Value Stream Mapping using Simulation at Metal Manufacturing Industry

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Abstract

Value stream mapping (VSM) is a powerful lean tool used to visualize the value added activities and helps to minimize the non-value added activities occurring in the manufacturing process. VSM on its own is a pen and paper tool which is very tedious and time consuming. Thus, dynamic VSM can be used through the integration of VSM and simulation modelling. This study addresses the development of current state and proposes future state VSM using simulation with a focus on a manufacturing industry to investigate how dynamic VSM can be adapted in the discrete manufacturing environment. Through the lean waste analysis done, improvements such as implementation of Poka-Yoke technique, continuous flow production, pull system and supermarket with Kanban were able to be proposed.

Keywords
Lean Manufacturing, Value Stream Mapping, Simulation

1. Introduction

Nowadays, businesses have grown to be more global and competitions are fierce. Thus, companies must strive to improve the effectiveness and efficiency of their operations in order to achieve their goal to satisfy the customer with the exact product, quality, quantity, and price in the shortest amount of time (Tinoco, 2004). With the ever increasing commitment to continually improve the process, Lean Production is now commonly embraced by many companies which valuable concept enables them to identify the actual value of their processes and removing the non-value added activities (Hines and Taylor, 2000).

In Lean Production, once the value has been defined, the production process will need to be mapped in order to gain perspective of the material flow and also the information flow. Value stream mapping (VSM) technique is the lean tool used to achieve this. VSM is an enterprise improvement technique by identifying wastes and its sources in order to continuously strive for a leaner production operation (Rother and Shook, 1999). VSM also provides the practitioner with a common platform to evaluate the current state and improve the production process (McDonald *et al.*, 2010).

The various benefits of VSM include its ability to provide the common language for people to communicate and streamline wok processes before applying suitable lean tools and techniques (Lee and Snyder, 2006). VSM also enables manufacturers to visibly view the supply chain issues in order to be more competitive, efficient and flexible (Serrano, 2009). In complex manufacturing environment in which there are plenty of processes with complicated product flow, VSM has proven to untangle the complication and enabled various lean improvement implementations (Duggan, 2002, Braglia, et.al., 2006).

Although VSM is able to provide a step by step approach to transform the manufacturing process into a leaner operation, it is still a static tool that is limited in the ability to dynamically capture the behaviour and complexity of the system (Lian and Landerghem, 2007). Therefore, an enhancement tool will need to be used and simulation is such tool that can be used where the standards icons in VSM are still maintained for ease of communication but using the data gathered as an input to dynamically model the value stream. The dynamic VSM can then be used to observe the effect of changes and improvement made to the production line without having to experiment in the actual production floor.

The main reason for the VSM project is to explore the opportunity on another type of production setting which is the metal industry. The second intent is to investigate how simulation can be used to compliment VSM tool such that the key principles of Lean Manufacturing can be tested in the virtual environment for their effectiveness without having to disrupt the manufacturing process in the actual production line.

This paper will start with some reviewed literatures on VSM and its integration with simulation. Then, the authors will describe in detail the development of the current state VSM using the data gathered at a metal manufacturing company. The current state VSM also acts as a framework for the development of the simulation model. A current state simulation model will then be used to perform lean waste analysis through the generation possible alternatives to observe the effect of the improvements. The optimized scenarios of the future state VSM will increase the management's confidence in adopting Lean culture in their companies.

2. Value Stream Mapping

Lean manufacturing is a comprehensive term referring to manufacturing methodologies based on maximizing value and minimizing waste in the manufacturing process (Borbye et. al., 2011). Lean manufacturing is an operational strategy oriented toward achieving the shortest possible cycle time by eliminating waste in production line (Liker, 2004). It is derived from the Toyota production system and its objective is to increase the value-added work by eliminating wastes and reducing unnecessary work.

