2016

Process Improvement by Lean Thinking in Trucking Industry

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Process improvement by lean thinking in trucking industry

A Thesis Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Manufacturing Engineering Technology

Minnesota State University, Mankato

By

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December 2016

Signature Date (05/06/2016)

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This thesis has been examined and approved by the following members of the student's committee.

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Advisor (Dr. Kuldeep Agarwal)

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Committee Member (Dr. Harry Petersen)

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Committee Member (Dr. Shaheen Ahmed)

Acknowledgement

I would like to thank Minnesota state university, Mankato for giving me an opportunity to pursue my master's degree in manufacturing engineering technology. It was pleasure to be part of department of automotive and manufacturing engineering technology and thanks to all support provided by department head Dr. Bruce jones

I want to thank specially to my academic advisor, Dr. Kuldeep Agarwal for his continues support with my courses and mentoring. I would like to thank my committee members Dr. Harry Petersen and Dr. Shaheen Ahmed for reviewing and provide valuable inputs.

I am grateful to director of operation, Dalta-waseca. Mr. Dave Vanna and CEO Dee Kapur for allowing me to complete my paper and training me at delta Waseca plant. I want to thank all the employees of delta Waseca for providing support and guidance needed to complete this paper. I am thankful for my friends and family for providing all the support in for my education.

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Abstract

Process improvement by lean thinking in trucking industry

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Manufacturing industries with complex production systems are struggling with designing optimal process to increase throughput. Companies will require high amount of labor and process improvement resources to sustain growth and delivery quality products to its customers. A chain of value added activities when designed and deployed with help of lean based methodologies can create high efficiency process. In this paper we have studies and implemented value added process based on the lean manufacturing methodologies which was adapted on the shop floor.

In many traditional truck body production industries have facing many problems like low production rate, big lead times, material flow issues, nonlinear layout, late customer delivery and low quality. To address this problems, a mythology has been designed with implementing process techniques for low efficiency work stations.

This study and implementation is conducted in crucial bottle neck areas. Tools used to conduct this study are time analysis, motion analysis, Standard working procedure (SWP), value stream analysis, 5S, Value layout, and bottleneck analysis. The value process implementation has converted production of two truck per day to three truck per day. Increase in production rate, quality and customer delivery have been witness when process is implemented and sustained.

Key works: Time analysis, Lean manufacturing, Process improvement, Value stream, implemented and sustained.

Chapter 1: Lean introduction

1.1 Introduction:

From early 1980's there was near trend in manufacturing industries to improve efficiency of production process by the idea of continues improvement. Many companies struggle to sustain their growth and product quality. There is new wave in manufacturing arena called lean manufacturing which was derived from Japanese toyota production system. It is proven over and over again that implementing lean techniques correctly can bring remarkable improvement to the process. Engineers and managers across the manufacturing fields attempted to increase productivity by decreasing cost and improving quality of product or a system. In this regards there are many tool and techniques emerged from lean thinking which can be applied to reduce manufacturing and production constrains.

However, now a day most companies in manufacturing sector fails to live up to its customer standards. Longer lead times and late delivery time is common senior in most of small manufacturing industries. Companies try to sustain growth and stay alive in global markets and their local competition, even investing heavily in state of the art technology and market strategies with no or little effect on growth. One of the main factors is because lack of development in creating culture of continues improvement in the organization. In other words, fail to training their workers to the idea of lean thinking. Nonetheless only small percentage of companies able to sustain lean process improvement and their ability to cultivate lean culture in workplace.

Whole idea of lean improvement is understanding where non value added activity is and converting into value added activity. Lean process looks at the entire operation of pant from raw material to customer delivery. In this paper we have used a holistic approach to understand process from upstream supplier to downstream customer.

1.2 Problem statement:

Delta-Waseca is medium size automotive (OEM) company located in south central Minnesota which producing truck trailer bodies from 18 feet to 30 feet long. Company is witnessing long delivery times with Lower quality products. Unhappy costumer and longer processing time at certain work station is common situation in the plant. Delta's supply chain is in total shambles with poor supplier relation and with no or little incoming material inspection procedures.

1.3 Research questions:

How can you identify major constrains in the plant?

How does chain of linked value activities improve identified bottlenecks?

What techniques to use to sustain the process improvement activity?

Does people really factor in process, if so how do you address improving or creating lean culture?

How do you create more agile supply relation management using lean thinking?

1.4 Methodology

This paper will focus on observing behaviors of production system when set of value added activities are implemented to gain smooth flow. The purpose of the study is to demonstrate set of lean strategies when implemented correctly can reduce overall product lead time. The researcher will conduct the value stream analysis from start to finish of production flow. When identified the major systems responsible for constrains will be attempt to understand the bottlenecks by conducting in time analysis and motion analysis. Each set of data will be collected and analyzed for identifying any potential patterns for improvement.

Fundamental knowledge of lean manufacturing background will be learned by the information gathered by studying research papers, text books and internet. It is significant to understand that the intension of this paper is not to provide detail description of each sub system on production flow but to focus on the holistic view of plant and determine solution based on the available resources and most importantly considering cost factors.

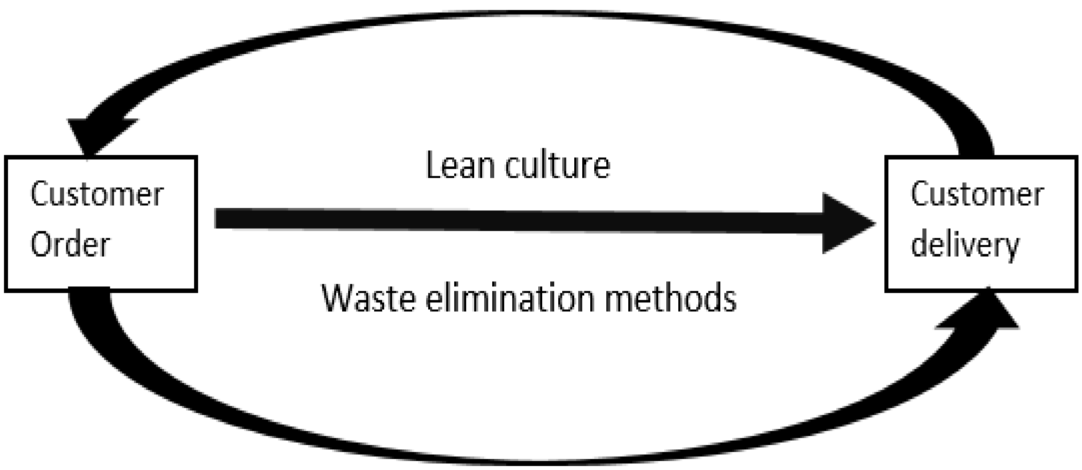

Figure 1 Lean thinking cycle

Chapter 2: Literature review

2.1 History of lean manufacturing:

New ideas emerge to tackle new conditions in which old methods are no longer seems to work. This is true in lean production, which was originated in different country at period where conventional methods in manufacturing systems does not work with traditional thinking. To understand the origins of lean manufacturing we need to dig deep into world of toyota production system.

Ford's mass production in early 1900's was just start of new manufacturing revolution. Model T was first automobile to achieve interchangeability. Ford insisted that all the gauges used in the plant should be of same metric. This helped in achieving simple process or in today's words user friendly, in which any one can repair and this laid ground work for production thinking in automotive world. Key to mass production was the complete and consistent interchangeability of parts and simplicity of attaching them to each other [1]. Material were delivered to the workstation rather than workers traveling and getting them. Assemblies remain in intended locations, processing time reduced tremendously and fords introduced continues assembly line to the world. Production in 1913 was at the peak with same work performed over and over resulted in faster work performance. River rogue and highland plant where models of near continues flow production and vertical integration-raw material like rubber, silicon and iron ore flowed into one end and model T came out from other end at incredible rate [3].

Eiji toyada, a Japanese engineer along with taiichi ohno took a trip to ford's river rouge plant in early 1950. Ford rouge plant was considered best manufacturing machine in the world with through put of 7000 unit's compared with Toyota less than 3000 units. After visiting the pant ohno and toyado came to concluded that there were some possibilities to improve the production system and mass production would never work in japan [1]. From this idea a revolutionary thinking was born which came to call as toyota production system later came to know as lean thinking.

During World War 2 most of Japanese industrials cities were destroyed. Economics condition in japan was very dull after the war compare to America. Most of manufacturing industrial could not compete with idea of mass production system because they lack unlimited supply of resources like raw material, electricity or labor. Japanese manufacturing companies soon realized that they need to focus resources on demand only basis. They started to produce small batched which helps in less inventory and less capital. Toyota realized importance of training its employees in demand based manufacturing thinking and It did not have to rely on the economies of scan as western counterparts and soon training resulted in more skilled labor. Toyota invested heavily on the workers in training and cultivating culture of continues improvement.

2.2 Lean Culture:

Many companies both manufacturing and service industries, after witnessing toyota production system started implementing lean techniques. Changing the company's behavior towards new process is no easy task. Many companies try to bring culture of continues improvement into their production system but fail to cultivate this change. Toyota's biggest asset was not their technology or next model or marketing strategy but its people. Creating lean leadership is very critical to cultivate and bring continues improvement behavior among the workers. Many workers are essential to understand the deviation in the process and they alone cannot change the process. Management need to buy into its process to make any changes to happen. Methods and tools are very important but they cannot achieve any results if leaders do not have a deeper understanding of lean [4]. Lean thinking strives to eliminate waste in all corners of plant form zero defects to zero inventory. To achieve this perfection long term continues improvement is necessary from both management and shop floor workers to share knowledge and information.

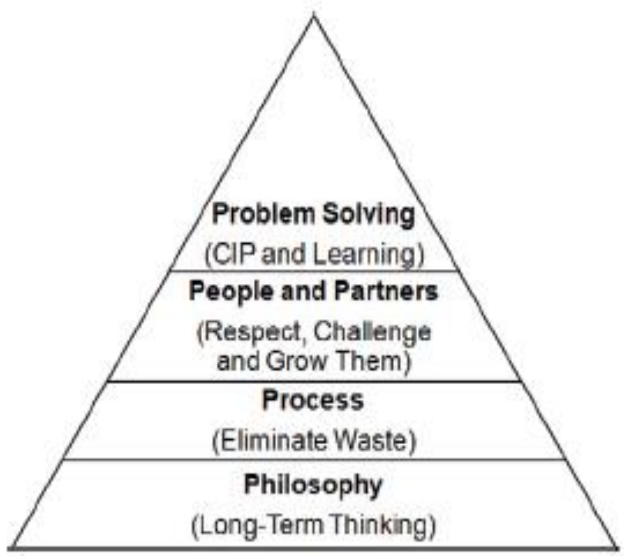

Figure 2: Model of lean production system [4]

Many argue that lean is philosophy, which is way of living in both professional and personal lives. To understand lean in detail we must understand the five core principles of lean thinking.

1: Value

2: Value stream

3: Flow

4: Pull

5: Perfection

2.3 Lean principles

2.3.1 Value:

The most important aspect of lean thinking is identifying the value. Each time when talked about value a common question arises "what is value and how do you define it". Value is defined by final customer in form of product or service to which they invest at specific time.

Value is created by the producer. From customer standpoint this is why produce exist [5]. Now different industries located in different geographical location defined value according to their prospective. For an example, German manufacturing industry is more focused on the complex technological aspect of product. Many German industries were led by the highly trained technical experts and invested their resources in highly refined process complexities to which many showed little or no interest. It is witnessed that complex design technologies and sophisticated process where too expensive for general customers. On other hand when looking at Japanese industrial markets they defined value where costumer is. In other words, product or service is designed by needs of customer and their ability to invest in it. In companies like toyota started designing their process by asking customers on their needs and local conditions. Customers like their product to local needs and with shorter lead times. Value is skewed by the nature of product, Origination structure, and complex process along with the thinking of company.

In today's world air travel is mostly filled with hassle from buying cheap ticket to long waiting (security check, flight delay and boarding time) and reaching destination with certain amount of road travel if its a small town that lacks air transport. Airline industrial built bigger airplane rather than encouraging the idea of improving transportation to smaller towns by designing smaller planes. Basic model in airline industry is flaws by the thinking of transporting large batch of passengers on large plan but it's not creating value by shorting passengers on hubs.

Lean thinking is more focused on creating value to specific product or service at specific cost at specific time period to specific customer. Value is created when organization starts to think and design process from customer prospective (no long flights or inefficient cars). If process results in designing wrong product to customer which they are not interested to pay for, then this will simple result in MUDA which we will discuss in later chapter of paper.

2.3.2 Value stream:

Value stream is set of all the actions needed to complete the process from order to delivery of product or service to final customer. From the conceptual task in which product is designed and tested for launch, the information cycle for order taking to customer delivery, transformation cycle where material physically change its shape to obtain final product. Identifying this three crucial steps of value stream is important step in lean manufacturing. Many companies try to map its value stream and try to identify waste activities. Value stream involved in mapping out every step in process form upstream supplier to final customer and documentation each step. In past when idea of idea of concurrent engineering does not exist, there was no sharing of information from different supplier to its manufacturing partners. This was partly because lot of companies invested in their own development and information is kept confidential. This created a vacuum for understanding the value added activities for the entire production cycle. This soon change after Japanese companies started to implement the concepts of concurrent engineering, eliminating barrier between supplier and manufacturer. Creating a value stream understanding will require to define the steps from order to final product which includes three categories: (1) those which actually create value as perceived by the customer; (2) those which create no value but currently required by the product development, order filling for production systems so they can't be eliminated just yet; and (3) those actions which don't create value as perceived by the customer and can be eliminated immediately [1]. The second criteria are called type once Muda because the steps are necessary to bring the product or service to customer and process is not hundred present value creating. Like inspection which is necessary for different production process to make sure high quality product is been delivered but in lean thinking it is an unavoidable non value activity with current technologies and production process. The third criteria are type two Muda or waste which can be eliminated when identified completely because it creates no value to either customer or producer.

