T0101			
TOOL	1/2 BORING BAR	BIN #		TOOL		BIN #	
INSERT	CCMT 2-1-14	BIN #		INSERT		BIN #	
BUSHING				BUSHING			
SLEEVE				SLEEVE			
							

Appendix D: The Engineering Realization of Lean Manufacturing

Decade	
2000 -	<p>2004: Shingo Prize-winning <i>Kaikaku</i> published by Norman Bodek, chronicling the history and personal philosophies of the key people that helped develop TPS</p> <p>2003: Shingo Prize-winning <i>Better Thinking, Better Results</i> published, case study and analysis of The Wiremold Company's enterprise-wide Lean transformation.</p> <p>2001: Totota publishes "The Toyota Way 2001" document, which makes explicit the "respect for people" principle.</p>
1990 -	<p>1996: <i>Lean Thinking</i> by Womack and Jones</p> <p>1991 - 1995: The business process re-engineering movement tried, but mostly failed, to transfer the concepts of standardized work and continuous flow to office and service processes that now constitute the great bulk of human activities.</p> <p>1991: <i>Relevance Lost</i> by Tom Johnson and Robert Kaplan exposes weaknesses in manufacturing accounting systems, eventually leading to the Lean Accounting movement</p> <p>1990: <i>The Machine That Changed the World</i> by Womack and Jones</p>
1980 -	<p>1988: Kaizen Institute of America holds kaizen seminars at Hartford Graduate Center (Hartford, Conn.), with TPS sessions taught by principals from Shingijutsu Co., Ltd.</p> <p>1988: Shingo Prize for Manufacturing Excellence created by Norman Bodek and Professor Vern Buehler of Utah State University</p> <p>1988: Shingijutsu hired by Danaher Corporation to assist in implementing TPS at Jacobs Chuck and Jacobs Vehicle Systems.</p> <p>1988: Kaizen Institute leads the first U.S. kaizen event at Jake Brake in Connecticut</p> <p>1988: First wholly owned U.S. facility Toyota Motor Manufacturing in Georgetown, Kentucky</p> <p>1988: Taiichi Ohno's <i>Toyota Production System - Beyond Large Scale Production</i> is published in English</p> <p>1985 - 1989: Shingo's books on <i>SMED</i>, <i>Poka Yoke</i>, and <i>Study of Toyota Production System from</i></p>

- Industrial Engineering Viewpoint* are published in the U.S.
- 1985: The Association for Manufacturing Excellence is officially formed from cast off APICS members.
- 1984: Several of AME's founders barnstormed for the APICS Zero Inventory Crusade, collectively making hundreds of presentations on what is now called lean manufacturing. APICS calls for the resignation of the steering committee for violating APICS special interest group rules. The committee decides to go out on its own.
- 1984: Toyota / GM joint venture NUMMI established in U.S.
- 1984: Norman Bodek forms Productivity Press
- 1983: First broader description of TPS by an American author – Zero Inventories by Robert "Doc" Hall is published
- 1980: Under the auspices of the Detroit APICS chapter, several future founders of the Association for Manufacturing Excellence organized the first known North American conference on the Toyota Production System at Ford World Headquarters, with 500 people attending. Featured speaker was Fujio Cho, who became president of Toyota.
- 1980: *Kanban: The Coming Revolution* is published. It is the first book describing TPS as "JIT"
- 1979: Several APICS members who had seen Toyota production facilities and understood the problems with MRP began to meet regularly.
- 1979: Norman Bodek forms Productivity Inc.
- 1979: First U.S. study missions to Japan to see the Toyota Production System
- 1978: Taiichi Ohno retires and becomes honorary chairman of Toyoda Auto Loom
- 1977: Nick Edwards presents a paper at the APICS conference describing the fallacies of MRP
- 1975: First English TPS handbook drafted by Sugimori, Cho, Ohno, et al.
- 1973: Oil Shock plunges Japan economy into crisis. Only Toyota makes a profit
- 1970 - 1973: Toyota - Regular supplier improvement workshops begin with top 10 suppliers
- 1969: Start of Toyota operations management consulting division
- 1965: Toyota wins Deming Prize for Quality
- 1962: Toyota - Pull system and kanban complete internally company wide
- 1960 - ○ Average die change time 15 minutes. Single minute changeovers exist.

- 50% defect reduction from QC efforts
- Initial application of kanban with main suppliers
- 1961: Start of Toyota corporate wide TQC program
- 1960: Deming receives the Japanese "Second Order of the Sacred Treasures" award, with the accompanying citation stating that the people of Japan attribute the rebirth of their industry to his work.
- 1957: Basic Andon system initiated with lights
- 1956: Shigeo Shingo begins regular visits to teach "P-Course"
- 1951: J.M. Juran publishes his seminal work The Quality Control Handbook
- 1951 - 1955: Further refinements to the basic TPS system by Ohno
- Aspects of visual control / 4S
- Start of TWI management training programs (JI, JR, JM)
- Creative suggestion system
- Reduction of batch sizes and change over time
- Purchase of rapid change over equipment from Danley corp
- Kanban implementation
- Production leveling mixed assembly
- 1950: Deming invited to Japan to assist with the Japanese 1951 census. He then gives the first of a dozen lectures on statistical quality control, emphasizing to Japanese management that improving quality can reduce expenses and improve productivity.
- 1950: Toyota financial crisis and labor dispute. Ends with 2146 people losing work. Kiichiro Toyoda steps down as President
- 1950 -
- 1947 - 1949: Ohno promoted to machine shop manager. Area designated model shop.
- Rearrangement of machines from process flow to product flow
- End of one man one machine. Start of multi process handling
- Detail study of individual process and cycle times
- 1940 -

- Time study and motion analysis
- Elimination of "waste" concept
- Reduction in work in process inventory
- In-process inspection by workers
- Line stop authority to workers
- Major component sections (Denso, Aishin etc.) of Toyota divested

1946: Ford adopts GM management style and abandons lean manufacturing

1943: Edsel Ford dies

1943: Taiichi Ohno transfers from Toyoda Auto Loom to Toyota Motor Corporation

1943: Ford completes construction of the Willow Run bomber plant, which reaches a peak of one B-24 bomber per hour.

1940: Deming develops statistical sampling methods for the 1940 census, and then teaches statistical process control techniques to workers engaged in wartime production.