In Lean Manufacturing there are many tools of making the process more efficient. One of which is VSM, a visualization tool oriented to the Toyota version of Lean Manufacturing (Toyota Production System) which helps people to understand and streamline work processes and then apply certain specific tools and techniques of the Toyota Production System (Lee & Snyder, 2006). Value stream mapping is a pencil and paper tool that helps us to see and understand the flow of material and information as a product makes its way through the value stream. Value stream mapping provides a common language for talking about manufacturing process (Rother & Shook, 1999).

VSM is a technique relatively recent that enables manufacturers to solve their economic problems in order to be more competitive, efficient and flexible (Serrano, 2007). VSM has been adopted and evolved to plant situations with complex characteristics (Duggan, 2002, Braglia, et. al., 2006) in which demand is random, the number of references is very diverse and have difficult grouping, there are plenty processes, many of them shared with other families and therefore the flows integration become complicated. VSM also has supporting methods that are often used in Lean environments to analyse and design flows at the system level. Although value stream mapping is often associated with manufacturing, it is also used in logistics, supply chain, service related industries, healthcare (Graban, 2008), software development, and product development.

Over the years, simulation has been used to construct dynamic VSM that could enable various alternatives to be explored and tested on the computer without affecting the actual production line. Various literatures have shown that simulation based VSM is able to provide information about the dynamic nature of production process and able to shorten the time to evaluate the effect of any changes made to the system (McDonald et. al, 2010, Braglia et. al., 2011, Lian and Landerhem, 2007, Parthana and Buddhakulsomsiri, 2012).

Simulation is also a tool which is capable of generating resource requirements and performance statistics whilst remaining flexible to specific organizational details. It can be used to handle uncertainty and create dynamic views of inventory levels, lead-times, and machine utilization for different future state maps. This enables the quantification of payback derived from using the principles of lean manufacturing, and the impact of the latter on the total system. The information provided by the simulation can enable management to compare the expected performance of the lean system relative to that of the existing system it is designed to replace (Detty and Yingling, 2000), and assuming that this is significantly superior, it provides a convincing basis for the adoption of lean. Abdulmalek and Rajgopal (2007) also supported that once the simulation model for the current system is verified and validated it can be used to evaluate the future state map and assess the relative impact of adopting the lean approach.

In this paper, the complimentary use of VSM and simulation will be tested at metal manufacturing facility. The methodology used in this project will include:

i. Product Selection
ii. Data gathering at the various work center (production, production planning, logistics, maintenance and purchasing).
iii. Development of Current State Value Stream Map (CVSM).
iv. Development of Simulation Model
v. Lean Waste Analysis using Simulation Model
vi. Proposing the Future Value Stream Map (FVSM).

3. Dynamic VSM at Metal Manufacturing

The first step to any VSM activity is to start with selecting a product family. The identification of the product families were done from the customer end of the value stream. A family is a group of products that pass through similar processing steps and over common equipment in downstream processes. The tool used for this step is Product Quantity (PQ) analysis. Tapping (2002), displays PQ analysis using product mix Pareto chart which graphically demonstrates the Pareto principle - also known as the 20:80 rules - and helps separate the “critical few” from the “trivial many”.