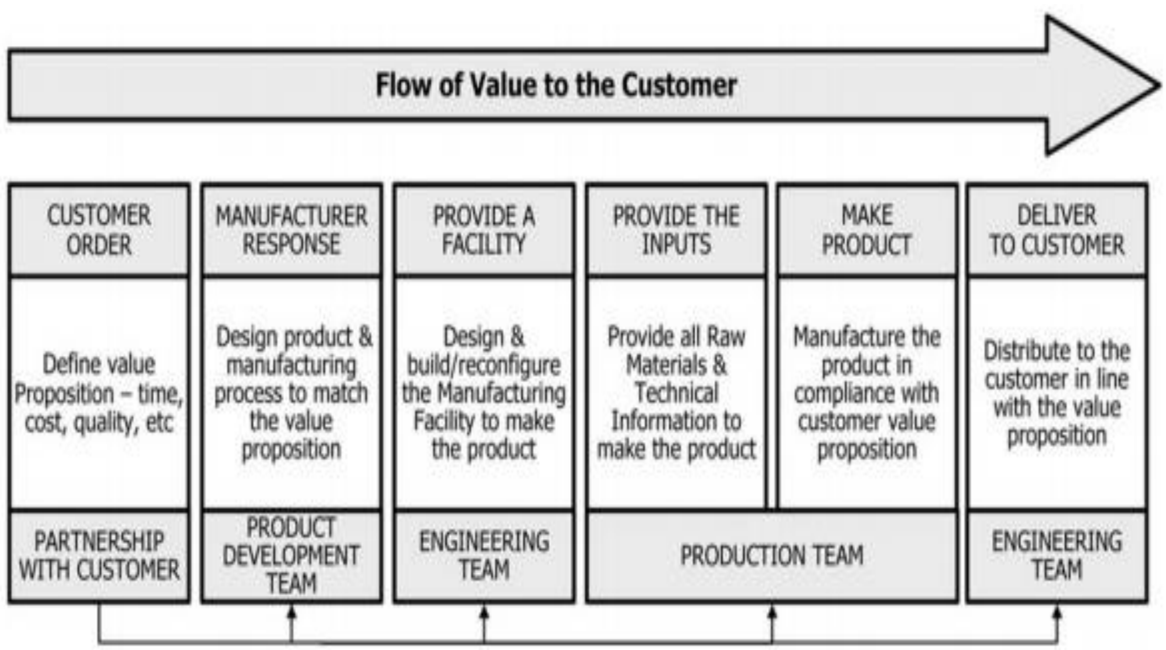

Figure 3: Value stream model [6]

2.3.3 Flow:

Flow is very interesting lean principle, when value stream is defined efficiently that is after eliminating all non-value added activities it is essential to make the production flow smoothly. In early 1913 henry ford was first to understand the concept of continues flow and ford implemented this concept to its model T continues assembly line where product flow through system. This model was useful when production value is more and product used same parts. By end of 1920 ford was able to produced more than two million units with continues flow. However, there was new challenge for manufacturing world, how do you create continues flow for small batched with different product mix. Ohno at toyota came up with idea of changing tools quickly to accommodate more flexible production process. Having continues flow with lower non value steps in production process is what makes manufacture more efficient in reduction cycle times. Many companies think stocking of material will help in elimination halts in production process and some companies' production process gets halted because right parts were not delivered at right work station. However, companies fail to understand that material distribution accounts for more than fifty percent of their manufacturing cost. It is a lack of flow in manufacturing processes which accounts for the huge warehouses which houses mass of inventory which consumes the working capital of the business [6].

2.3.4 Pull:

In order to get most efficient process, companies need to look beyond the production floor. Agile supply chain is essential for better process without any material delays from the supplier or lots on floor. Operating efficient supply chain will not only help better material destitution system but also reduced cycle time which in turn increases plant throughput. One most widely used methods in lean thinking is pull system.

Basic idea behind the pull system was customer will pull the value and once the value is consumed by the customer replenishment will take place, on this order customer will be dictating the demand and this completely opposite to the stock to buy models. There are three basic types of pull system; replenishment pull, sequential pull, and mixed pull system with elements of the previous two combined [7]. In a pull system entire supply chain activity from purchasing to deliver, production activity from raw material to final product is based on the demand rather than forecast. We can understand pull system by looking at the Walmart's supermarket. The replenishment activity only takes place when customer pulls the product form the shelf. A signaling system is used to replenish the empty shelf using a system called Kanban which is explained in detail in later chapter. On production floor, pull signals may be as simple as one operator turning to his predecessor and asking for the required item. In more formal environments, the operator wishing to pull a resource into his area might pass a card with the required item number to the lower level [8].

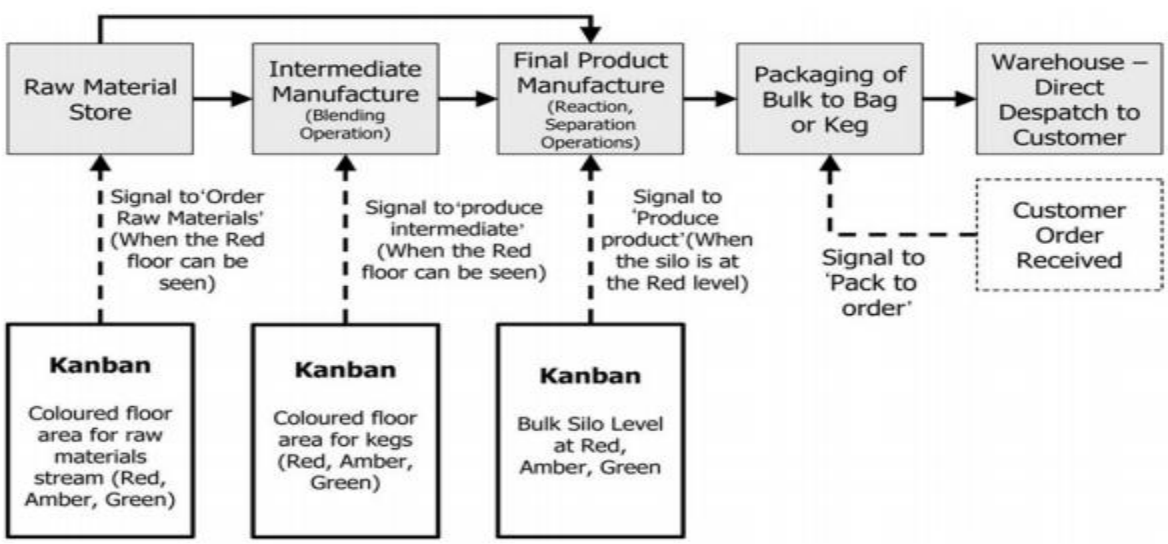

Figure 4: Kanban based pull system [8]

2.3.5 Perfection:

Perfection is the last principle and perhaps hardest to achieve. All the previous our principles will help to achieve in identifying waste and elimination it systematically but final principle helps in sustaining the implemented improvement.

Each principle from identifying value, where customer is willing to pay, to designing value stream for eliminating Muda, creating continues flow to implementing pull to use demand based models where only customer can create. Each production process will gain efficiency based on the new improvements however sustaining will be key to make sure they will not deviate from intended specifications. Perfection is more based on the cultivation lean culture. As the team implemented continues improvement, the idea will that perfection can be achieved. Total perfection is hard or nearly impossible to achieve in real word but eliminating waste and getting close to prefect system.

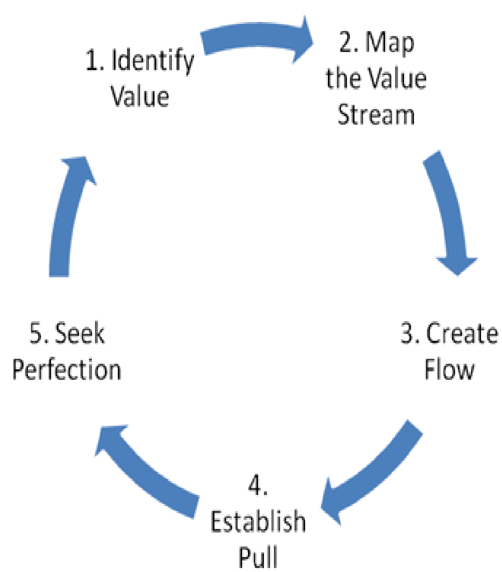

Figure 5: Lean principle cycle [25]

2.4 Seven types of waste:

In lean world waste can be defined as any activity that does not create value to its producer or consumer. Lean tools and techniques are designed to eliminate non value added activist in system. In any production process 90 percent of activity is considered waste. Lean thinking always strived to identify and eliminate waste at any given opportunity in a system. The systematic attack on waste is also a systematic assault on the factors underlying poor quality and fundamental management problems [10].

According to Toyota production system there are seven types of waste.

1. Overproduction – Occurs when operations continue after they should have ceased. This results in an excess of products, products being made too early and increased inventory.

2. Waiting – Sometimes referred to as queuing and occurs when there are periods of inactivity in a downstream process because an upstream activity has not delivered on time. Sometimes idle downstream processes are used for activities that either do not add value or result in overproduction.

3. Transport – Unnecessary motion or movement of materials, such as work in progress (WIP) being transported from one operation to another. In general transport should be minimized as it adds time to the process during which no value is added and handling damage can occur.

4. Extra processing – Extra operations such as rework, reprocessing, handling or storage that occur because of defects, overproduction or excess inventory.

5. Inventory – All inventory that is not directly required to fulfil current customer orders. Inventory includes raw materials, work-in-progress and finished goods. Inventory all requires additional handling and space. Its presence can also significantly increase extra processing.

6. Motion – Refers to the extra steps taken by employees and equipment to accommodate inefficient layout, defects, reprocessing, overproduction or excess inventory. Motion takes time and adds no value to the product or service.

7. Defects – Finished goods or services that do not conform to the specification or customer's expectation, thus causing customer dissatisfaction.

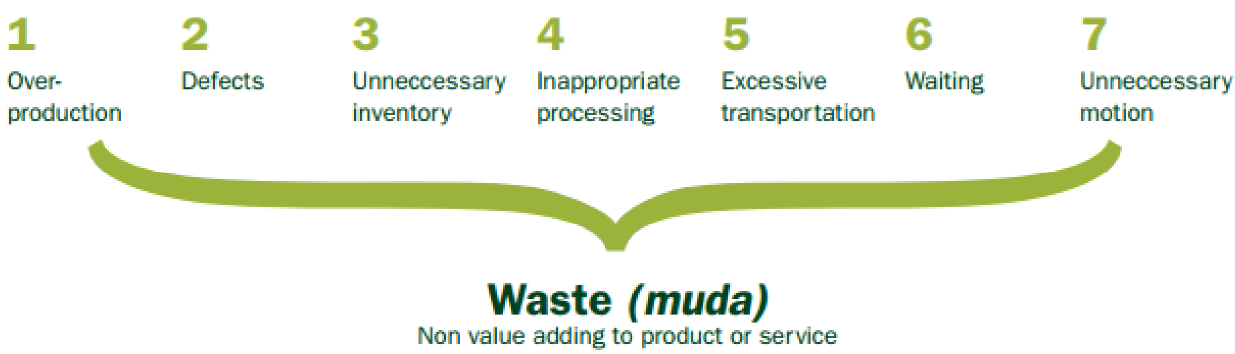

Figure 6: Types of waste [10]

2.5 Value Stream Map:

From the above we have learned that it is important to define and identify value. Once the value is being defined we can identify non value added activity from value added activity. To understand the value added process and flow we use lean tool called value stream mapping (VSM). VSM is most important tool in lean arsenal. Traditional value stream map is drawn using paper and pen from the customer to supplier and carefully draw the visual representation of each process to complete the cycle. It helps you to visualize more than just a single process but gives a holistic view of entire production system from raw material to finished goods or service. VSM is the very famous tool in continues improvement because of its two key characteristics: one its material flow and second information flow. Second characteristics is as important as the first one because in lean manufacturing oppose to mass production, process output is based on previous process. In other words, first process only make what second process need at specific time and this is achieved by information flow. Using VSM, many OEM's and their top-tier suppliers have changed their existing facility layouts, as well as existing systems for material handling, inventory control, purchasing and scheduling, to reduce the total throughput times of orders and current levels of work-in-process (WIP) inventories [13]. Value stream has two states, current and future.

The current state map is baseline view of existing process from which all improvement is measured [11]

The future state map represents the vison of how the project team sees the value stream in the future after improvements have been made [11].

Current state VSM is an initial analysis of the entire plant. Drawing current state will include material flow from supplier to final delivery including information flow with cycle times. Value stream mapping is always starts with the customer and ends with supplier. Once the VSM is analyzed and nonvalue activities has been identified we can draw the future version of VSM based on value specified by the customer.

In lean thinking, the critical place to begin any improvement effort is clear specification of the value of a product as perceived by the end customer. Otherwise you will run the risk of improving value stream that efficiently providers the end customer other than what's really wanted. Thus mapping begins with the customer requirement [12].

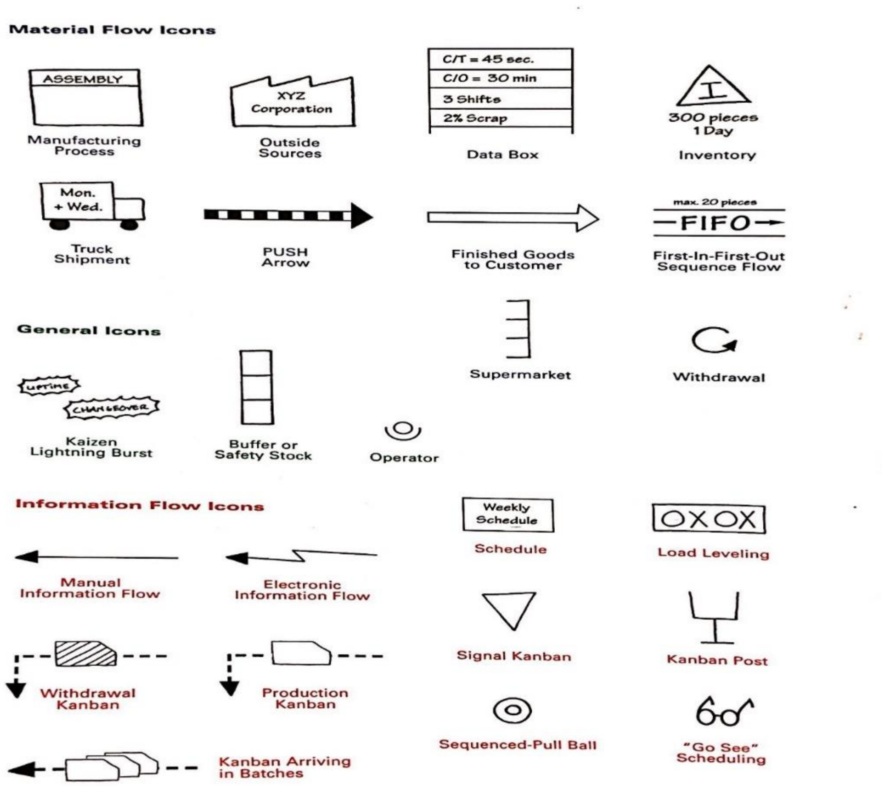

Figure 7: Value stream map symbols [12]

Value stream map is divided into three sections

1. Process or Production flow
2. Information flow
3. Time line and travel distance

2.5.1 Process or Production flow:

This portion of the map is most associated with the flow of production process. Process is always flows from left to right side on the sheet. When value stream map is drawn in this way it is possible to identify the process and sub process allowing the team to see the opportunities to eliminate non value added activities. Process box is drawn to each process and when material flown to next process push or pull arrow is used to depict. Triangle sign is used for inventory sign when material stocked in-between the process.

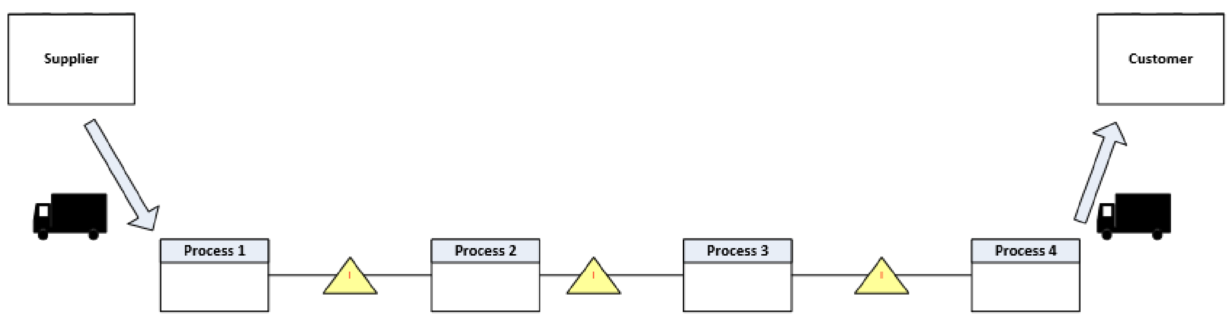

Figure 8: Basic process flow in VSM [11]

2.5.2 Information flow in VSM

The next stage in VSM is information flow and probably most important in terms of lean thinking because process only starts once previous process reliever information signal to start next process. Much of the chaos and confusion that often appears within a value stream can be traced directly to non-value added communication [11]. Information always travel from customer to supplier from right side to the left of paper see figure 9. In current state VSM information flow is not structured but once the non-value added activity is identified and removed, information flows more smoothly -right information to right place at right time.