1940: Consolidated Aircraft builds one B-24 bomber per day. Ford's Charles Sorensen visits to see if Ford's methods can improve on that number.

1939: Walter Shewhart publishes Statistical Methods from the Viewpoint of Quality Control. This book introduces his notion of the Shewhart improvement cycle Plan-Do-Study-Act. In the 1950's his colleague W Edwards Demming alters the term slightly to become the Plan-Do-Check-Act cycle

1938: Just-in-time concept established at Koromo / Honsha plant by Kiichiro Toyoda. JIT was later severely disrupted by World War II.

1937: The German aircraft industry had pioneered takt time as a way to synchronize aircraft final assembly in which airplane fuselages were moved ahead in unison throughout final assembly at a precise measure (takt) of time. (Mitsubishi had a technical relationship with the German companies and transferred this method back to Japan where Toyota, located nearby in Aichi Prefecture, heard about it and adopted it.)

1937: Toyota Motor Corporation established. Kiichiro Toyoda President

1937: J.M. Juran conceptualizes the overall Pareto Principle and emphasizes the importance of sorting out the vital few from the trivial many. He attributes his insight to the Italian economist Vilfredo Pareto. Later the term is called the 80/20 rule.

	1933: Automobile department established in Toyoda Auto Loom
	1929: Sakichi Toyoda sells foreign rights to loom and Kiichiro Toyoda visits Ford and European companies to learn the automotive business
	1928: Ford's River Rouge plant completed, becoming the largest assembly plant in the world with over 100,000 employees.
	1926: Henry Ford publishes <i>Today and Tomorrow</i>
	1924: Walter Shewhart launches the modern study of process control through the invention of the control chart
1920 -	1924: Sakichi creates the auto loom
	1914: Ford creates the first moving assembly line, reducing chassis assembly time from over 12 hours to less than 3 hours.
	1912: The Ford production system based on the principles of "accuracy, flow and precision" extends to assembly.
	1911: Sakichi Toyoda visits U.S. and sees Model T for the first time
	1910 - 1912: Ford brought many strands of thinking together with advances in cutting tools, a leap in gauging technology, innovative machining practices, and newly-developed hardened metals. Continuous flow of parts through machining and fabrication of parts which consistently fit perfectly in assembly was possible. This was the heart of Ford's manufacturing breakthrough.
1910 -	1910: Ford moves into Highland Park - the "Birthplace of Lean Manufacturing"
	1908: Ford introduces the Model T
	1906: Italian economist Vilfredo Pareto creates a mathematical formula to describe the unequal distribution of wealth in Italy. He notices that 80% of the wealth is in the hands of 20% of the population
	1905: Frank and Lillian Gilbreth investigate the notion of motion economy in the workplace. Studying the motions in work such as brick laying they develop a system of 18 basic elements that can depict basic motion.
1900 -	1902: Jidoka concept established by Sakichi Toyoda
1890 -	