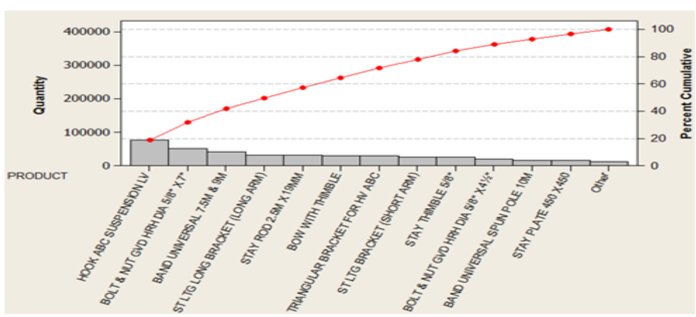

Figure 1: Pareto Chart for Product Quantity Analysis

Results from Figure 1 shows a combination of eight products; Hook ABC Suspension LV, Bolt & Nut GVD HRH Dia 5/8" x 7", Band Universal 7.5m & 9m, St Ltg Long, Bracket (Long Arm), Stay Rod 2.5m x 19mm, Bow with Thimble, Triangular Bracket For HV ABC, and St Ltg Bracket (Short Arm) together make up to 80% of the total quantity produced. The chart also provides the information that product to quantity ratio is approximately 20:80 (in other words, 20% of the product types account for 80% of the total quantity of products produced), thus we have a high volume, low-variety product mix on which we should focus value stream improvement efforts.

From PQ analysis, we continue to develop the Product Routing Matrix (PRM) to learn about how each family moves through the process. Table 1 illustrates the PRM of the metal manufacturing process. The table shows the eight products and the processes that each product needs to go through. For example, three products; Hook ABC

Suspension LV, ST LTG Bracket (Short Arm), and ST LTG Long Bracket (Long Arm) has passed through similar processing steps and over common equipment in downstream process.

Table 1: Metal Manufacturing Product Routing Matrix

Qty.	PROCESS / PRODUCT	Cutting	Stamping	Rolling	Threading	Welding	Platting	Assembly	Resupply
77000	Hook ABC Suspension LV	X	X		X		X	X	
52000	Bolt & Nut GVD HRH Dia 5/8" x 7"								X
42000	Band Universal 7.5m & 9m		X				X	X	
32000	ST LTG Long Bracket (Long Arm)	X	X	X		X	X		
31000	Stay Rod 2.5m x 19mm	X			X		X	X	
29500	Bow With Thimble	X	X				X	X	
29000	Triangular Bracket For HV ABC		X				X	X	
26500	ST LTG Bracket (Short Arm)	X	X	X		X	X		

3.1 Product Selection- Hook ABC Suspension LV

From the PQ analysis and PRM and discussion with the management, Hook ABC Suspension LV is chosen to represent the product family in the CVSMThis suspension hook can be customized as per the customer's specifications. In addition, the suspension hook is widely known for its durability, quality, and corrosion resistance and is used by the client for cable suspension or dead end clamp. The customer currently ordered the product every 3 months in batches of 77000 pieces per order or 25,667 units per months using galvanized mild steel as the raw material. Figure 2 shows the basic components of the Hook ABC suspension.

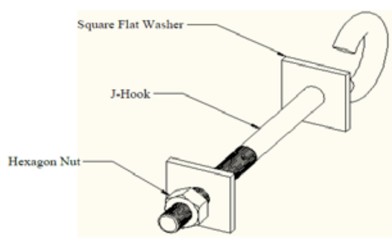

Figure 2: Basic components for Hook ABC suspension LV

3.2 Data Gathering at Various Work Centre

The material flow begins at the receiving area as raw material and travels through the plant until it reaches the shipping area as finished goods. The sequence of production steps to produce Hook ABC Suspension LV is shown in Figure 3.

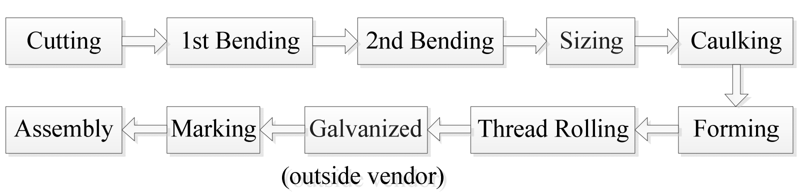

Figure 3: Process flow for Hook ABC Suspension LV

The information on the resources required to produce the Hook ABC suspension are also gathered in order to fully understand the nature of the process in the production line. The process from cutting until thread rolling is done in the same factory. However, the galvanized process requires the product to be sent to another processing factory located quite a distance away and is causing a high lead time to the overall process stream. The product will return to the factory to go through the marking and assembly process before being sent for packaging and ready to be shipped to customer. In addition to the product process flow, information on each process cycle time, changeover time, availability time, machine uptime and operator allocation are also gathered in order to develop the CVSM.