2.5.3 Time line:

The last state of VSM is time line which documents processing and lead time of the sub and entire process. This state is used by the team to analyze the date and identify the waste. As show in the figure 9, the top line measures the process lead time, sometimes called as lead time or reduction lead time in manufacturing settings [11]. This time is based on the entire inventor and demand by the customer in the value stream that need to be completed. Below line is cycle time which is sub process time for each process. This time is added at the end of line.

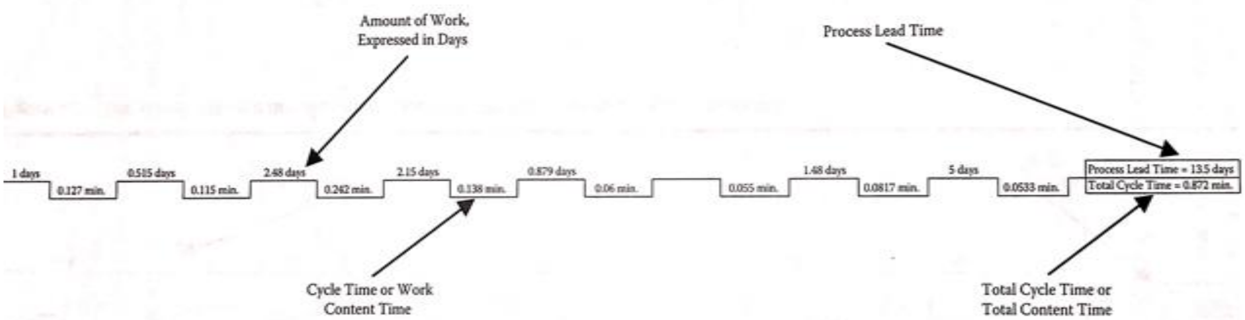

Figure 9: Basic illustration of time line in VSM [11]

2.6 5S work place methodology:

The 5S system is one of the most important techniques in lean manufacturing. When a company's transitions to lean thinking 5S is the first techniques advocated by many lean gurus. The basic idea of 5S is very profound and simple, to keep workstation or work area clean. 5s creates clean and discipline work environment. This "there is a place for everything and everything is in its place" type of organization, characteristic of companies such as toyota, the pioneer of lean production, exposes inefficiencies and disruptions in workflow so these problems are no longer hidden and can be solved [14]. The average workstation in manufacturing plant have unnecessary items stuffed in corners just in case if they needed one day [15].

The 5'S terms are originated in Japan which goes as seiri, seiton, seiso, seiketsu, and shitsuke. There brief definition is described in below table.

Terms	**Definition**
Sort (seiri)	Remove all unnecessary items from location
Set in order (Seiton)	Set remaining items in designated place
Shine (Seiso)	Keep the area swept and clean
Standardize (Seiketsu)	Standardize the process
Sustain (Shitsuke)	Follow the process each day.

Table 1: The 5 S system

In implementation the 5s system in many manufacturing companies fail at fifth S (sustain). Sustaining this system is mainly depending on the companies' ability to adapt to lean culture.

2.7 Kanban System:

Kanban is signaling system developed by Toyota for better inventory control mechanism. Kanban is an effective tool in increasing production process in manufacturing environment. The word KAN means visual and BAN means card in Japanese which is basically a card used to signal to start a process. Traditionally in inventory management this Kanban cards are placed in empty bins signaling that material need to be replenished. This method is based on the pull system which demand driven rather than forecast driven. In manufacturing, Kanban system requires supplier commitment in providing fast services to provide effective supply of raw materials [16]. When the bin is empty on the floor supplier will replenish when Kanban card is placed on the bin with quantity required see figure 10. Most of the time high degree of supplier relationship is needed to implement ideal Kanban system for production floor. Kanban process varies depending on the manufacturing company and their production process, demand rate, product variation and unstandardized process. Due to the difficulty in using the Kanban system in its original concept in such diverse situations, variations (or adaptations) to the system (different from the ‘‘original’’) were created to adapt properly to companies’ specific reality [17].

To overcome such problems, various types of Kanban systems and related techniques have been developed. Adaptive Kanban is allowed to change the number of Kanban cards with respect to unstable demand [18]. Traditional Kanban cards has been replaced with modern digital version of signal system thanks to emergence of information management technologies. Real time information is being shared with different suppliers to provide accurate information of raw material inventories which enables better routing systems and decreased production halts due to material shortage. Many manufacturing industries started deploying better ERP systems to steam line there supply chain activities. Kanban systems started evolving with information systems adapted by the companies to develop better inventory management strategies.

Focus on Material distribution became key component in most of the manufacturing firms who strive to reduce working capital. However, there are few companies still struggle with implementing optimal Kanban systems on production floor.

Figure 10: Basic illustration of Kanban card [24]

2.8 Value analysis:

Value analysis is system, a set of complete techniques, properly arranges for solo purpose of efficiently identifying unnecessary costs before, during and after the fact [20]. A value analysis is performed in many different way depending of the purpose of identifying the value. Time value analysis is one most common in lean continues improvement projects. When the bottleneck is identifying in production system, to understand the root cause, it is important to know each step of the process from design phase to development phase. Analyzing each sub process will provide details on where improvement is possible and how value can be increased. Recording and document time date will help team or company to understand the trends in the process. In typical lean thinking most the process have 70 percentage of waste. Comprehensive time value analysis will provide target areas in production process.

2.9 Total quality management (TQM):

Total quality management gained popularity in early 1990 when global market became more competitive for many manufactures. Managers constantly trying to increase process effective to deliver superior quality than their rivals at both international and domestic levels.

TQM is an integrated management philosophy and set of practices that emphasizes, among other things, continuous improvement, meeting customers' requirements, reducing rework, long-range thinking, increased employee involvement and teamwork, process redesign, competitive benchmarking, team-based problem-solving, constant measurement of results, and closer relation- ships with supplier [21]. TQM as set of ideas are very useful in bring superior quality process for customer base for both manufacturing and service industrial. Latter is arguably controversial because TQM origins are from manufacturing sector. To deploy and sustain TQM top management's involvement is empirical and to achieve companies intended goals clear vison for quality management should be designed which included all the departments, Employees and suppliers to fulfill customer satisfaction.

Designing the production process to produce the product that customer is willing to invest is what makes company successful however, central idea of TQM is not only to make customer happy but to achieve customer delight by exceeding expectation of the customer. There are number of tools developed from past decades to achieve this purpose, once of them is house of quality see figure 11 which is designed specifically to understand customer requirements and translate into engineering language. Total quality management involves in design, production process, Customer satisfaction, customer date, Process engineering and Product delivery.

In this context TQM can be defined as "TQM is a corporate culture characterized by increased customer satisfaction through continuous improvements, in which all employees actively participate" [22].

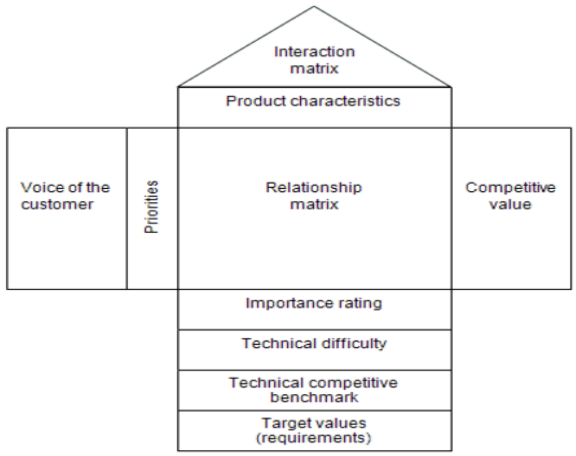

Figure 11: House of quality [22]

2.10 ABC analysis:

Inventory management in every manufacturing organization plays a critical role in maintaining working capital to optimal limit. When a company spends more than 50 percent of the financial resources on the material and rest on the operations, Salaries and variable costs, purchasing patterns play a significant role in maintaining flow of cash. To meet the customer deliver time, it's important to design well suited supply chain strategy. Sometimes with manufacture complex products need multiple sub parts that goes into the systems to make final product. To meet the efficiency and demand for every station material cannot be delayed and must be delivered on time. Different raw material has different lead times, Companies need to understand material importance in respect to production process and impacts of overall efficiently of the plant. Automotive companies have wide range of inventory items that need to be managed. As more and more customers demand a wide range of products, the need to increase the variety of inventory items is also increases.

The basic principle of ABC analysis is based on 80-20 rule, which states as 80% of the effects is caused by 20% of the causes. This observation was first made by an Italian economist, Vilfredo Pareto, and is called Pareto's law. As applied to inventories, it is usually found that the relationship between the percentage of items and the percentage of annual dollar usage follows a pattern in which three groups can be defined [23]:

Group A About 20% of the items account for about 80% of the dollar usage [23].

Group B About 30% of the items account for about 15% of the dollar usage [23].

Group C About 50% of the items account for about 5% of the dollar usage [23].

In ABC analysis Class A indicates that 80% of cash goes to 20% of material, getting tight control on 20% of the material will reduce working capital tremendously. ABC classification can also be used in warehouse systems with segregating high value material to low value material. Its helpful tool during designing layout, raw materials can be segregated based on the constant usage to rarely usage. If class A items are used on daily bases, Class B and C are used not so frequently layout can be designed by separating all their item classification for better logistical support for production.

Chapter 3: Methodology

3.1 Research methodology:

The current state of production system at delta Waseca was poorly maintained with constant troubles with longer processing times, reworks and quality issues. To address the situation a systematic approach is developed to analyze the entire plant to understand effects of this symptoms. When the analysis is conducted and constrains were understood, a methodology is developed to increase the production rate of plant by optimizing the operation activities from raw material to final product.

Plan was developed looking at the holistic view of production process considering working capital of the company at specific time and supplier relations. In this chapter we have explained the methods used to achieve higher production rate with implementing new process to existing production system using lean thinking approach. The main goal of this paper to study and understand the entire holistic value stream and implement the changes based on the five core principles of the lean manufacturing.

As the methodology was devised based on the lean manufacturing principles and process improvement tool used to identify the bottlenecks in current system. When the bottleneck were identified and the process is analyzed, new process is designed based on the available resources in relation to financial situation of the company.

Major emphasis is given to the inputs provided by the shop floor workers and their feedback on the current process. It is noted again and again that most important pillar in lean thinking is the involvement of people.

Lean principles	Methodology steps	Tools
Value	Analyze customer value	Gemba walk
	Analyzes plants situation	Observation tool
	Understand plants capacity	process knowledge
Value stream	Conduct value stream for entire plant	Value stream mapping
		Bottleneck analysis
	Identify the bottlenecks	Time analysis
Flow	Analyze flow for entire plant	Plant layout
	Make material flow in same direction	Safety analysis
	Reduce transit distance	Location design
Pull	Pull material based on order	Kanban two bin system
	Control inventory based on demand	ABC analysis
		EOQ models
Perfection	Cultivate lean culture	Daily meetings
		Standardization of process
	Sustain the implemented process	Employee empowerment
		Training documentation

Table 2: Lean methodology matrix

Methodology matrix is developed see table 2, to understand the steps need to make the change happen on the work floor.

3.2 Identifying the value chain

A systematic approach is developed to identifying current state bottlenecks. Value stream map is drawn for the entire plant, constrains are identified by analyzing value stream and current conditions. Current state value stream map is analyzed by entire team and data is collected.

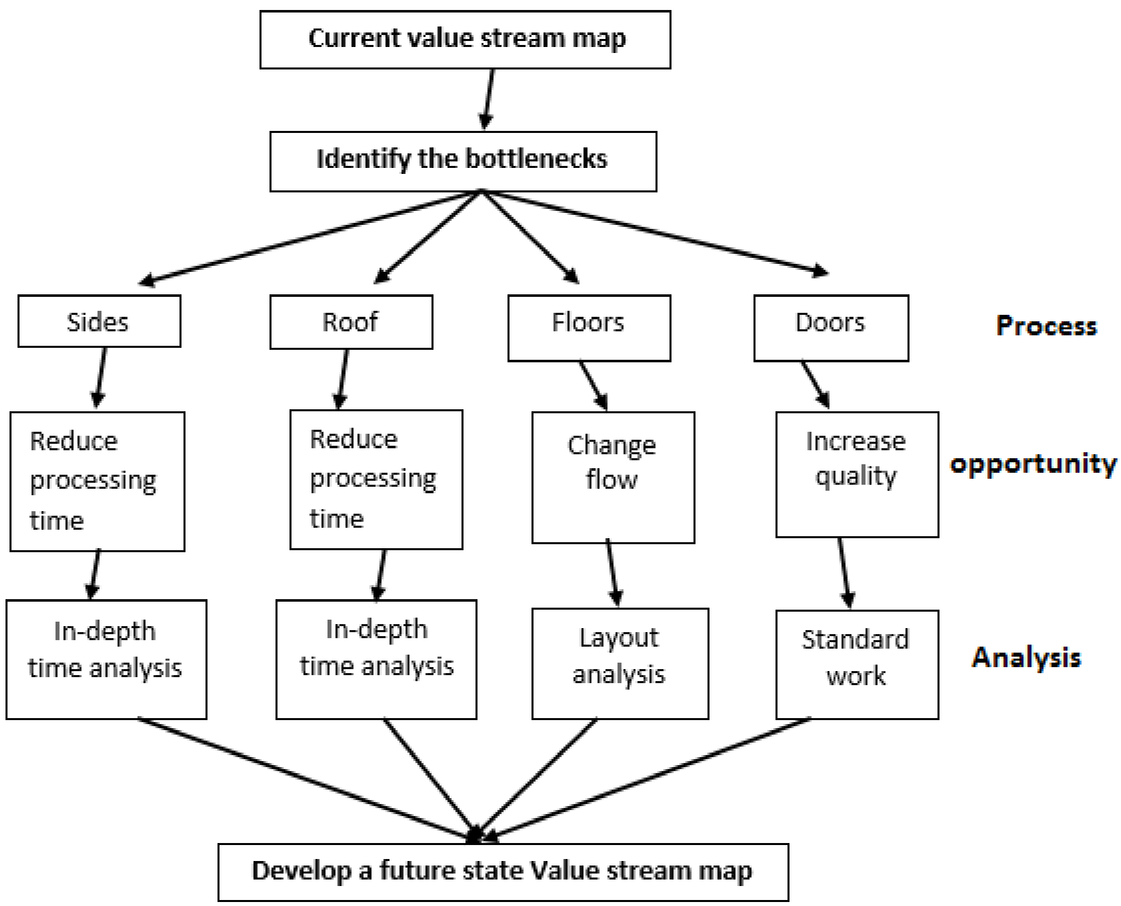

Figure 12: Methodology diagram

3.3 Data collection process:

Data collected from each process to analyze the potential opportunities to improve the process.