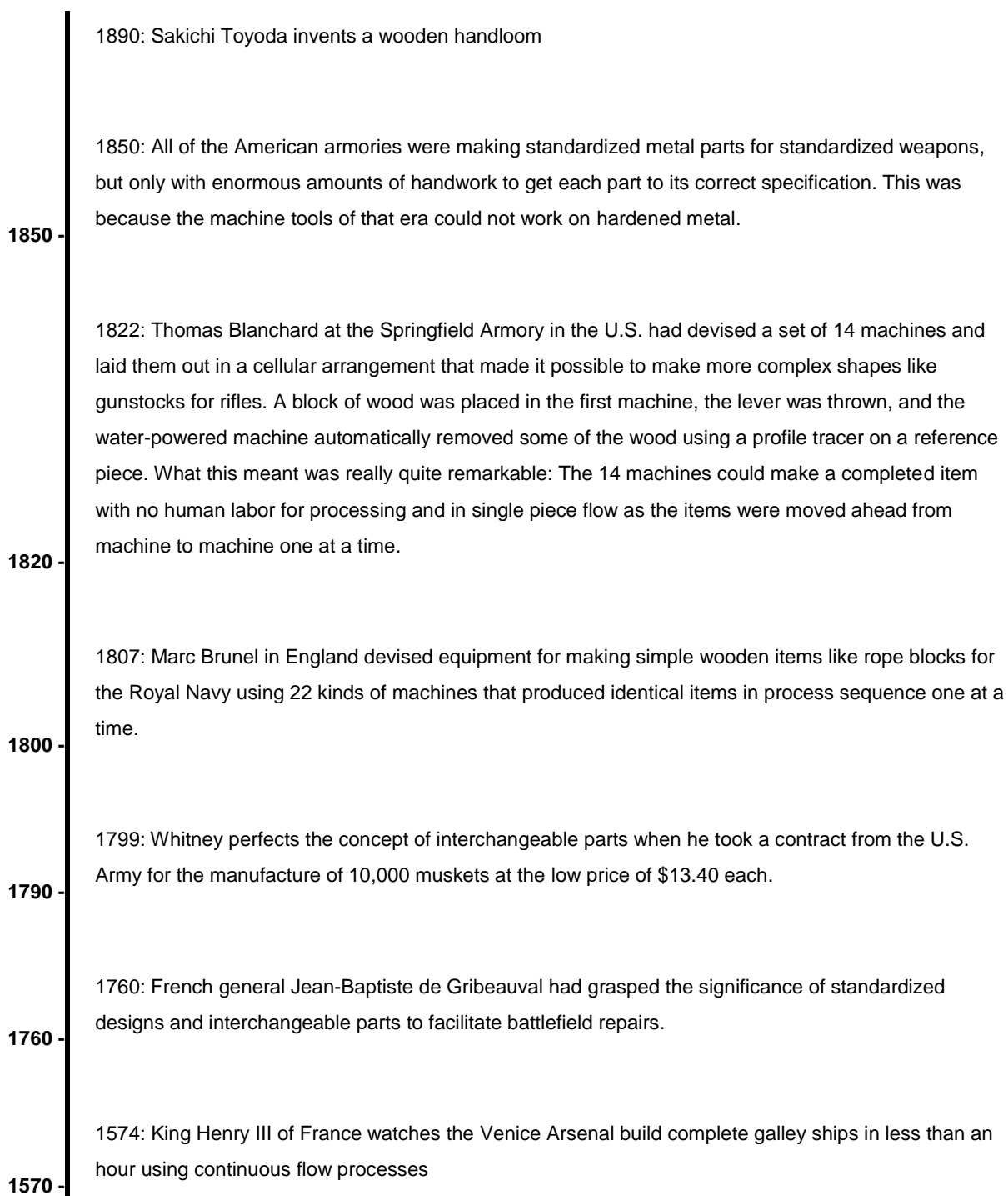


Figure 9-1 Lean Timeline

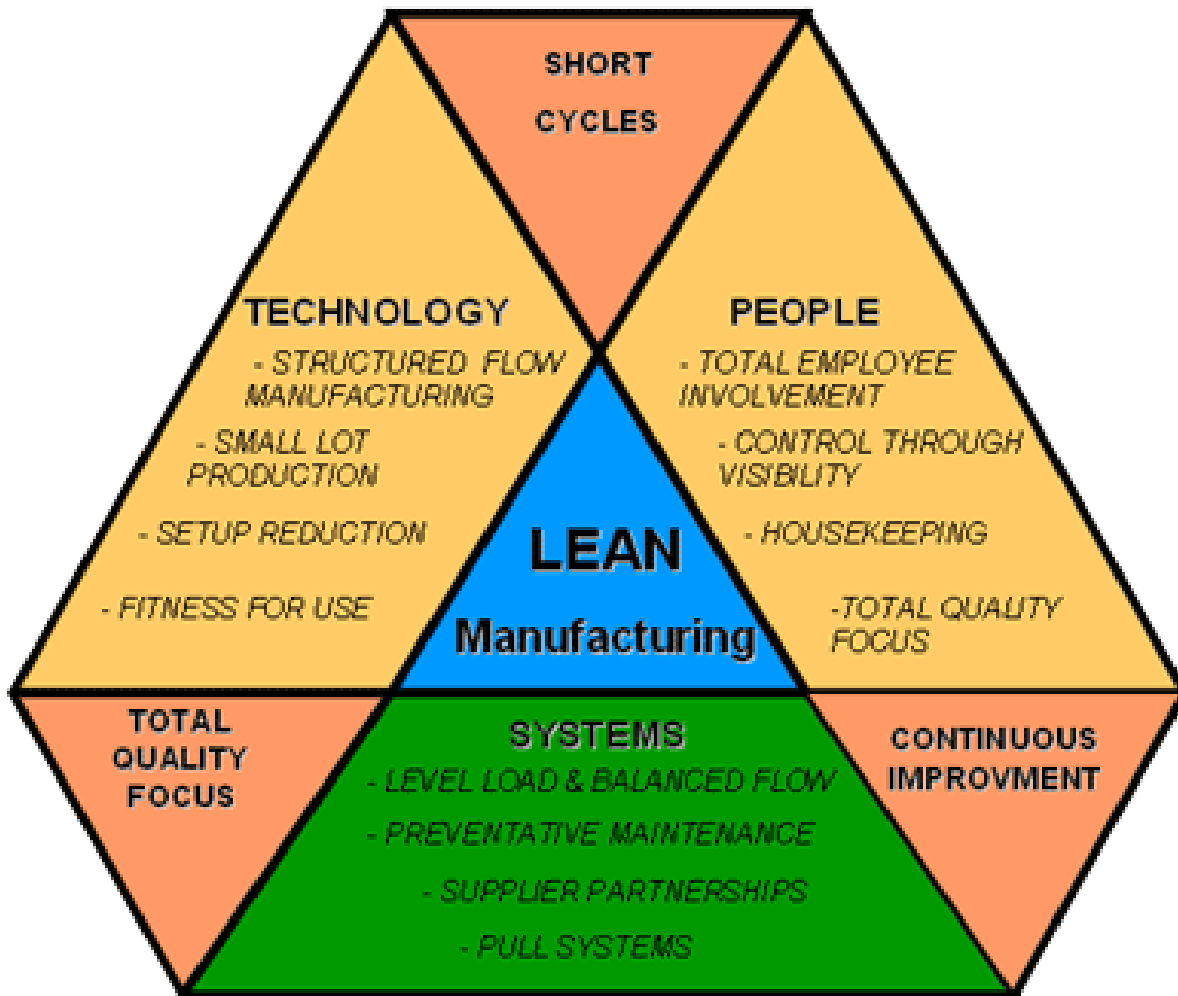


Figure 9-2 Lean Systems

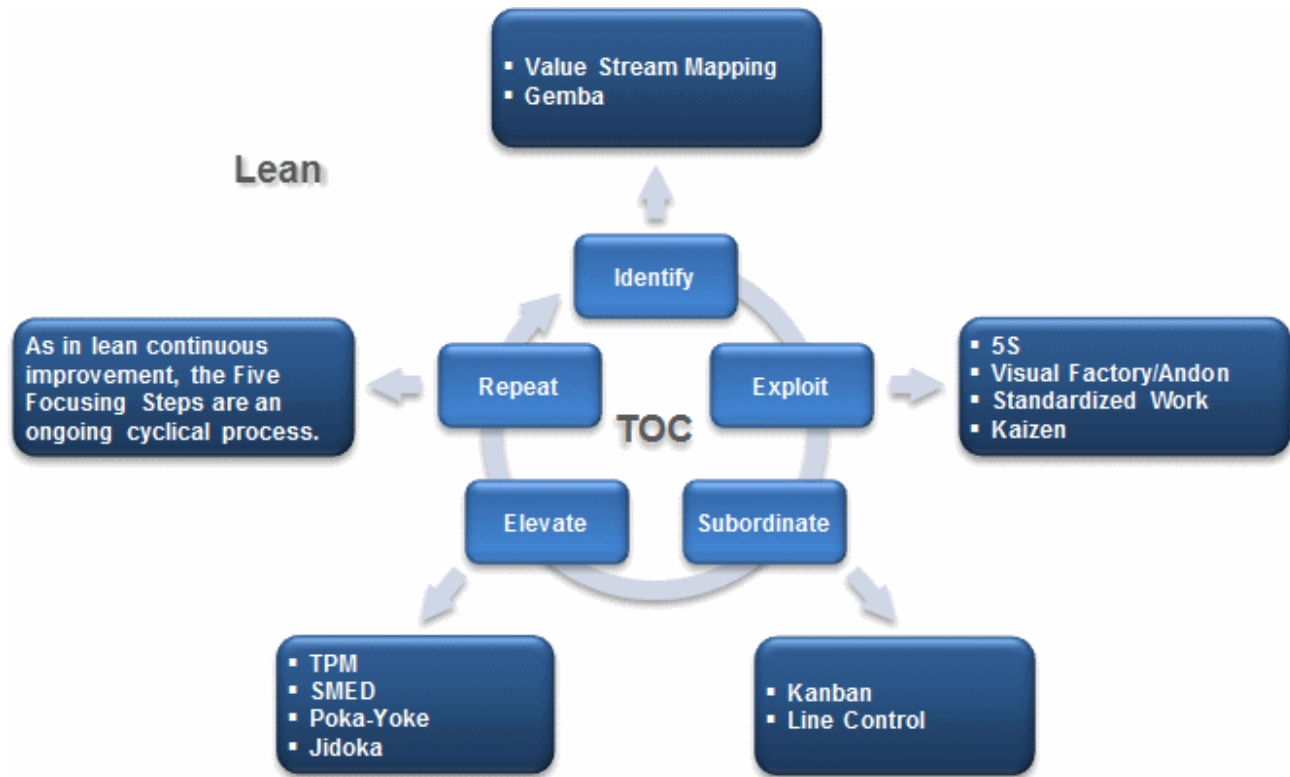


Figure 9-3 Lean Methods

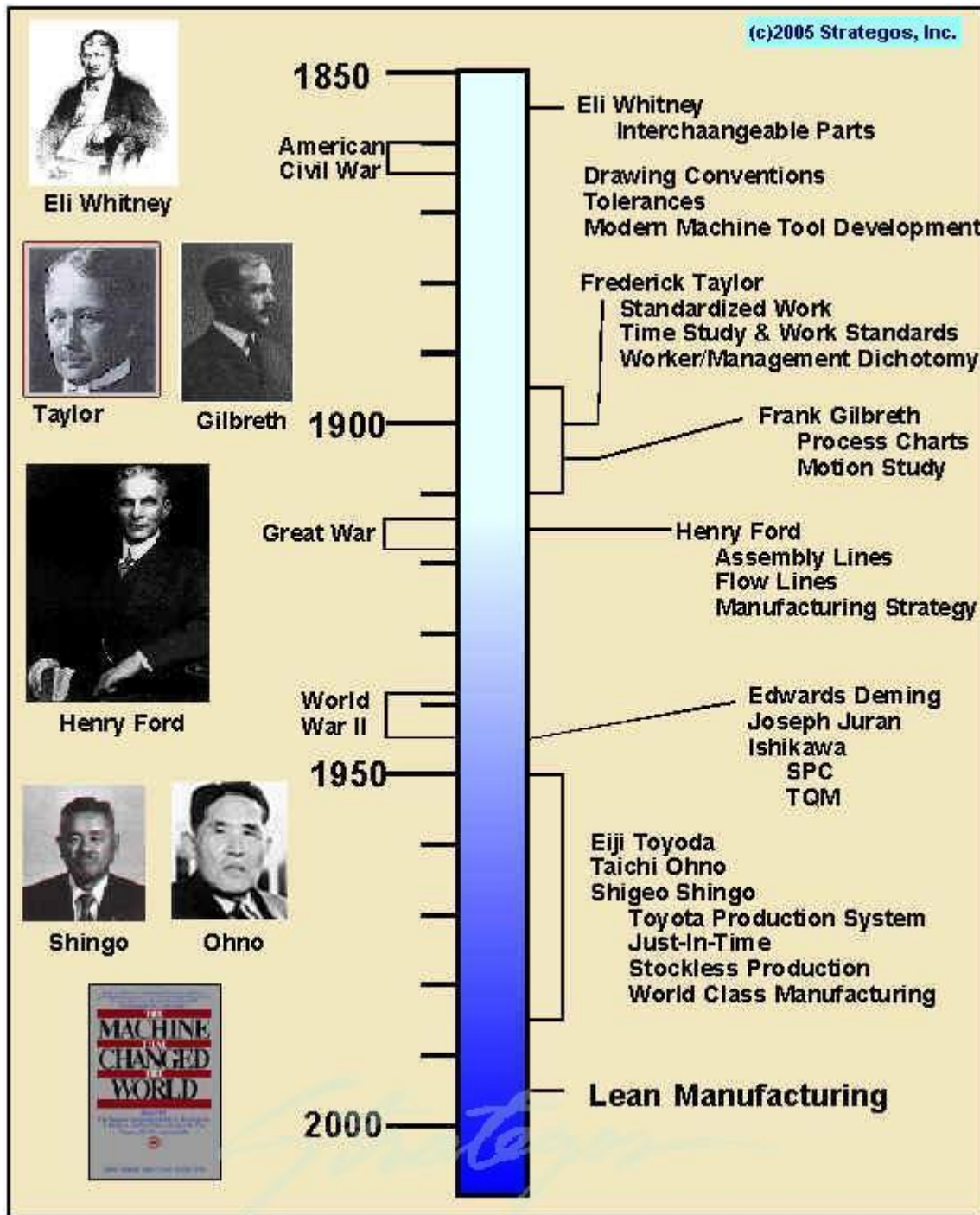


Figure 9-4 Timeline Image

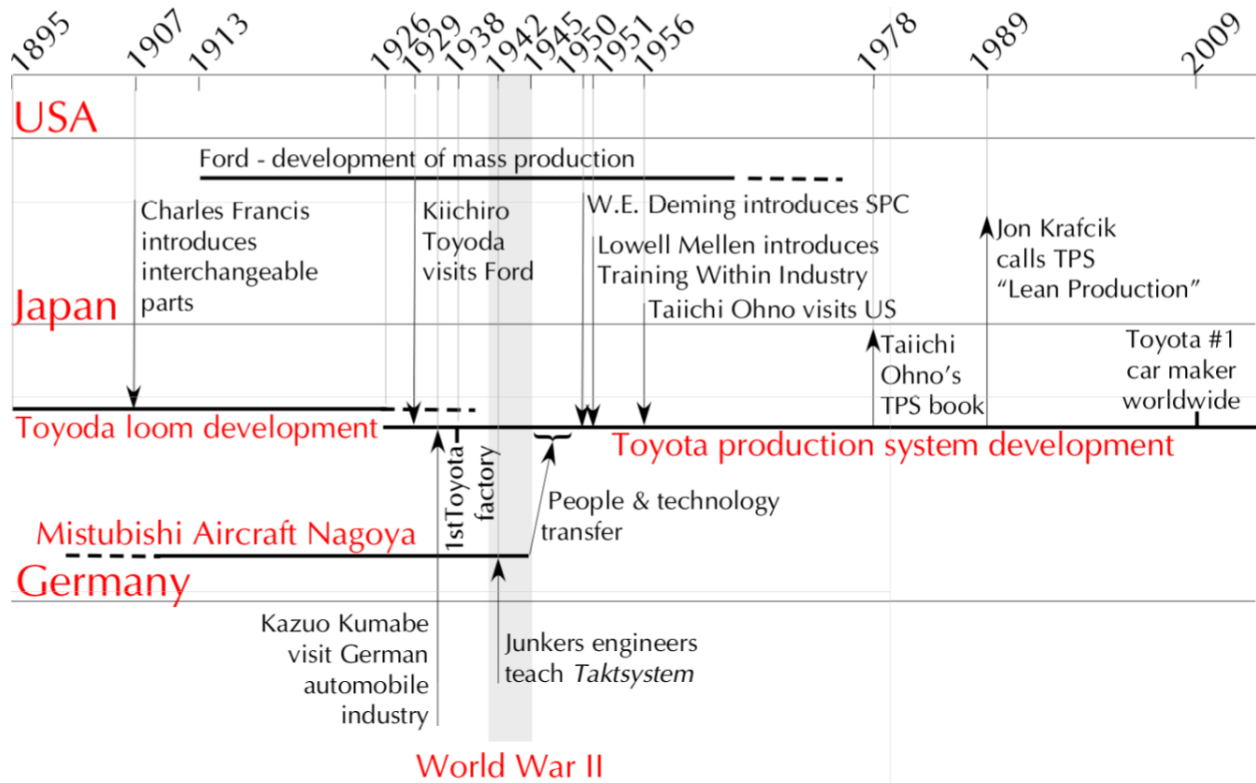


Figure 9-5 World Lean Timeline

Appendix E: Tools, Techniques and Technology for Eliminating Non-value Added Functions

- Equipment availability is less than 95%.
- Machines breakdown suddenly without warning. (_____ Happens!)
- Machines do not operate at design parameters.
- Changeover and set-up of equipment requires more than 10 minutes.
- First Run Capability is less than 99%.
- New equipment is high-tech.
- Newly-installed equipment must be “de-bugged”.
- Customers' products require higher quality performance.
- Plants are “dirty, dark, and stinky”.
- Most associates in the company are indifferent to the production facilities and equipment.
- Areas of responsibility are not clearly defined.
 - Equipment and process design
 - Equipment sourcing
 - Equipment acceptance