3.3 Current State Value Stream Map (CVSM)

The current state map is depicted in Figure 4. Information regarding the operation name, number of operators required, cycle time (C/T), changeover time (C/O), total available time and uptime percentage are given in each box. The cycle time is calculated in sec/batch. The changeover time is derived from estimates provided by the production personnel. The available time is calculated based on regular production time of 8 hours per shift.

From the CVSM, the total production lead time is calculated to be 13 days. Total processing time of the current stream is 209 seconds, which is also the value added time. This means only 0.04% out of total production lead time of the time is required to produce one pieces of Hook ABC Suspension LV product family. In other words, the CVSM has revealed that 99.96% of the total production lead time consists of wastes and have opportunities to be improved.

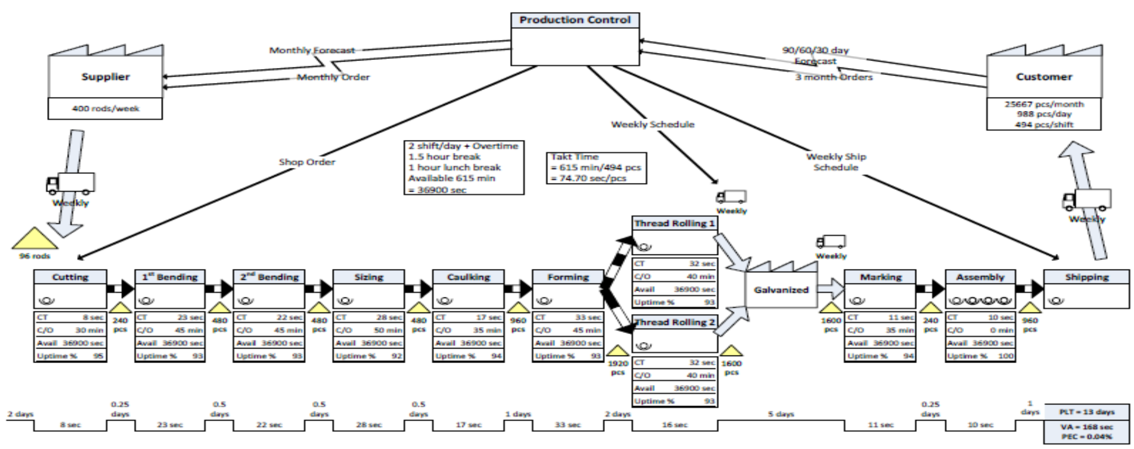

Figure 4: Current State VSM (CVS) of Hook ABC Suspension LV

3.4 Development of Simulation Model

A simulation model which imitates the CVSM was constructed using Simul8 software. The discrete event system modelling require input data such as cycle time, processing time, schedule repair time, total down time and inventory. However, to ensure model randomness, we use Minitab statistical package to determine the cycle time distribution to be used in the simulation model. There are two different views of the model. The first is a "facility view" that describes the work cells and related resources that make up the factory.
The second is a "product view" that describes the flow of work through the facility. Data related facility view was collected from each stations and machines. Moreover, the product should be described to be produced, along with the process plan that defines its flow through the factory. The collected data include: quantity of demanded parts by the nest stations, earliest start date and due date for completion of a job, order times for

each part by the next stations, initial quantity for each part in supermarkets, cycle time for each operation, buy lead time for suppliers, quantity and arrival date for parts from outside suppliers, production and reorder lot size for outside suppliers, numbers of worker and available working hours.

It is important to be able to determine if the system meets specifications and if its outputs are correct. Thus, one of the most essential and difficult tasks faced by the researchers is the verification and validation processes. The approach used to verify this simulation model is by constructing a flow diagram that includes each logically possible action in system can take when an event occurs, and follow the model logic for each action for each event type. The verification flow diagram presented (Figure 5) the flow of material and information as a product makes its way through the value stream.