Time sheets where used to collect the data for each individual process, which is used to target areas for kaizen team to look for process improvement opportunities. For the target area, In-depth time analysis is conducted to each sub process from material travel time to final assembly time. Stop watch is used to collect time data for each process and data is documented which in turned used to analyze the bottlenecks. Table 3 is an example of time sheets, date analyses and results are discussed in detail on next chapter.

JOB TYPE	TYPE OF BODY	START DATE	START TIME	END DATE	END TIME	TOTAL TIME (Hr.)
UNDERCOAT	QXTSS-80-12'6"-96-	5/3/2016	11:30:00 AM	5/3/2016	1:30:00 PM	**2.00**
ASSEMBLE	QX-85-16-102-CURT	5/3/2016	6:45:00 AM	5/3/2016	12:00:00 PM	**5.25**
ASSEMBLE	QX-85-16-102-CURT	5/3/2016	6:45:00 AM	5/3/2016	2:00:00 PM	**7.25**
ASSEMBLE	QX-85-16-102-CURT	5/4/2016	6:00:00 AM	5/4/2016	11:00:00 AM	**5.00**
ASSEMBLE	QX-85-16-102-CURT	5/5/2016	6:00:00 AM	5/5/2016	11:30:00 AM	**5.50**
RADIUS	QX-85-16-102-CURT	5/4/2016	10:45:00 AM	5/4/2016	4:20:00 PM	**5.58**
ASSEMBLE	QXT-85-16-96	5/11/2016	6:02:00 AM	5/11/2016	11:26:00 AM	**5.40**
ASSEMBLE	QXT-85-16-96	5/11/2016	12:00:00 PM	5/11/2016	2:30:00 PM	**2.50**
ASSEMBLE	QXT-85-16-96	5/11/2016	12:00:00 PM	5/11/2016	2:30:00 PM	**2.50**
FLOOR	QXT-85-16-96	5/9/2016	3:50:00 PM	5/9/2016	4:15:00 PM	**0.42**
FLOOR	QXT-85-16-96	5/10/2016	6:00:00 AM	5/10/2016	7:30:00 AM	**1.50**
REARS	QXT-85-16-96	5/9/2016	8:00:00 AM	5/9/2016	11:00:00 AM	**3.00**
ROOFS	QXT-85-16-96	5/10/2016	6:01:00 AM	5/10/2016	9:30:00 AM	**3.48**
ROOFS	QXT-85-16-96	5/10/2016	1:09:00 PM	5/10/2016	4:20:00 PM	**3.18**
ASSEMBLE	QX-103-26-102	5/5/2016	9:35:00 AM	5/5/2016	4:20:00 PM	**6.75**
ASSEMBLE	QX-103-26-102	5/5/2016	12:00:00 PM	5/5/2016	3:30:00 PM	**3.50**
FLOOR	QX-103-26-102	5/4/2016	7:00:00 AM	5/4/2016	9:00:00 AM	**2.00**
RADIUS	QX-103-26-102	5/9/2016	2:10:00 PM	5/9/2016	4:20:00 PM	**2.17**
RADIUS	QX-103-26-102	5/10/2016	6:00:00 AM	5/10/2016	10:00:00 AM	**4.00**
ASSEMBLE	QX-103-26-102	5/9/2016	6:20:00 AM	5/9/2016	6:40:00 AM	**0.33**
ASSEMBLE	QX-103-26-102	5/9/2016	8:30:00 AM	5/9/2016	11:00:00 AM	**2.50**
ASSEMBLE	QX-103-26-102	5/9/2016	8:30:00 AM	5/9/2016	3:00:00 PM	**6.50**
FLOOR	QX-103-26-102	5/4/2016	3:30:00 PM	5/4/2016	4:20:00 PM	**0.83**
FLOOR	QX-103-26-102	5/5/2016	6:00:00 AM	5/5/2016	8:00:00 AM	**2.00**

Table 3: Time sheet

3.4 process analysis:

A methodology is developed to analyze the current production system and implement the new system to increase the efficiency of plant. In this chapter data is analyses and results obtained from the analysis is discussed. This paper is limited to research questions presented in chapter 1. Every attempt is made on the floor to bring the lean change into reality, as this paper not only present the theoretical finding but most of the finding have been implemented and sustained in real world scenario.

After the initial analysis is conducted with current state value stream mapping, four process which are critical to the process efficient are been identified. Changing the current production system for this targeted area will reduce the processing time on the shop floor and increase the production of one more trailer each day. Each research question is attempted to solve by the unique system design based on lean thinking and floor input, after all they are one who need to agree on the process.

How can you identify major constrains in the plant?

To understand the major constrains in the plant that are responsible for low production rate a value stream analysis is conducted, Value stream map which helps to understand the material flow and information flow along with processing time is drawn for entire plant. Looking at the value stream continues improvement team has identified the target area which are sides, roof and floor which are critical process to build entire trailer. Production line begins with the sides and roof process and without the sides and roof there is no assembly, if there is no assembly there is no trailer down the lane. Working time calculated to be 570 minutes with excluding 60 minutes break.

$$\boldsymbol{To\ achive\ additional\ unit for\ each\ process, following\ condition\ must\ be\ satisfied}$$

$$(\boldsymbol{Ps}, \boldsymbol{Pr}, \boldsymbol{Pf}) \leq \boldsymbol{Tk.t} \qquad (\boldsymbol{condition})$$

$$\boldsymbol{Ps} = \boldsymbol{Process\ time\ for\ sides}, \boldsymbol{Pr} = \boldsymbol{Process\ time\ for\ roof},$$

$$\boldsymbol{Pf} = \boldsymbol{Process\ time\ for\ floors}, \boldsymbol{Tk.t} = \boldsymbol{Takt\ time}$$

3.4.1 Sides process

For the sides process average time were recorded for four trails see figure 13. With the current process for sides each set takes on average of more than 6:00 hours to complete. At this rate current system could not produce more than one set of sides per day as total available working time is only 570 minutes per shift.

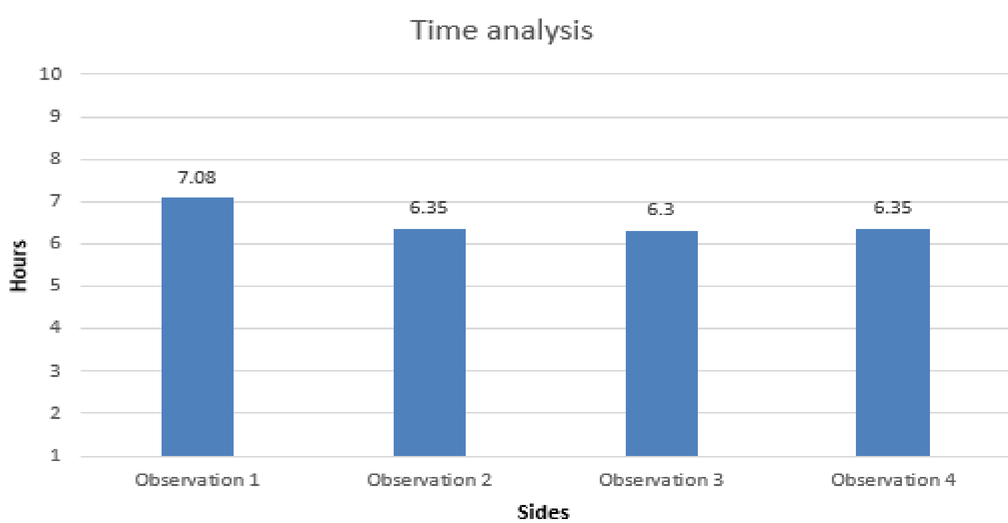

Figure 13: Time analysis for side's process

To get the addition sides in the process we need to reduce the processing time for each sides. An in-depth time analysis is conducted on each sub process, recording each step to second. Based on the documented times a trend is identified to decrease to processing time.

It is noted that three major sub process (Marking, measuring and drilling) accounts for the 35% of total process. Dividing this process with main stream process will save 35% of processing time for each side body. This process is Type 2 waste, which is needed for process to transform the material into final part but customer is does not see the value in this. Now the target area for process improvement is identified we have used the novel thinking based on the available resources to design new process to eliminate waste.

$$Tk.t = \frac{Available\ working\ time}{Demand\ per\ day}$$

Current demand is at 38 units per one month, which is 2 per day (given 19 working days per month)

$$Tk.t = 285\ minutes\ per\ side\ unit$$

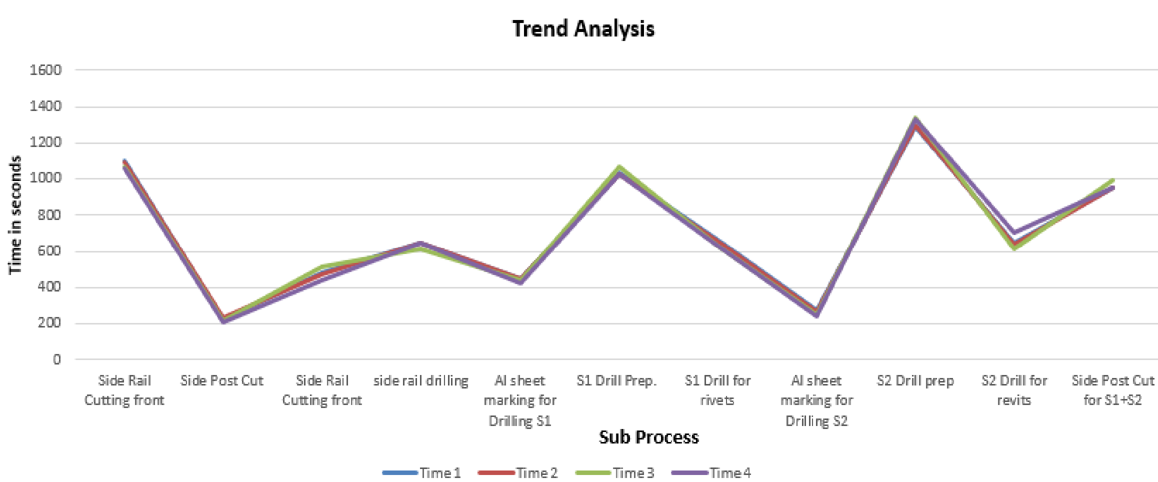

Figure 14: Trend analysis for sides

Above graph shown that each process recorded show same time trend for drilling, marking and measuring process. Elimination measuring and marking process from the main process will reduce human interaction on the process which in turn helps in less rework from the station.

Figure 15 shows the opportunity time which can be reduced from the main process. New working process is deigned based on the trend and looking at the holistically at the process.

Figure 15: Value analysis graph

Dividing the process improvement opportunity time from the main process time will decrease the cycle time for side's process. Worker need to drill two sets for extrusion for sides with more than 600 holes, Before the drill process worker need to cut the extrusion to appropriate length while walking to material lot and station. Once the material is cut, measuring, marking for exact length and drill patters is exposed to various human errors.

Three main sub process marking, measuring and drilling are bottlenecks for side process. Table 4 show the time difference from the main processing time.

Process	Time 1(Seconds)	Time 2(Seconds)	Time 3(Seconds)	Time 4(Seconds)
Cutting operation	2762	2754	2795	2660
Marking operation	718	718	694	672
Drilling operation	4276	4267	4274	4339
Total time(seconds)	7756	7739	7763	7671

Table 4: Sub process time for sides

Based on the time analysis new process is designed to eliminate cutting, marking and drilling operations from the main process in sides work station. Looking holistically at the process, extrusion that need to complete the sides are shipped from the supplier based in Michigan. With the big lean times material most of the time misses the shipping dead line.

3.4.2 Roof processes

In the trailer industry roof is the part with thick sheet supported by aluminum extrusions. This process is similar to side's process. Time analysis is conducted for roof process to understand the bottlenecks in details.

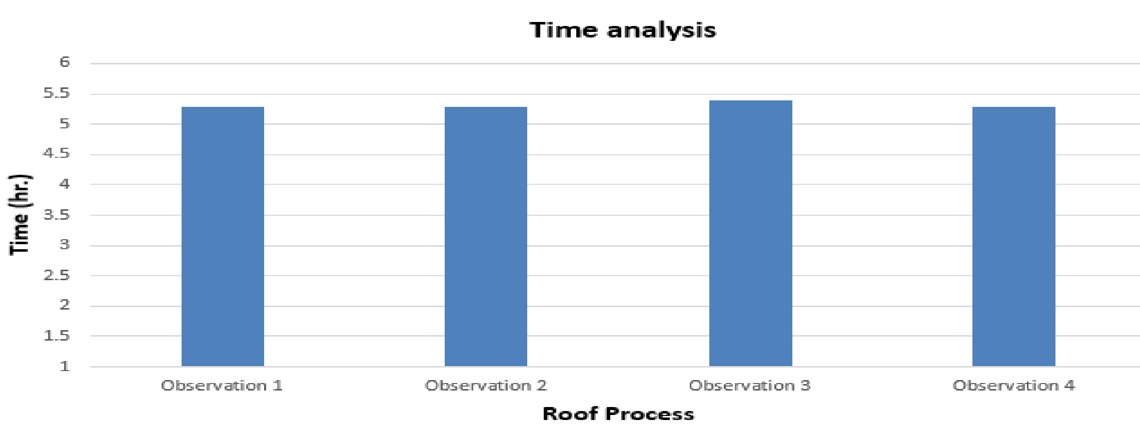

Figure 16: Time analysis for roof process

Total of four observations are conducted to understand the process have any deviation than past process. In-depth time analysis is conducted by recording all the sub process to the second and trend is identified from the four observations.

$$Tk.t = \frac{Available\ working\ time}{Demand\ per\ day}$$

$$Tk.tr = 285\ minutes\ per\ roof\ body$$

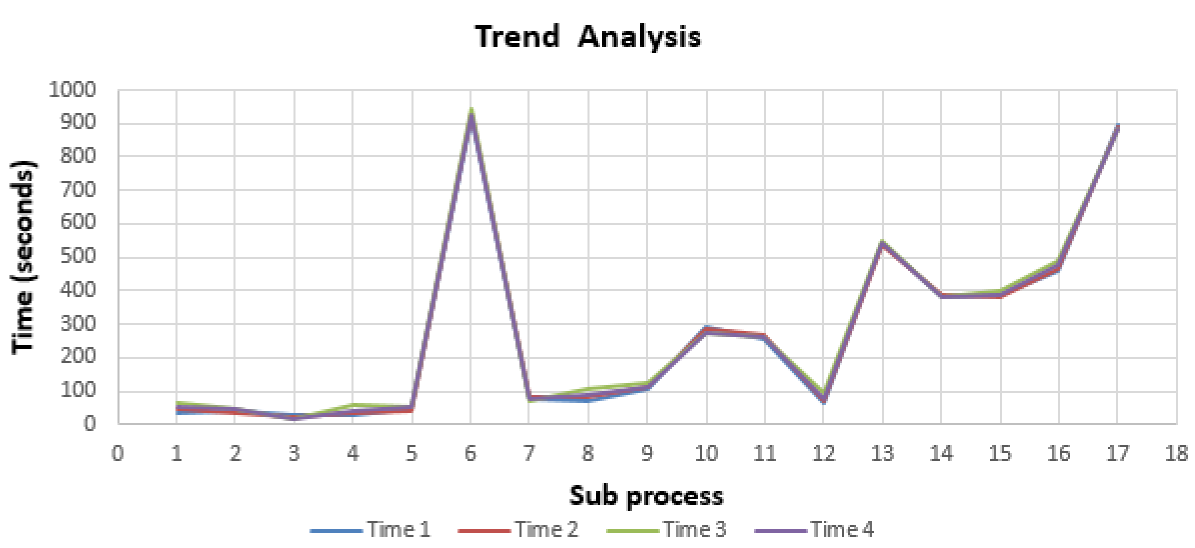

Figure 17: Trend analysis for roof process

Figure 17 shows the trend analysis for roof improvement process. Sub process 5 to 7 and 14 to 17 are time consuming, developing a plan to reduce this targeted process will reduce overall production time for roof process. To get addition roof to increase the plant process time should not be more than 4.4 hr. per unit in roof station. To eliminate the non-value added activities for roof same process as of sides is followed. Removing the cutting, drilling and measuring operations from the main process will reduce 35% of workload which will in turn decreases total processing time for roof.