 - Equipment maintenance
 - Operator (s)
 - Maintenance

Figure 10-1 Pre-TPM Checklist

Overall Equipment Effectiveness (%)

$$= \text{Availability} \times \text{Performance Efficiency} \times \text{Quality Rate (a.k.a. FTC)}$$

$$= \frac{\text{(Operating Time)}}{\text{(Net Available Time)}} \times \frac{\text{(Ideal Cycle Time) x (Total Parts Run)}}{\text{(Operating Time)}} \times \frac{\text{(Total Parts Run - Total Defects)}}{\text{(Total Parts Run)}}$$

EE has the same meaning as APU (Actual Productive Uptime) and several other industry terms. This is a measure of true uptime and productivity. We use this measurable to monitor and improve performance of all work areas, not just machines or bottleneck machines. Here, an "area" is defined as 1 or a sequenced group of operations which are roughly in 1-piece flow)

Figure 10-2 OEE-Overall Equipment Effectiveness (%)

1	Clean and inspect	Eliminate all dirt and grime on machine, lubricate, tighten bolts and find and correct problems
2	Eliminate problem sources and inaccessible areas	Correct sources of dirt and grime; prevent spattering and improve accessibility for cleaning and lubrication. Shorten the time it takes to clean and lubricate
3	Create Cleaning & Lubrication Standards	Write standards that will ensure cleaning, lubrication, and tightening can be done efficiently. (Make a schedule for periodic tasks)
4	Conduct general inspection training	Conduct skills training with inspection manuals and use general inspections to find and correct slight abnormalities in equipment
5	Conduct autonomous Inspections	Prepare standard Checklists for autonomous inspections. Carry out the inspections
6	Standardize with visual workplace management	Standardize and visually manage all work processes. Examples: <ul style="list-style-type: none"> > cleaning, lubrication, inspection standards > shop floor materials flow standards > data recording method standards > tool and die management standards
7	Implement autonomous equipment management	Develop company policies and objectives; make improvement activities part of everyday practice; keep reliable data (MTBF); analyze it, and use it to improve equipment.