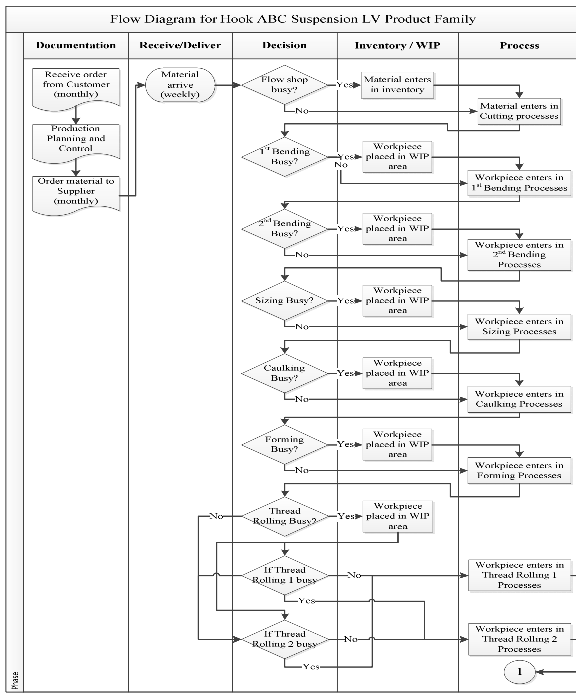

Figure 5: Partial Flow Diagram of the Product View

The flow begins when customer request their requirement by three month contract. After production control has received customer order, they will order material at supplier by monthly. However, the supplier has been directed to deliver the material weekly. When the materials are received, it needs to be placed in the inventory stage for several days before starting the cutting processes. After that, the work pieces will be placed at Work in Process (WIP) area waiting in queue for the next process.

Next, the work pieces will flow through to the value stream. When the work pieces are assembled at the last station, the product will be waiting at the finish goods inventory to be delivered weekly to the customers. The flow shows the process to be repetitive since the same customer will be requesting the same product in the next three months.

The simulation model is now ready to be developed based on this flow chart. These sequences are critical in order for the developer to conceptually plan the flow and each logical possible action can be captured in accurately.

The goal for the validation process is to produce a model that represents true system behaviour closely enough for the model to be used as a substitute for the actual system for the purpose of experimenting with the system, analysing system behaviour and predicting system performance and the other goal is to increase the credibility of the model to an acceptance level. Thus, the initial sampling test is done by running the simulation model with 10 replications. Then, a power and sample size test was done and the result showed 32 observations are required to validate the model. From Figure 6, the steady-state of real system and simulation model respectively is considered as 7.82 seconds and 7.83 seconds. Both values are not too significantly thus, this simulation model is valid and ready to be used to develop the future state value stream map (FVSM).

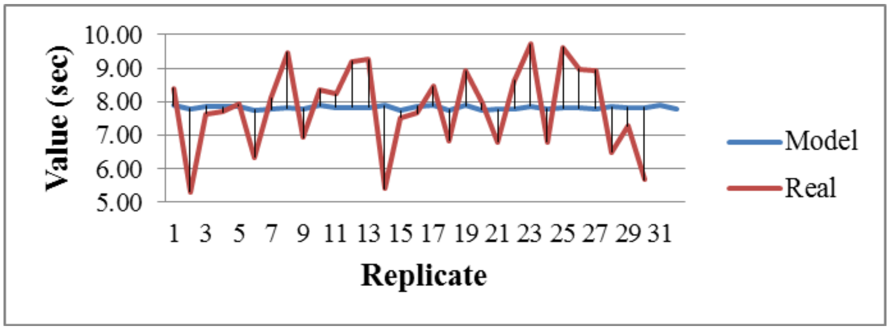

Figure 6: Model Validation: Replication Result

3.5 Future State Value Stream Map (FVSM)

The purpose of VSM is to highlight sources of waste and try to eliminate that waste by analyse the current state maps and then develop the future state maps. The goal is to build a chain of production where the individual processes are linked to others process either by continuous flow or pull. The researcher has found that the most useful aid to develop future state maps is the following list of questions. We follow a systematic procedure to try answering a series of structured questions; which allows us to come up with an ideal future state map that will help in eliminating or at least reducing different types of waste in the current manufacturing system. Based on the answers, the future state idea is marked directly on the current state map and after the possible solutions are explored, the FVSM are possible to be proposed.