Sub Process	Time 1 (seconds)	Time 2 (seconds	Time 3 (seconds	Time 4 (seconds
Cutting operation	548	535	566	563
Measuring operation	2141	2208	2286	2222
Drilling operation	1901	1908	1933	1906
Travel time	30	24	15	18
Total time (Seconds)	4620	4675	4800	4709

Table 5: Sub process time for roof

3.4.3 Floor process

Floors process is the underbody of trailer, this process is divided into three as chassis structure, wood floor and painting process to provide anti corrosion properties. Biggest challenge with this process is flow of the material itself, When the underbody is produced it is moved manually pushing all the way to paint boot in the plant and returning once the painting process is completed. Each time minimum of four workers need to leave their workstation and help move 600 pounds' unit.

Another constrain identified by the kaizen team is raw material unloading and material transportation process to floors station. Current process uses fork lift to unload 30 feet long wooden bars which are safety issues as they are tilting while unloading and entire unloading processing take more than 6 hours with three workers.

See figure 18 for plant layout for floors, Black arrows illustrate material flow as once the floors go to paint boot and returns to same location for assembly process.

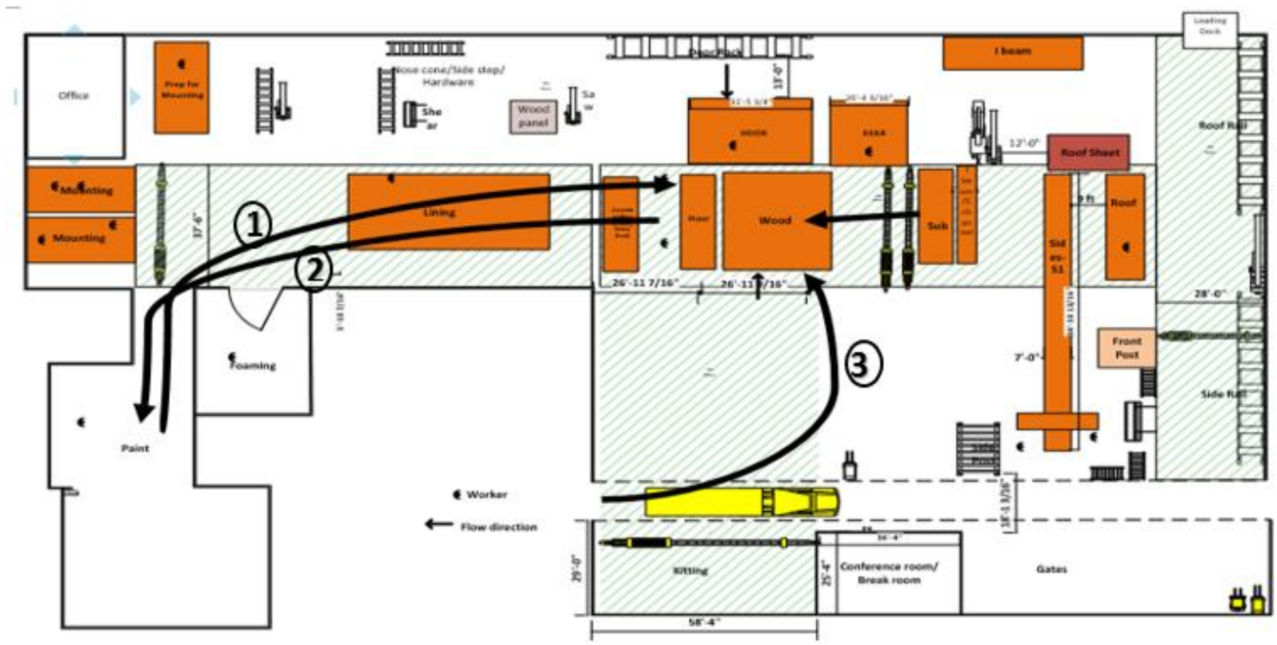

Figure 18: Plant layout for floor process

Different materials interacting with different workstation and to understand this interaction, matrix is created with identifying more than 600 parts and how they interact with each cutting stations. Data was collected on each part in the inventory system and motion analysis was conducted on the each of the items to track the travel path from one workstation to other station.

Material movement (from floor to undercoating)	Material movement (from undercoating to assembly)	People needed for matrial mvement	Unloading time for single kit	Unloading time for full load	People needed for unloading	Total wokers	Total time in minutes
7	7	4	15	390	3	7	404

Table 6: Non value activity time for floor process

Table 6 shows the total time required for material movement and unloading time for floors.

Parts	Floors + Subs	Linning	Mounting	D (EllIS band saw)	G(Betenbender)	H (Bender)	L (Ellis band saw	M(uni hydro)	Y saw Dewalt	E samco cuttin	A (ellis band saw)	B (craftsman saw)	C (dewalt saw)	k Drill Press	
GUSSET-STAINLESS BRKT	x				x	x				x					4
TUBING-STEEL 1" X 1" 1/8" 20'	x						x	x							3
TUBING - STEEL 2X2X1/4X24'	x						x	x							3
TUBING - STEEL 2X2X11GA 20'	x						x	x							3
CONNECTOR - FRONT 109 AE-02-010-07005 106 3/8 (2.925) DIE SS0592/6063T-6												x	x		2
CONNECTOR - REAR 109 107 7/8 (7.389 DIE SS0053/6063T-							x					x			2
ANGLE STEEL 1X1X1/8X20'	x			x											2
ANGLE STEEL 2X2X1/8X20'	x			x											2
ANGLE STEEL 3X2X3/16X20'	x			x											2
ANGLE STEEL 1X3X10 GA FROM 4X10 MCNEILUS # SA-1X3 REAR 12/PER SHEET	x			x											2
CHANNEL STEEL 2X1X3/16 20'	x			x											2
CHANNEL STEEL 3X3.5X20'	x			x											2
CHANNEL STEEL 4X5.4X20'	x			x											2
CHANNEL STEEL 8X8.5X20'	x			x											2
TUBING - STEEL 2 X 4 X 24' 11	x			x											2
FRAME - TOP TKRD72	x			x											2
CROSSMEMBER 3 I-BEAM STD 94" CLIP/DO NOT WAX	x			x											2
CROSSMEMBER 4 I-BEAM 102 METAL #100" CLIP/DO NOT	x			x											2
CROSSMEMBER 4 I-BEAM STD METAL #94" CLIP/DO NOT WAX	x			x											2
CHANNEL STEEL 6X20'			x				x								2

Table 7: Material interaction matrix for floors

In table 7 each "X" state that material has travelled through that following station for required operations. Based on the travel path and required station for operation to change the raw material into final product, layout is designed with moving all required material near to the stations. This table is only limited for floors but entire list with must more detail tables are mentioned in appendix.

3.4.4 Door process:

This process is interlinked with side's process as when the sides are produced for some of the units due to customer specifications entire frame comes with side door frame see figure 19. Measurements are calculated from the actual sides frame process, which means door process can only start once the side process is completed. This is resulting in waiting time at doors workstation where jobs are started late and completed late. During the analysis of door process it is found that due to the complicated working process at door station there is lot of reworks being taking place. It is observed that this is mainly due to lack of proper training for workers at the stations. This observation presented with another challenge, this one is more concerned with the people rather than process. As company delta Waseca is treasure box for information related to process and material. In other words, there is lot tribal knowledge with the workers who did not pass on the process information to their successor at the station and this was also because lack of proper documentation and transparency.

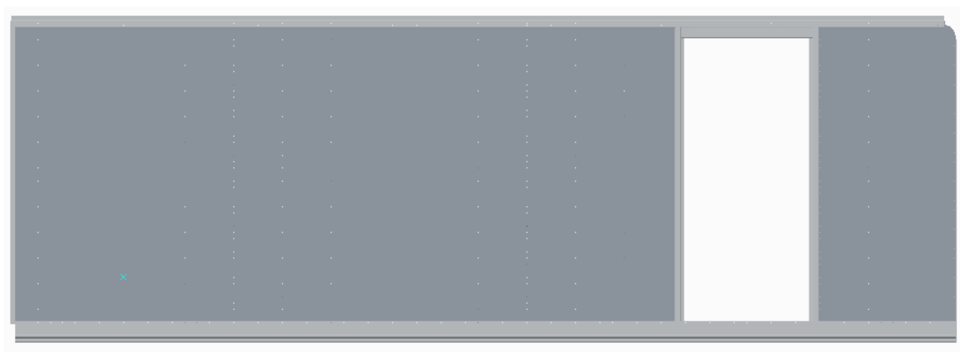

Figure 19: Side Panel with door frame

Chapter 4: Results

In this chapter results after the in-depth analysis for all four major constrained process are been recorded. Lean techniques is used to analysis the process at each of four work stations. Each bottleneck has been studied and different techniques has been identified to eliminate the non-value process.

4.1 Sides Results:

Delta Waseca does not have CNC capabilities however, a sister company (Opus Mach) location in Detroit, just few hours from supplier have state of the art machining systems. Diverting the entire traffic from suppliers to Opus Mach and pre drill all the material need to make the final sides body. Table 8 illustrate the new side's process times.

Observations (sides)	Old process (hr.)	New process (hr.)
Time 1	7.08	4.68
Time 2	6.35	3.95
Time 3	6.3	3.9
Time 4	6.35	3.95

Table 8: Sides new process time results

New process shows the better lead time and superior quality as most of the cutting is done with CNC programming. Eliminating drilling process reduced the final processing time from 390 minutes (6.30 hours) to 247 minutes (3.9 hours). With the available working time of 9.5 hours two side's body can be produced within 8 hours of total production in sides work station.

New process is explained with comparison with the old process for sides using value stream mapping see figure 20. Supplier lead time played a significant role in throughput efficiency. Changing the supplier base and diverting the traffic to machine centers in Detroit helped tremendously in reduction overall cycle time for sides process.

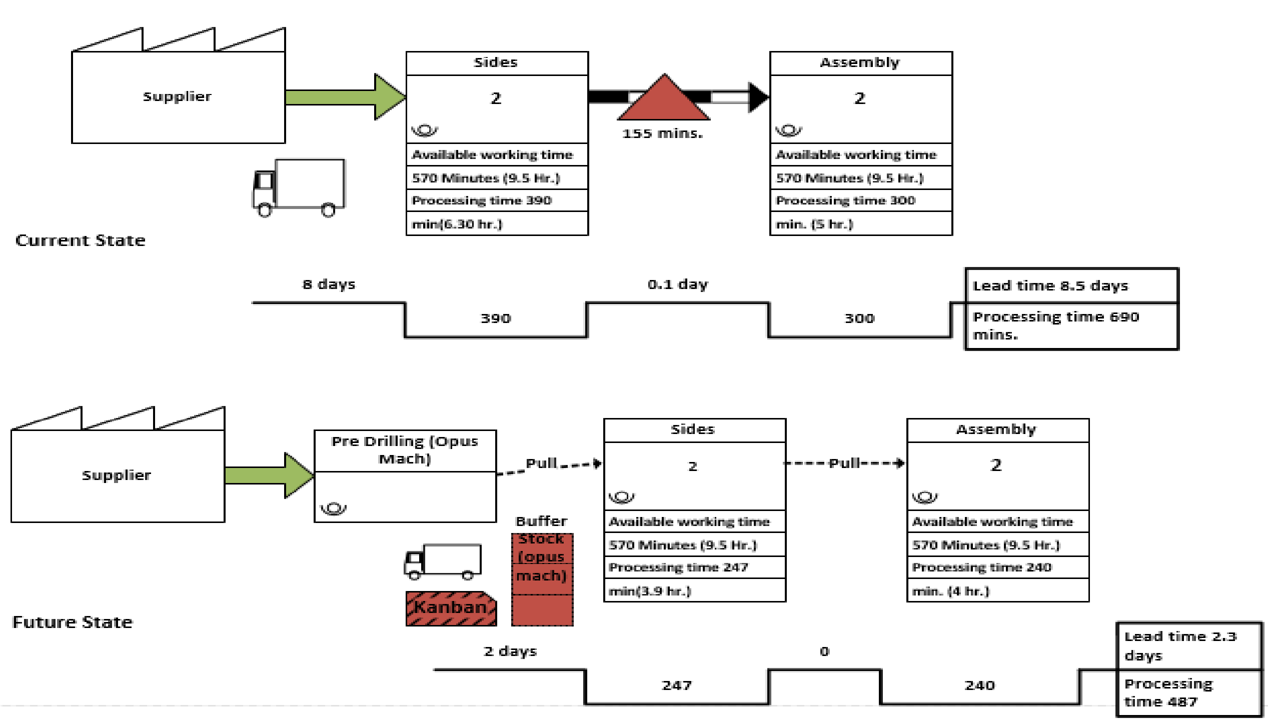

Figure 20: Value stream map for side's process

Based on the new analysis new takt time is calculated for side's process. Considering the demand for two units per day for 19 working days in month.

$$Tk.ts = 285 \; minutes \; per \; unit$$

$$Ps \; \leq Tk.ts \qquad (Condition)$$

$$Note: ts \; is \; time \; for \; sides \; process$$

Ps is abbreviation for side's process and condition should be satisfied to get addition units at station.

Above equation Ps should be less than the takt time in the workstation to achieve required pace time for demand.

$$Ps = 247.2\ minutes\ per\ unit. \quad (247.2 < 285)\ Condition\ is\ met\ for\ sides\ process$$

Above results in the sides workstation is below required takt time to produce 2 units per day.

New process time is 247 minutes per unit.

4.2 Roof process results

As roof process is almost same as sides process where installing the extrusion and riveting together. This process involves heavily on drilling and riveting, to divide this from actual process similar approach is taken as side's process. As material comes from the supplier in Michigan and which is diverted to opus Mach for pre drilling the extrusions. New implemented process has saved on average of 78 minutes per unit in roof station See table 9.

Observations	Old process (hr.)	New process (hr.)
Time 1	5.33	4.05
Time 2	5.34	4.05
Time 3	5.41	4.08
Time 4	5.36	4.06

Table 9: Roof new process time results

New strategy able to save 1 hour 30 minutes approximately comparing to original process time of 5 hours 30 minutes. With the available working time of 9.5 hours, process can produce two roof at the station with 4 hours approximately for each unit.