Figure 10-3 7 Steps of Autonomous Maintenance

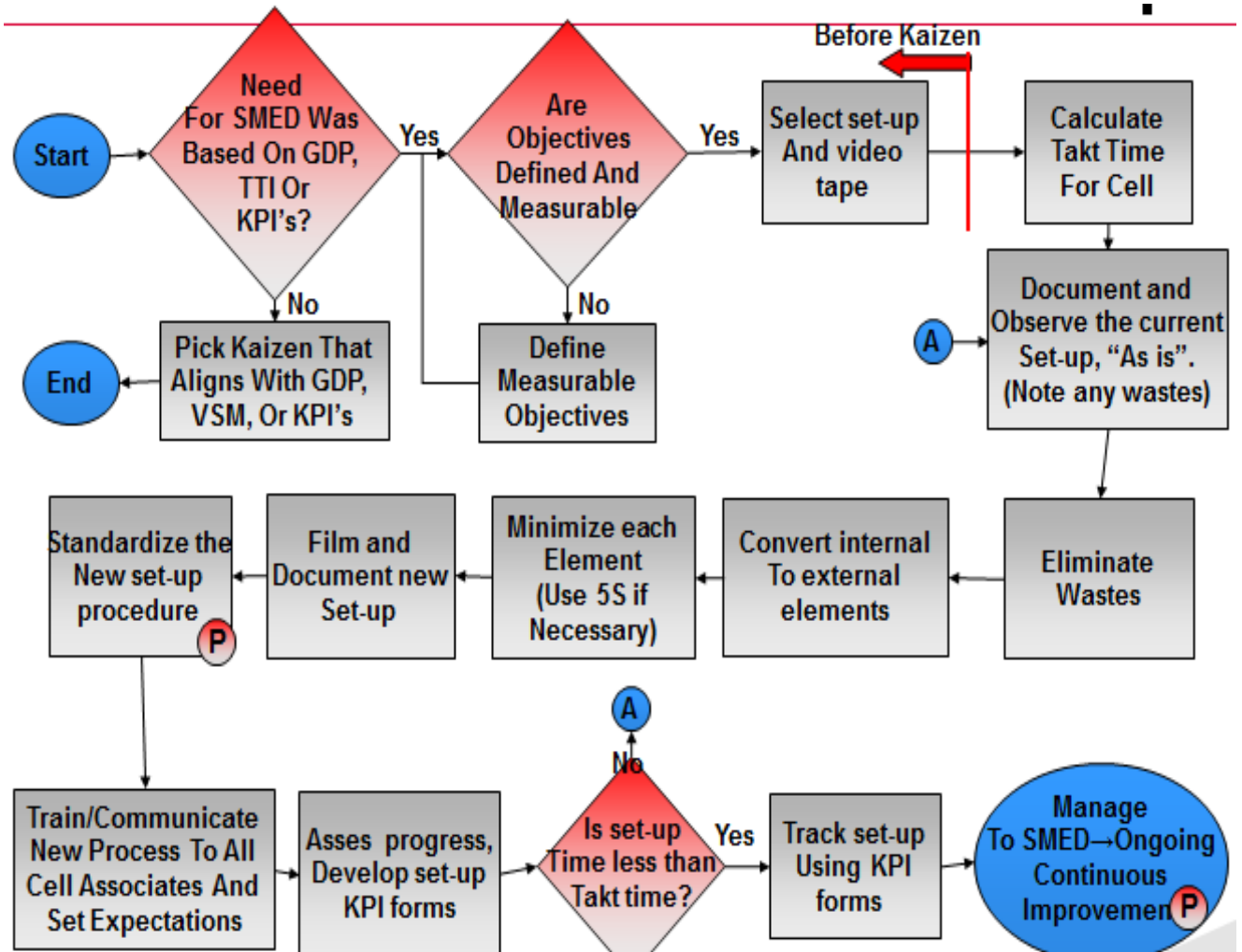


Figure 10-4 SMED Caption

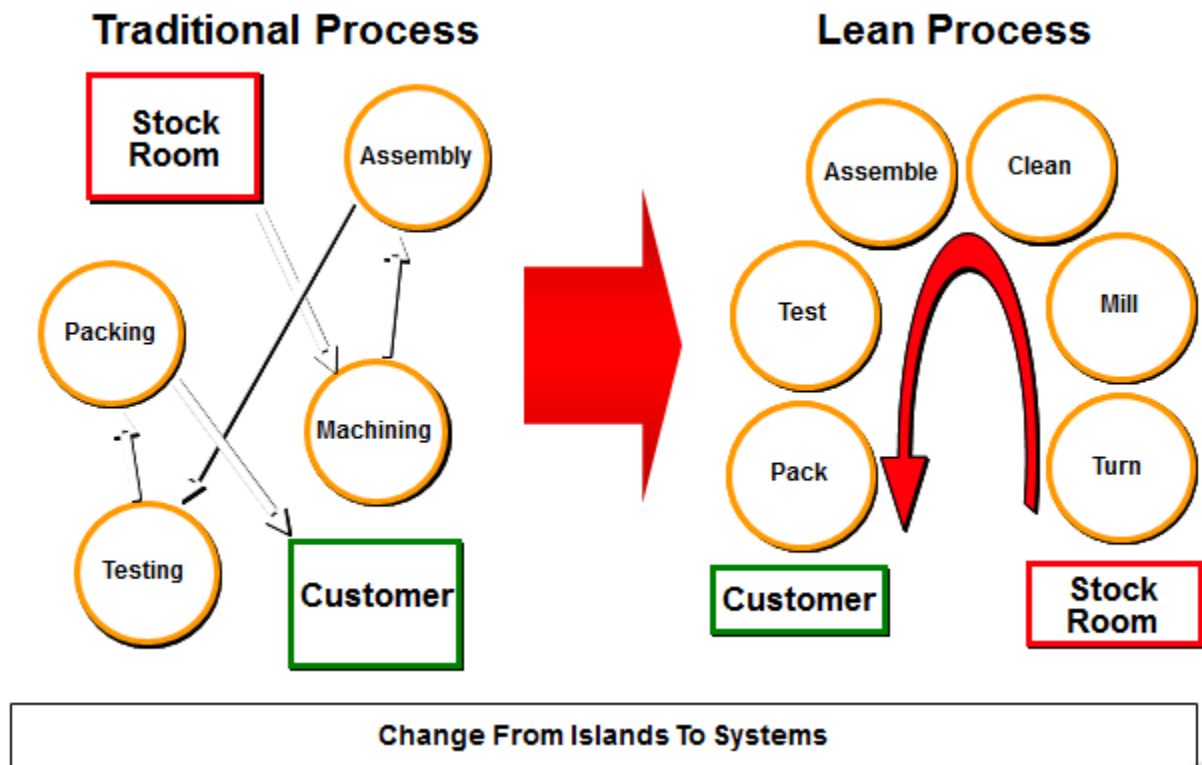


Figure 10-5 Flow Modification

Appendix F: The Seven Types of Non-value Added Functions and Their Recognition

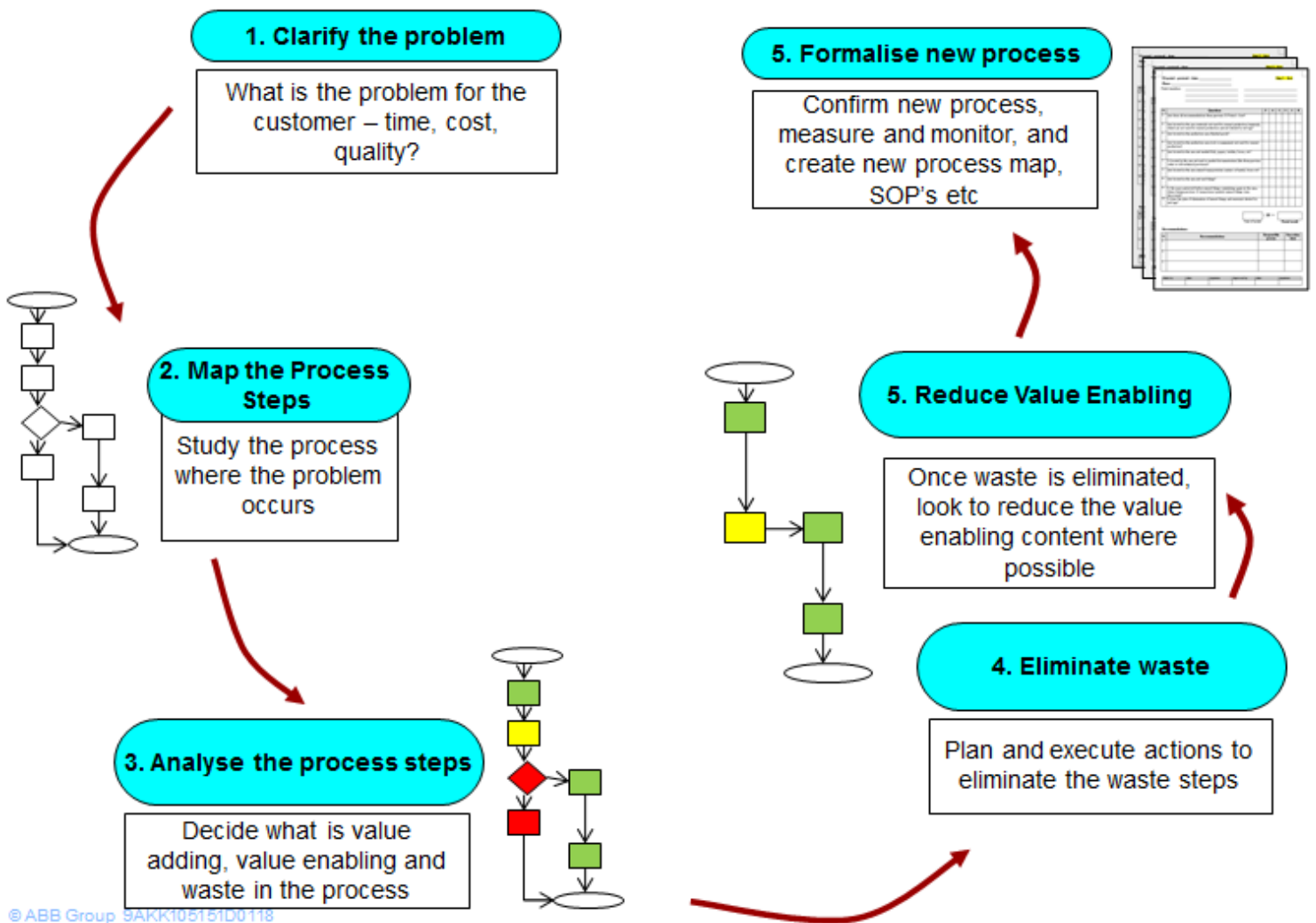


Figure 11-1 - Graphical Elimination of Waste

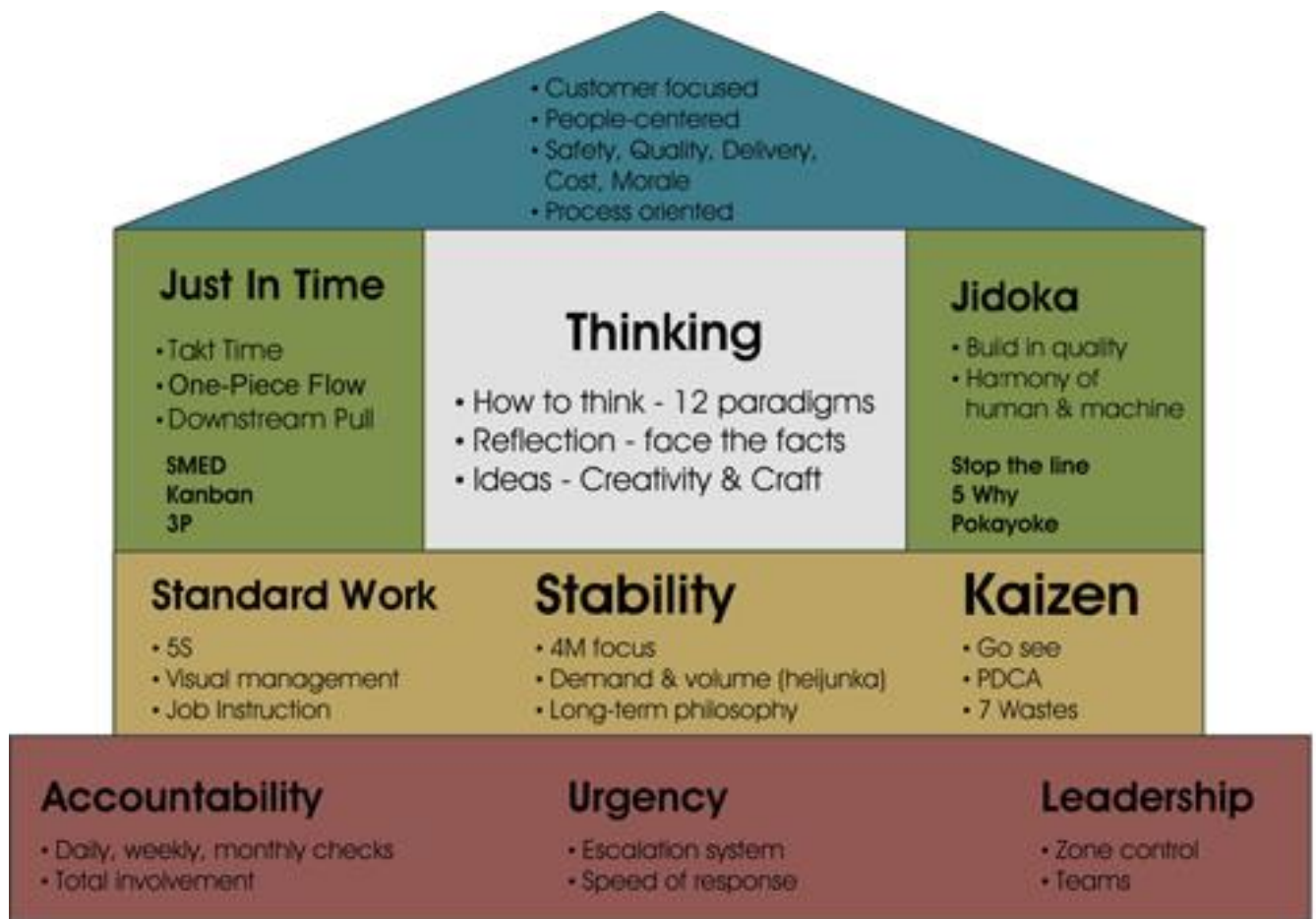


Figure 11-2 Graphical Interpretation of Lean

Over production	<ul style="list-style-type: none"> • Production of items sooner or in greater quantities than required for customer demand • Often caused by poor planning or incorrect bottleneck assumptions 	Overproduction discourages a smooth flow of production and leads to excessive work in process inventory. This increases overall delivery times and reduces ROCE.
Inventory	<ul style="list-style-type: none"> • Any raw material, Work in Process (WIP) or finished goods which are being stored i.e. no longer having