3.5.1. How to reduce the bottleneck in the value stream?

From simulation, the forming process is found to be the bottleneck for the whole process. However, based on discussion with the management, the forming process is not needed if the sizing process is done well. Since this type of waste is considered as over-processing in Lean Manufacturing, the management has formed a special team to look into how to redesign the jigs and fixtures used sizing process such that the forming process can be eliminated. The result of eliminating the forming process was able to reduce the Total Production Lead Time from 13 days to 11 days which is a 15% improvement.

3.5.2. Where can continuous flow introduced in the value stream?

In pure continuous flow, the cycle time equals the lead time, as the product never sits in a queue waiting to be worked on. In other words, the waste of waiting time also can be eliminated. In fact, continuous flow production does not require the inventory in between the processes. So, waste of inventory also can be eliminated when product is not queuing for to the next process.

The proposal is to reconfigure the 1st bending, 2nd bending and sizing workstation into one workstation (operation 2, 3 and 4 in Figure 8: After Improvement). This means the operator is required to complete these 3 processes before moving on the next process which is caulking and marking (operation 5 and 6 in Figure

8: After Improvement). Since the cycle time at the thread rolling process is very fast, only one machine is needed and the threading process time still does not exceed the overall production Takt time.

Thus, for this recommendation the motion, inventory, and waiting wastes are able to be eliminated.

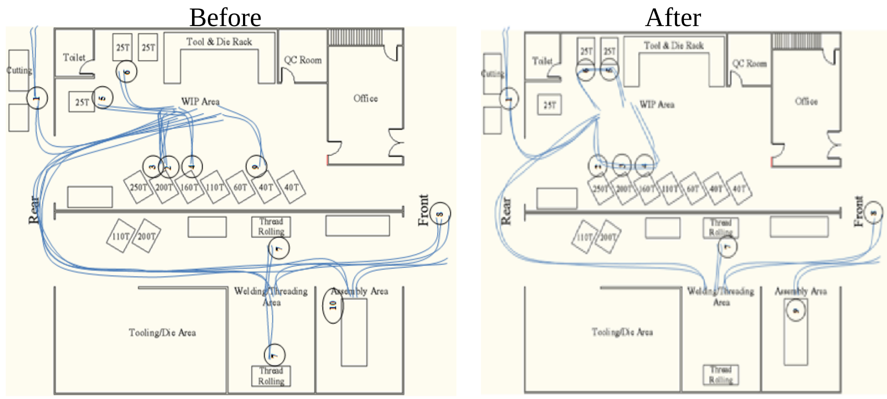

Figure 8: Spaghetti Diagram of Before and After Workstation Assignment Improvement

3.5.3. Where Kanban concept needs to be introduced?

Based on customer requirement, the company make weekly deliver to 4 different customers with different production quantities. product can sent to a finished goods supermarket first. Currently there is no specific batch sizing determined in the production line. Consequently, a batch quantity of 60 units per tray is introduced to make it easy to meet the different quantities needs of the customers. The quantity is determined to optimize the steel rod utilization during the beginning of the process. After the shipping department withdraws trays from the supermarket to prepare them for delivery, the kanban from those trays are sent back to assembly line to trigger another batch of production.