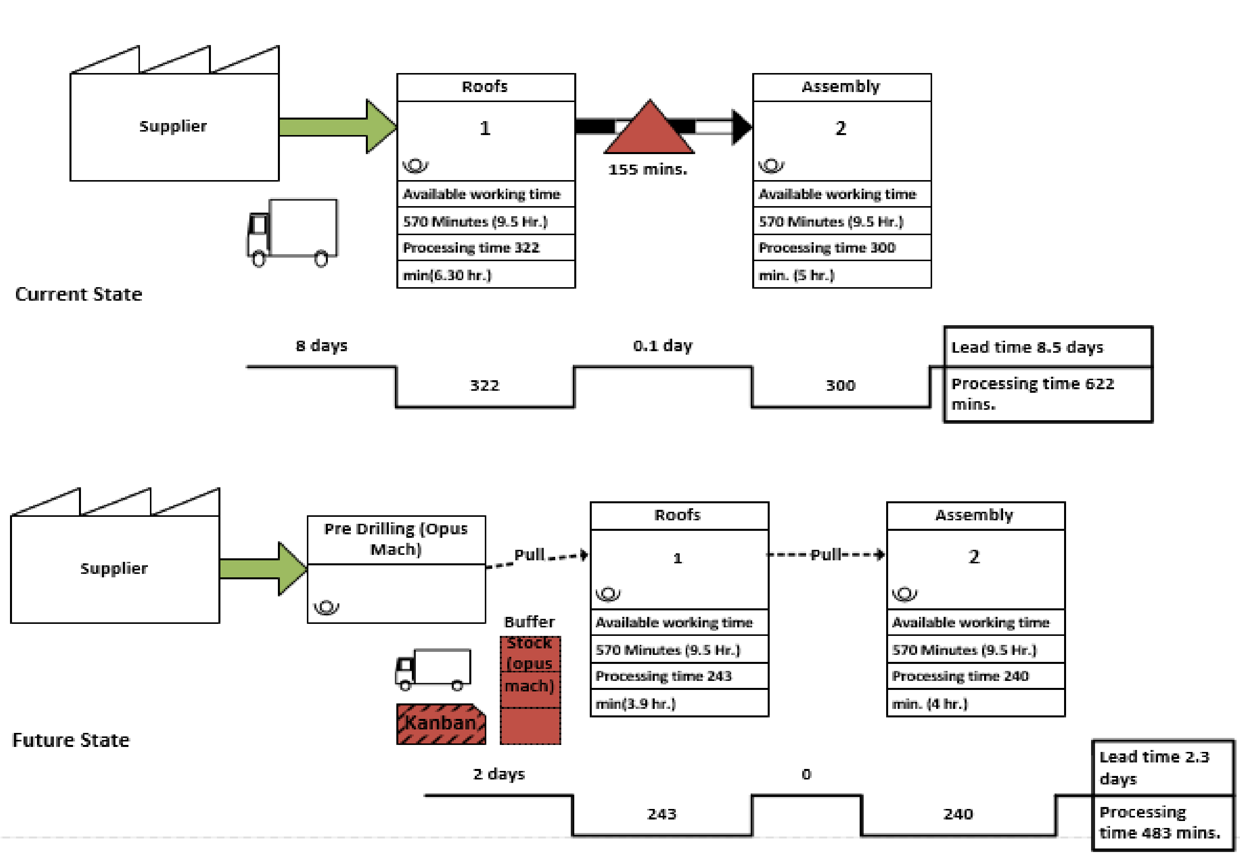

Figure 21: Value stream map for roof process

Based on the new analysis new takt time is calculated for roofs process. Considering the demand for two units per day for 19 working days in month.

$$Tk.tr = 285\ minutes\ per\ unit$$

$$Pr \leq Tk.tr \qquad (Condition)$$

$$Note: tr\ is\ time\ for\ roof\ process$$

Pr is abbreviation for roof process and condition should be satisfied to produce addition unit at the work station. Above equation Pr should be less than the takt time in the workstation to achieve required pace time for demand.

$$Pr = 243 \; minutes \; per \; unit. \quad (243 < 285) \; Condition \; is \; met \; for \; roof \; process$$

New process time for roof station after improvements is 243 minutes per roof.

4.3 Floor process results:

To tackle this constrains in the process, change in the material flow is important. To understand how material is travelling and interacting from each work station, a material interaction matrix is created. Looking at the interactions optimal layout is designed taking material flow and safety issues into consideration. Figure 22 shows the new layout for floor process with optimized flow for both material and transportations.

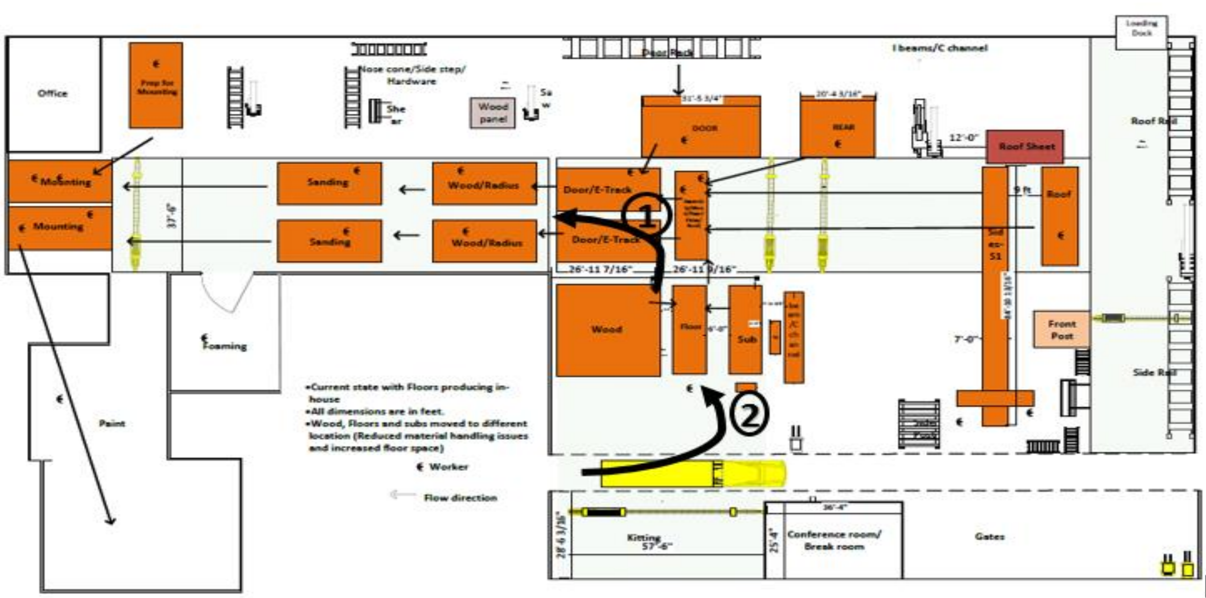

Figure 22: New layout for floors

In new layout, material flow is more linear than older flow. Black arrow with 1 shows the how material flows after floors are put together. Arrow 2 shows raw material receiving flow for floors process.

$$Ft = 78\ minutes$$

$$Note: Ft\ is\ floor\ transit\ time\ from\ one\ station\ to\ other\ and\ material\ unloading\ time.$$

Material movement (from floor to undercoating)	Material movement (from undercoating to assembly)	People needed for matrial mvement	Unloading time for single kit	Unloading time for full load	People needed for unloading	Total wokers	Total time in minutes
0	0	0	3	78	2	2	78

Table 10: New results for floor process

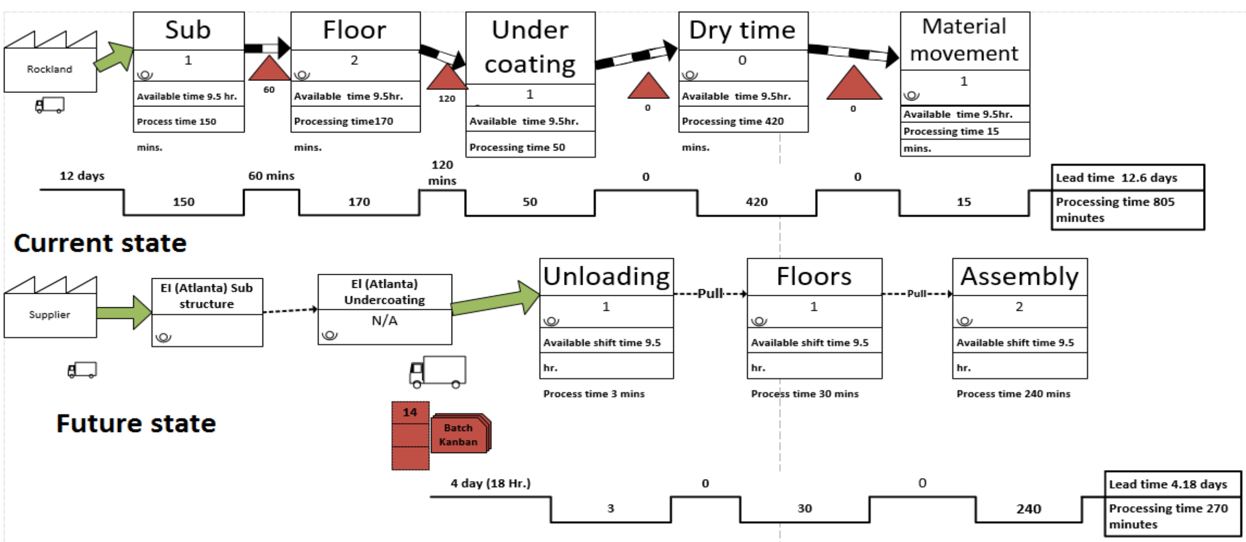

Figure 23: Floors value stream map

$$Pf = 270\ minutes\ per\ unit$$

$$Pf < Tk.t\ (takt\ time)$$

$$Pf = 270\ minutes\ per\ unit. \quad (270 < 285)\ Condition\ is\ met\ for\ floor\ process$$

4.4 Door process results:

Analysis for entire door process from raw material to final production had conducted and it is concluded that improper documentation and training is root cause for low quality and rework. After the collecting required data and input from the floor new standards for each sub process is developed.

For the doors process standard working document is developed, with integrating with training Manuel. Standard working process is one of hardest process to sustain but before that to implement standard work it is important to identify the best practice with required design changed for achieving high quality. Standard working chart is designed with in detail graphical representation of work with explanation of each sub process. Safety is given top priority when working on floor and Personal protective equipment (PPE) is included in the chart along with quality symbols. Figure 21 show the example of implemented standard working chart at doors work station.

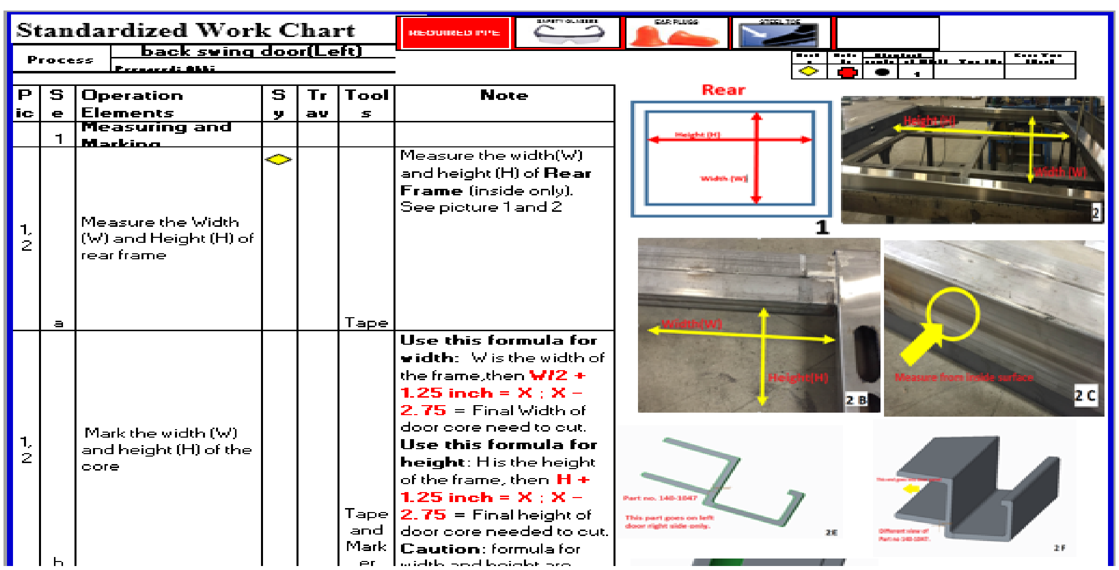

Figure 24: Standard working chart for door process.

Chapter 5: Conclusion

The results of the study were successfully implemented on the floor with lean thinking. Production floor workers played instrumental to achieve this chances by conduction kizen events and extracting the tribal knowledge and applying it to the process helped team to understand bottlenecks in detail. To increase the plant efficiency for sides, roof and floors developed condition has met and processing time are reduced

$$(Ps, Pr, Pf) < Takt\ time$$

$$Ps = Sides\ process\ time, \mathrm{Pr} = Roof\ process\ time, Pf = Floor\ process\ time$$

$$\therefore\ Condition\ is\ satisfied\ for\ all\ three\ major\ process$$

With the product being related to automotive industry, each process improvement where conducted in par with occupational Safety and Health Administration (OSHA), National Highway Traffic Safety Administration, Federal motor safety administration and International Organization for Standardization (ISO).

All the design and process chanced are made with standard verification process and chanced were recorded in engineering chance notice prior to approval. Implementing the process chance with lean thinking will take the organization long way and entire teams participation form managerial level to floor labor level will make the chance lot easier. Small projects are target to make the change happen at the initial stages and eventually once the projects are being successful and team members are more confident about the change, major process changes are carried out.

To sustain the lean culture every day meeting was conducted to talk about the production process and scheduling with the leads and workers for 20 to 30 minutes. This meeting lead to leadership development for some the floor workers and started to lead some projects in absents of supervisor or floor manager.

All employees constantly strived to bring more change on the floor to reduce the lead time and increase the quality of the product. As the company, delta Waseca invest heavily in the lean process implement along with integration of new technologies to build superior quality product in trucking industry.

Reference

1. Womack, J. P., Jones, D. T., & Roos, D. (1990). *Machine that changed the world*. Simon and Schuster.
2. Worley, J. M., & Doolen, T. L. (2006). The role of communication and management support in a lean manufacturing implementation. *Management Decision*, *44*(2), 228-245.
3. Krafcik, J. F. (1988). Triumph of the lean production system. *MIT Sloan Management Review*, *30*(1), 41.
4. Dombrowski, U., & Mielke, T. (2013). Lean leadership–fundamental principles and their application. *Procedia CIRP*, *7*, 569-574.
5. Womack, J. P., & Jones, D. T. (2010). *Lean thinking: banish waste and create wealth in your corporation*. Simon and Schuster.
6. 6 Melton, T. (2005). The benefits of lean manufacturing: what lean thinking has to offer the process industries. *Chemical engineering research and design*, *83*(6), 662-673.
7. Smalley, A. (2007). Connecting assembly with batch processes via basic pull systems. *Arquivo eletrônico disponível no site http://www. artoflean. com. Arquivo capturado no dia*, *10*(09).
8. Schrotter, C. (2000). Looking for lean/pull manufacturing solutions. *Manufacturing System*, *18*(4), 62-64.
9. Hicks, B. J. (2007). Lean information management: Understanding and eliminating waste. *International journal of information management*, *27*(4), 233-249.