value added to them • Caused by overproduction – inventory builds up between processes 	Adds cost, requires space, hides process defects, can encourage damage. Reduces ROCE.
Motion	<ul style="list-style-type: none"> • Unnecessary worker movement within a Process • Caused by poor workplace layout, poor process planning, poor housekeeping, no Standard Operating Procedures. 	Adds time & cost and can be a safety issue.
Waiting	<ul style="list-style-type: none"> • People or Parts that are waiting for a work cycle to be completed • Caused by unreliable Supply Chain, bottlenecks, down time 	Creates excessive lead time, causes bottlenecks, causes additional time & cost.
Transportation	<ul style="list-style-type: none"> • Unnecessary movement of items between processes and inventory • Caused, by poor layout and / or process design and planning, unstructured or not understood Value Stream, complex material flow... 	Leads to increased time & cost to transport & search, and increased Defects due to accidents.
Over processing	<ul style="list-style-type: none"> • Processing beyond the value required by the Customer • Caused by lack of customer focus, "Always done <i>it this way</i>" attitude, lack of understanding 	Can result in scheduled work time being longer than needed, Parkinson's Law in project task execution, increases in time & cost.
Defects	<ul style="list-style-type: none"> • A defect is when the Customer believes they did not get what they paid for. Can have many causes including process variation, customer requirements not understood correctly, mistakes ... 	Defects can lead to additional time and cost, and more critically it can reduce customer confidence.

Figure 11-3 Overview of 7 Wastes

Appendix G: Proposed Machine Shop Layout Images



Figure 12-1 – Colorized Top-Down View of Proposed Layout

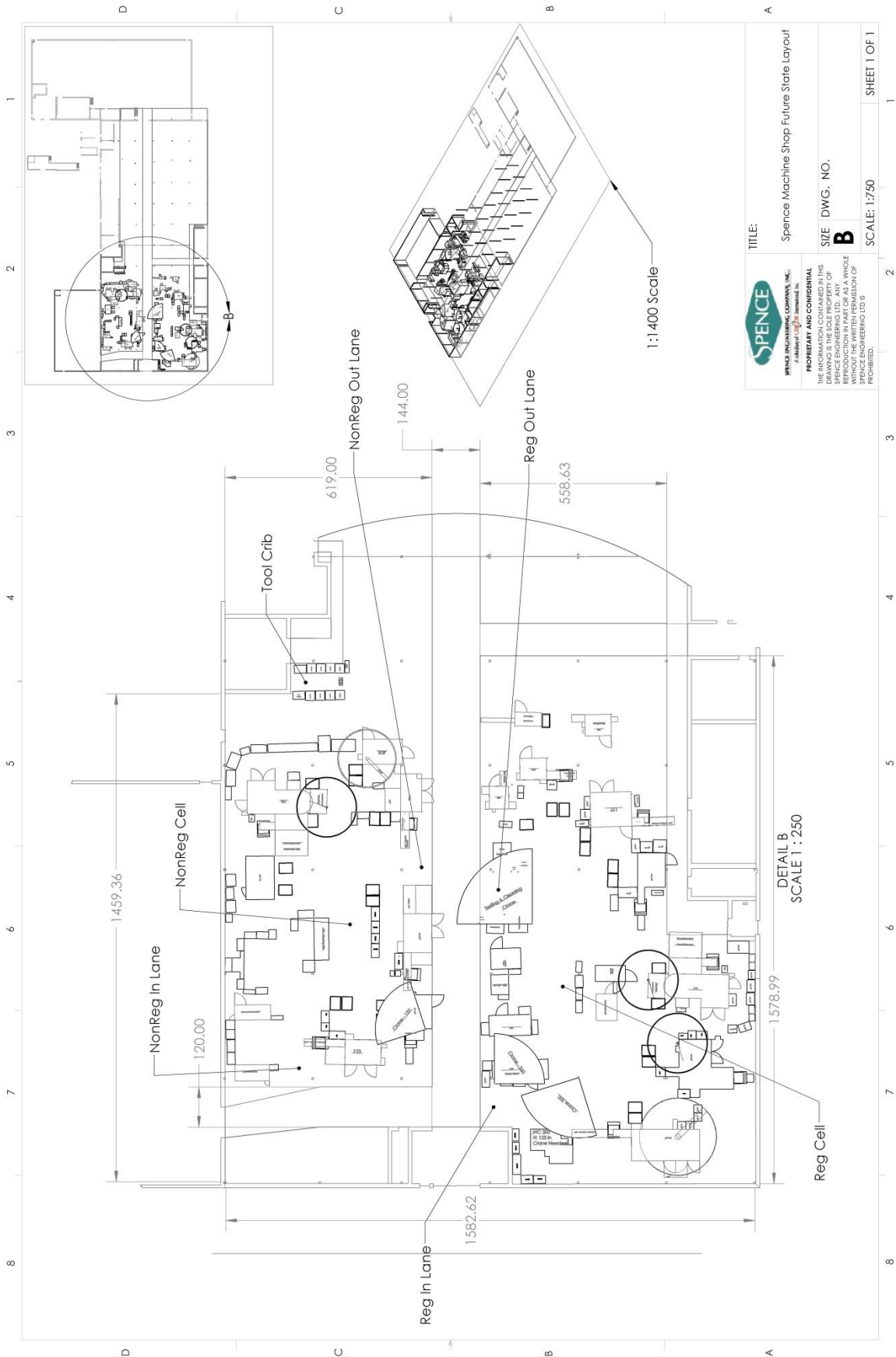


Figure 12-2 – Detailed CAD Drawing of Proposed Layout