3.5.4. Where will the pull system supermarket be used in the value stream?

Kanban system produces exactly what is ordered, when it is ordered, and in the quantities ordered. Kanban can act as a system of information that integrates the production line, connects all processes one to another, and connects the entire value stream to customer demand. Based on the combined processes in question 2, we considered to use the pull system supermarket at six places. The first kanban is placed before the cutting process. The weekly delivery of steel rods from supplier is stocked at this supermarket. Then, the daily demanded rods are pulled out from the cutting process based on second kanban requirement. Next, the third kanban will be located in between the proposed grouped operation of 1st bending, 2nd Bending and Sizing. That is, a batch of 60 pieces will be pulled from the previous workstation into the production kanban. Then, the chauking and marking process will pull the work-pieces to the fourth kanban to be pulled by thread rolling process. Product will enter the fifth kanban before travelling out from the factory to the galvanized process. With the batching system, the initial lead time of 5 days can be reduced to 3 days and product will enter the sixth kanban to be pulled by the assembly process. Each empty container from the six kanbans will be sent back to the previous workstations ready to be refilled.

The lean waste analysis done has enabled us to highlight the sources of wastes in the production system and with the support of simulation modelling, we are able to explore various options to improve the processes. Figure 9 summarizes the questioning scenarios discussed. The FVSM shows a 70.7% reduction in Production Lead Time (PLT) from 13 days to only 3.81 days. The process time or value added time has reduced 10% from 168 sec to 151 sec. We are also able to reduce 2 operators by combining the 1st bending/ 2nd bending/sizing operation and also the caulking and marking operation which makes up to 14% reduction on workers requirement. The process cycle efficiency (PCE) has also improve from 0.04% to 0.11%.

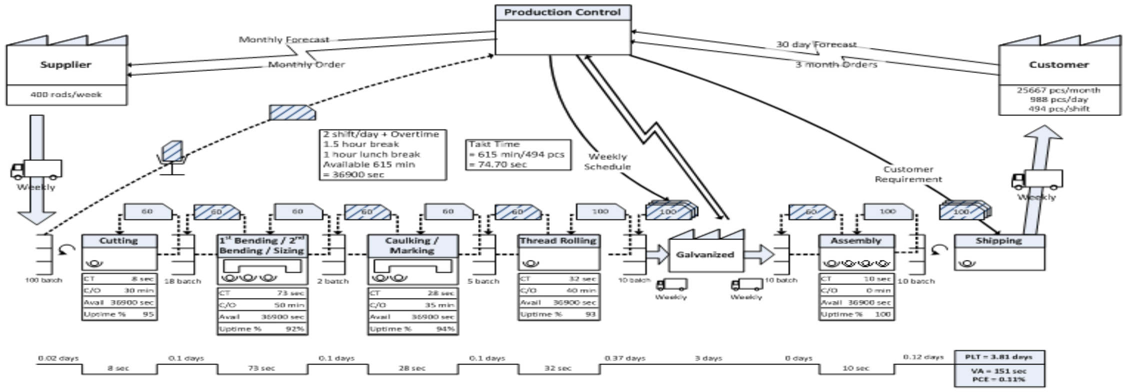

Figure 9: Future State Value Stream Map

4. Conclusions

The dynamic VSM has demonstrated that simulation is a powerful tool to be used to enhance value stream mapping at the metal industry. The manufacturer is faced with higher operation cost and increased demands from the customers. This requires them to be more creative and lean manufacturing is used to assist in surfacing out the wastes occurring in the process stream. Based on Product Quantity analysis and Product Routing Matrix, The Hook ABC Suspension LV has been chosen to be used as the product to be used to develop the CVSM. The CVSM has enabled us to communicate with the company's management and together we were able to visualize the various types of wastes occurring throughout the manufacturing processes.

Through the lean waste analysis, opportunity to eliminate the bottleneck which is the forming process by re-evaluating the jig and tools design of the sizing process was captured in the simulation model. The possibility to combine a few processes and reduce operators was also explored. Through line balancing, the two thread rolling machines were reduced to only one enabling another operator to be reduced at this operation. Moreover, through the introduction to the kanbans and pull supermarket system, the total production lead time was able to be further improved.

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Biography

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