10. Hines, P., & Taylor, D. (2000). *Going lean: a guide to implementation*. Cardiff: Lean Enterprise Research Centre.

11. Nash, M. A., & Poling, S. R. (2011). *Mapping the total value stream: a comprehensive guide for production and transactional processes*. CRC Press.
12. Rother, M., & Shook, J. (2003). *Learning to see: value stream mapping to add value and eliminate muda*. Lean Enterprise Institute.
13. Irani, S. A., & Zhou, J. (2011). Value stream mapping of a complete product. *Department of Industrial, Welding and Systems Engineering, The Ohio State University, Columbus, OH*, *43210*.
14. Chapman, C. D. (2005). Clean house with lean 5S. *Quality progress*, *38*(6), 27-32.
15. Hubbard, R. (1999). Case study on the 5S program: the five pillars of the visual workplace. *Hospital materiel management quarterly*, *20*(4), 24-28.
16. Rahman, N. A. A., Sharif, S. M., & Esa, M. M. (2013). Lean manufacturing case study with Kanban system implementation. *Procedia Economics and Finance*, *7*, 174-180.
17. Junior, M. L., & Godinho Filho, M. (2010). Variations of the kanban system: Literature review and classification. *International Journal of Production Economics*, *125*(1), 13-21.
18. Lin, C. J., Chen, F. F., & Chen, Y. M. (2013). Knowledge kanban system for virtual research and development. *Robotics and Computer-Integrated Manufacturing*, *29*(3), 119-134.
19. Karger, D. W., & Bayha, F. H. (1987). *Engineered work measurement: the principles, techniques, and data of methods-time measurement background and foundations of work*

measurement and methods-time measurement, plus other related material. Industrial Press Inc..

20. Miles, L. D. (2015). *Techniques of value analysis and engineering*. Miles Value Foundation.
21. Powell, T. C. (1995). Total quality management as competitive advantage: a review and empirical study. *Strategic management journal*, *16*(1), 15-37.
22. Dahlgaard, J. J., & Mi Dahlgaard-Park, S. (2006). Lean production, six sigma quality, TQM and company culture. *The TQM magazine*, *18*(3), 263-281.
23. Arnold, J. T., Chapman, S. N., & Clive, L. M. (2001). Introduction to materials management.
24. Lean Manufacturing: The Basics of Kanban | Seton Blog. (2013). Retrieved October 01, 2016, from http://www.seton.com/blog/2013/11/lean-manufacturing-the-basics-of-kanban.
25. 5 Lean Principles Every Engineer Should Know. (n.d.). Retrieved October 01, 2016, from https://www.asme.org/engineering-topics/articles/manufacturing-design/5-lean-principles-every-should-know.

Appendix A: Time sheet

DELTA WASECA

Time Sheet

Supervisor Name.. **Date**......................................

Order Number	Job and Type	Start Time	Finish Time	Workers Name

Figure 25: Time sheet for floor workers

Appendix B: Old and new plant layouts

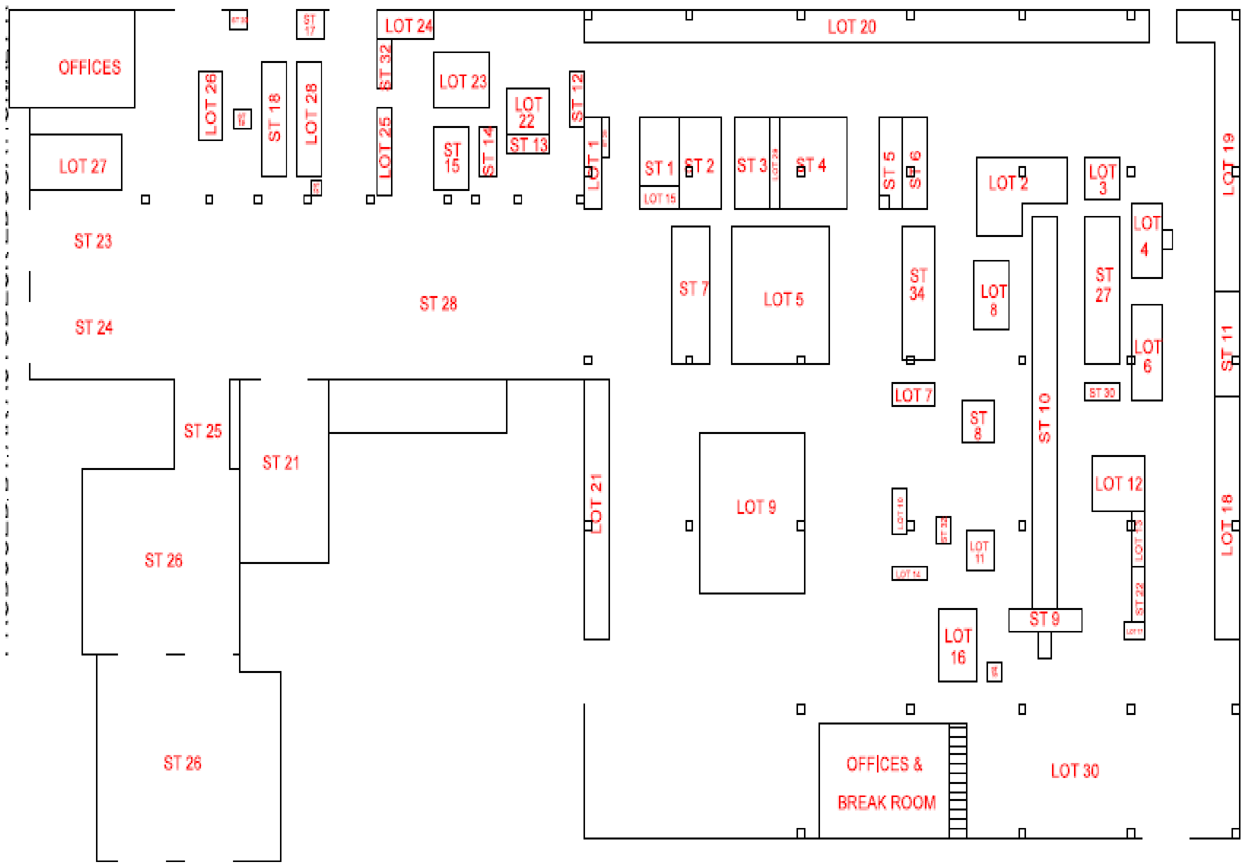

Figure 26: Plant layout before improvement

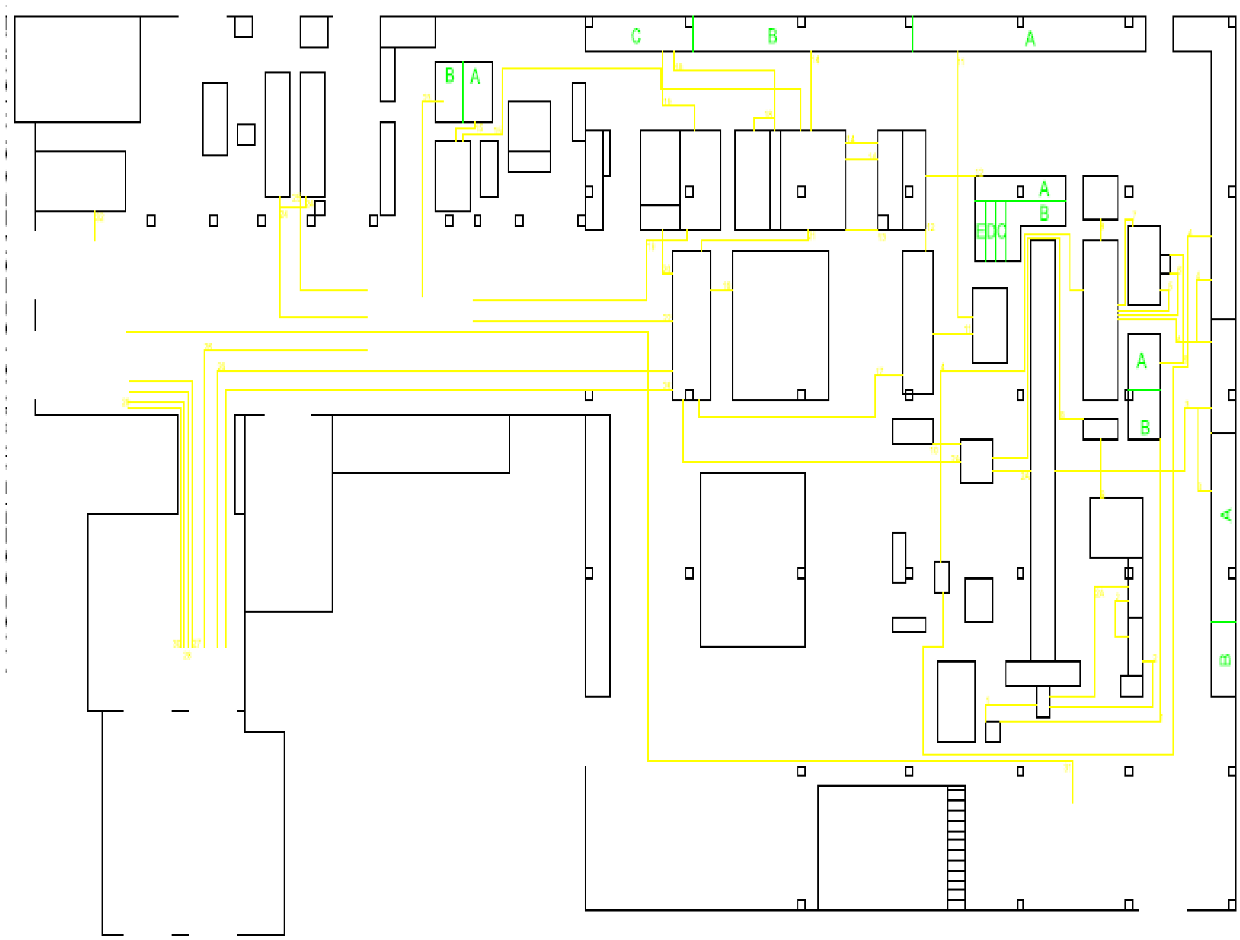

Figure 27: Material travel path for old layout

Station	Description	Lot	Description
1	Rear post	1	Door extrusions & seats
2	Door making	2	A: Steel Channels B: Roof Skins C: Steel D: Wheel pan E: Reinforsment steel for sub-structure
3	Door Parts	3	Roof skins in use
4	Rear Door frame making	4	Roof lights & corner castings
5	Stanless steel polishing	5	Wood plates (floors)
6	Saw	6	A: Roof bow & trim B: Front connectors & side posts
7	Wood floor assembly / Sides and roof assembly	7	Tools / Rock guard
8	Front cabin sheet assembly	8	Crossmember beams
9	Press brake	9	Multi use area
10	Conveyor	10	Scrap metal
11	Rails cutter	11	Connector STD
12	Wood sheet cutter	12	Front Corner posts
13	Wood sheet workplace	13	Side Panels
14	Wood plates workplace	14	Scrap metal
15	Shear	15	Rear posts
16	Drill press	16	Side posts
17	Table saw	17	Side Panels
18	Band saw	18	A: Side rails B: Front corners & side panels & rails
19	Iron worker parts & acceoseries	19	Roof rails
20	Table cutter	20	A: Crossmember beam B: Rear post & header C: Whiting door & door extrusions
21	Foam	21	Radiuses for fronts (connection between front & roof)
22	Sheet cutter	22	Wood sheets
23	Mount	23	A: Guage smooth (steel & aluminum) B: E-Track
24	Mount	24	Nose Cone
25	Lights assembly	25	Bolts & rivits
26	Paint	26	Flat metals
27	Roof assembly	27	Walk ramps / lights
28	Wood sanding / Door assembly / Accessories	28	Steps (footing) / frame extensions
29	Door extrusion & seat cutter	29	Door extrusions
30	Drill	30	Multi use
31	Band saw		
32	bender		
33	post cutter		
34	Sub structure welding		

Table 11: Lots and station

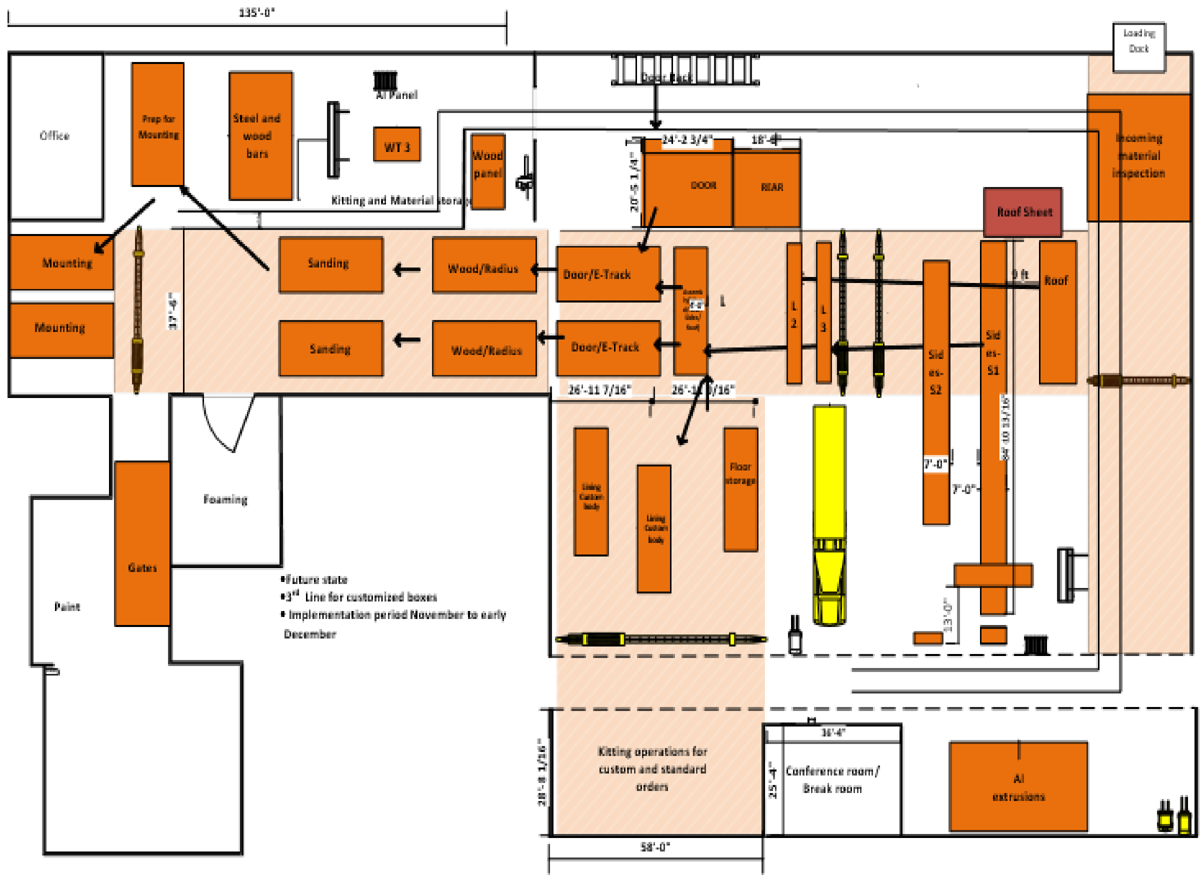

Figure 28: New layout

Appendix C: Sides process data and trend analysis

Sides Sub Process	Time 1	Time 2	Time 3	Time 4	Average Non value added time	Average Processing time
Side Rail Cutting front	1848	1845	1822	1907	517	1855.5
Side Post Cut	1100	1095	1068	1060	240	1080.8
Sheet Cut Front	226	231	219	207		220.8
Rivets install after side rails install	540	537	577	537	73	547.8
Taping Front	114	109	86	87	36	99.0
Rivet install and Press breake	376	381	354	413		381.0
Side Rail Cutting front	524	521	509	583	330	534.3
Side Rain install + drill	482	477	517	442	460	479.5
side rail drilling	626	631	608	596		615.3
install rock gard	648	645	618	645		639.0
Sheet cut S1(Left)	308	303	291	281		295.8
Rivet plus Press Break S1	1496	1501	1541	1533	650	1517.8
side rail insatll S1	434	431	408	493		441.5
Al sheet marking for Drilling S1	1136	1131	1104	1096	100	1116.8
S1 Drill Prep.	446	451	439	427	77	440.8
S1 Drill for rivets	1032	1029	1069	1029		1039.8
install Rivets S1	660	655	632	633		645.0
Taping S1	258	263	236	295		263.0
Sheet cut S2 (right)	212	209	197	271		222.3
Rivets + Press Break S2	1166	1161	1201	1126		1163.5
Side rail install S2	190	195	172	160		179.3
Al sheet marking for Drilling S2	648	645	618	645		639.0
S2 Drill prep	272	267	255	245	112	259.8
S2 Drill for revits	1292	1297	1337	1329	20	1313.8
install Rivets S2	644	641	618	703		651.5
Taping S2	132	127	100	92		112.8
Side Post Cut for S1+S2	644	649	637	625		638.8
Seal Rivets S1	954	951	991	951		961.8
Seal Rivets S2	1848	1853	1830	1831		1840.5
Total time in seconds	22871	20231	20054	20242	2615	20849.5
Total minutes	381.18	337.18	334.23	337.37	43.58	347.5
Total hours	6.35	5.62	5.57	5.62	0.73	5.8
Final time	7.08	6.35	6.30	6.35		6.5
S1 and S2 are two side (Left and Right)						

Table 12: Sides process data sheet

Sides Sub Process	Time 1	Time 2	Time 3	Time 4	Average Non value added time	Average Processing time	Average Processing time (minutes)
Side Rail Cutting front	1100	1095	1068	1060	240	1080.8	18.0
Side Post Cut	226	231	219	207		220.8	3.7
Side Rail Cutting front	482	477	517	442	460	479.5	8.0
side rail drilling	648	645	618	645		639.0	10.7
Al sheet marking for Drilling S1	446	451	439	427	77	440.8	7.3
S1 Drill Prep.	1032	1029	1069	1029		1039.8	17.3
S1 Drill for rivets	660	655	632	633		645.0	10.8
Al sheet marking for Drilling S2	272	267	255	245	112	259.8	4.3
S2 Drill prep	1292	1297	1337	1329	20	1313.8	21.9
S2 Drill for revits	644	641	618	703		651.5	10.9
Side Post Cut for S1+S2	954	951	991	951		961.8	16.0
Total Seconds	7756.00	7739.00	7763.00	7671.00	909.00	7732.25	128.87
Total minutes	129.27	128.98	129.38	127.85	15.15	128.87	
Final time minutes	144.42	144.13	144.53	143.00			
Total hours	2.4	2.4	2.4	2.4			2.15

Table 13: Sides data sheet improvement opportunity

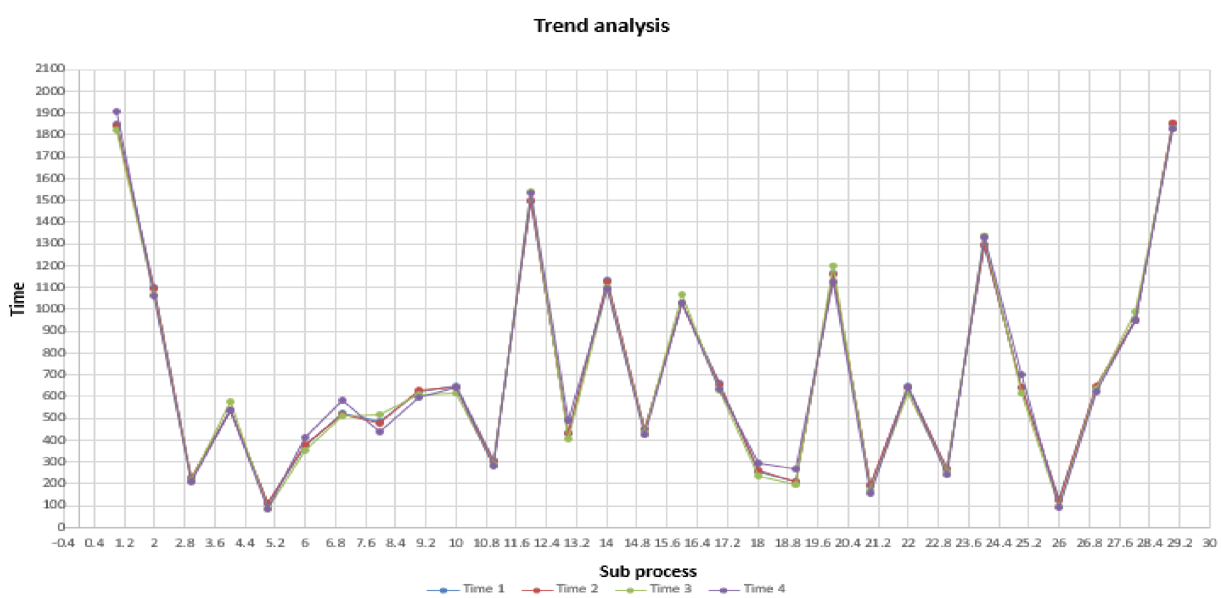

Figure 29: Trend analysis for side's process

Appendix D: Roof process data and trend analysis

Process	Time 1	Time 2	Time 3	Time 4
Measuring	37	45	65	55
Cutting	39	35	46	48
Traveling from saw to station	30	24	15	18
Measuring and marking	30	35	57	43
cutting with different saw	49	38	50	54
Material movement	30	45	31	36
Attaching corner casting + clamp	51	59	47	49
drilling and rivet sealing	98	94	114	104
Moving tools	48	42	53	57
Placing connectors in jig	15	20	11	14
part transport	46	35	57	43
Measuring and marking	918	933	945	923
cutting	75	83	69	74
Placing roof rail on jig	73	69	57	59
Connect roof rail to rear connectors and clamp	315	309	329	319
Drill and seal rivets	72	77	88	81
removing clamps	44	33	24	27
Drill prep	68	83	105	91
drilling and riveting	106	114	126	111
Adjusting Jig	210	206	192	197
Drilling	290	284	272	274
Riveting	228	233	253	243
Rivet sealing	294	283	294	303
Marking with templet	254	269	260	263
Measuring +marking for appearance lights	63	71	93	79
Drilling roof rail	540	536	548	545
Installing grommets	974	968	954	959
drilling and installing appearance lights	1145	1150	1138	1140
Roof light prep	1404	1393	1413	1403
install roof light clamp	286	301	312	295
Measuring + marking	381	389	380	383
Wiring	4083	4079	4101	4087
Lights	456	450	462	461
Chalking	209	214	200	205
Clamping to jig	415	404	392	394
Installing skin from roller	172	187	207	197
Marking +cutting	448	456	467	457
Adjusting jig for skin	103	99	90	93
Cutting	385	379	401	387
chaulking roof bow	503	508	520	508
Scribe and sealing seal with clamp	405	394	380	385
Installing and clamp	514	529	517	519
Measuring and marking	458	466	486	476
Hammering	63	59	70	72
Drilling	897	891	882	885
Rivets and seal	797	802	824	810
Removing clamps	92	81	93	97
chalking	258	273	259	264
Installing AP lights	120	128	116	118
Remove holds	29	25	45	35
chaulk on corner cast	581	575	586	590
Total seconds	19201	19255	19496	19330
Total minutes	320.016667	320.9167	324.9333	322.1667
Total hours	5.33361111	5.348611	5.415556	5.369444

Table 14: Roofs process data sheet

Sub process	Part	Time 1	Time 2	Time 3	Time 4
Measuring	Rear connector	37	45	65	55
Cutting	Rear connector	39	35	46	48
Traveling from saw t	Rear connector	30	24	15	18
Measuring and mark	Rear connector	30	35	57	43
cutting with different	Rear connector	49	38	50	54
Measuring and mark	Roof rail	918	933	945	923
cutting	roof rail	75	83	69	74
Drill prep	Starter bow	68	83	105	91
drilling and riveting	Starter bow	106	114	126	111
Drilling	Roof bow	290	284	272	274
Marking with temple	Roof rail	254	269	260	263
Measuring +marking	AP lights	63	71	93	79
Drilling roof rail	roof rail	540	536	548	545
Measuring + marking	roof bow	381	389	380	383
Cutting	Roof trim	385	379	401	387
Measuring and mark	roof trim	458	466	486	476
Drilling	roof trim	897	891	882	885
Total time seconds		4620	4675	4800	4709
Total time minutes		77	77.9167	80	78.4833
Total time hours		1.28333	1.29861	1.33333	1.30806

Table 15: Roof data sheet for improvement opportunity

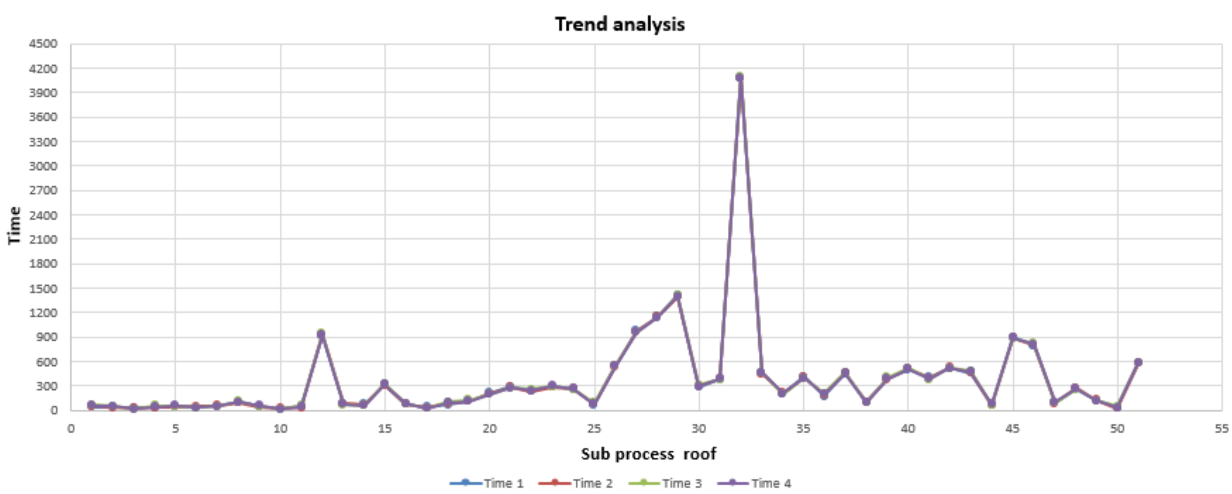

Figure 30: Roof trend analysis

Appendix E: Value stream maps

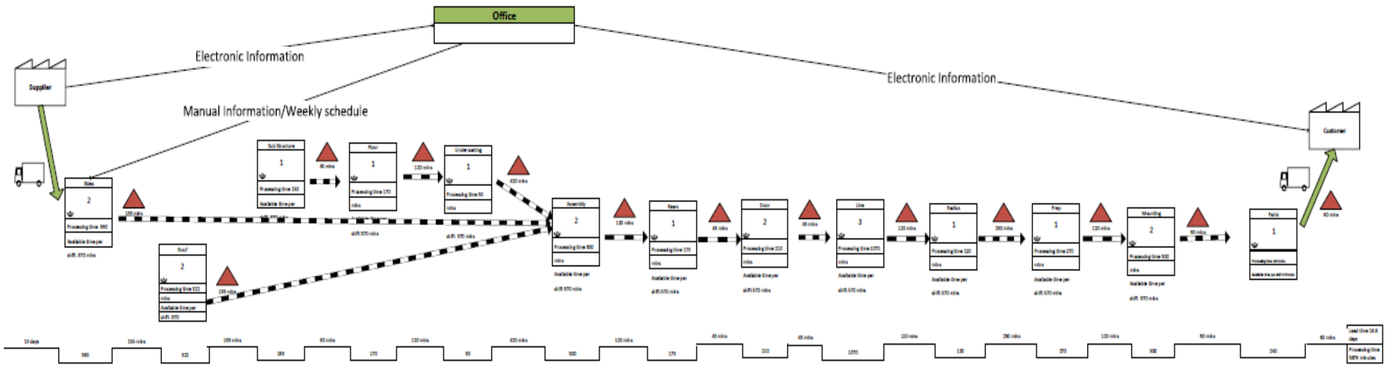

Figure 31: Current state value stream map

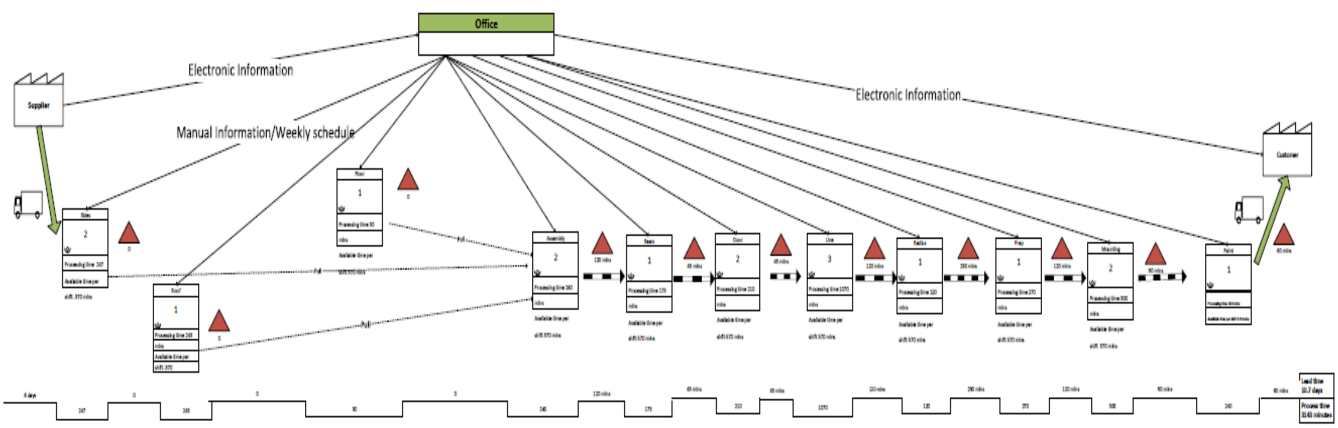

Figure 32: Future state value stream map