ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIAL ENGINEERING

MECHANICAL DESIGN AND MANUFACTURING ENGINEERING PROGRAM

Implementation of lean through development of alternative manufacturing process using simulation model

Case study at kangaroo shoe factory

A Thesis submitted to the school of Graduate Studies of Adama Science and Technology University (ASTU), School of Mechanical, Chemical and Material Engineering, for the partial fulfilment of the requirements of the Degree of Master of Science in Manufacturing Engineering.

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Advisor: Habtamu Beri (PHD)

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By: Hana Bekele

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DECLARATION

I, Hana Bekele hereby declare that the thesis entitled **"Implementation of lean through development of alternative manufacturing process using simulation model"** submitted to the Adama Science & Technology University, Adama, in partial fulfillment of the requirements for the award of the degree of Master of Science in Manufacturing Engineering, Mechanical Design & Manufacturing Engineering Program, School of Mechanical, Chemical and Material Engineering is a record of original and independent research work done by me under the guidance of **Dr. Habtamu Beri,** Dean, School of Mechanical, Chemical and Material Engineering, Adama Science & Technology University.

It has not been presented as a thesis in any other university and all sources of materials and supporters used for this thesis are accordingly sited and acknowledged.

_____ _____

Hana Bekele Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

Habtamu Beri (PHD) _____ _____

Advisor Signature Date

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It has been great honour for those who have helped much for realizing this thesis. It is my heartfelt thanks for Dr. Habtamu Beri for his follow up and guidance starting from inception to the final version of this paper. I would like also to pass my wholehearted thanks to my mother Worknesh Geresu for her great support in all direction.

My case study is made at Kangaroo Shoe factory and I would like to acknowledge the factory management for accepting my idea and allowing me to work in the factory. If not supported well at all level within the factory, it would be difficult to bring such organized data collection and finding results.

My dearest Samuel, You remained calm, patient and such comforting boy in all those days I was in rush for my work without giving you the time you deserve and I would like to thank you so much for showing such virtue in your early stage.

Abstract

This research is crafted with an intention to implement lean manufacturing system on footwear industry in Kangaroo shoe factory to improve its manufacturing system. The system improvement will be supported by two tools selected from lean packages.

All presently occurring production that are necessary for the selected style of footwear product (the physical and information flow) will be mapped and analyzed to identify the waste there by provide improvement suggestion for the construction of newly modified map with new flow. The main input data that are encoded to Arena software includes activity description, identified type of activity, process observation time and number of workers. The VSM current status map output will be simulated using arena software and depicted quantitatively in the form expected result with tabulated explanation. The simulation result includes the amount of, the total number of WIP, simulation time interval, number of product in, VA and NVA time per entity, total time per entity, accumulated NVA time and accumulated waiting time based on as-is manufacturing system. This result is verified comparing with actual production. The section wise average error encountered are 0.008% in preparation, 0.056 % in stitching section and 0.032% in lasting and finishing. After application of lean improvement to the current production system (i.e.; application of VSM and bottleneck analysis), the modified production system is mapped and the newly modified type of input data have been encoded to arena software and finally simulated using Arena to result the to-be manufacturing system incorporated with improvement option. And this newly developed manufacturing system (opportunity for further improvement) proposed to Kangaroo shoe factory with main changes such as; 3.125% final production output increment in lasting and finishing section, (5.88 ≈ 6) % WIP reduction. in stitching, 32.5% and 41.1% total processing time reduction in stitching and preparation section respectively.

Key words: lean, VSM, Bottleneck analysis and Arena.

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Abbreviations:

- FG Store: Finished Goods Store
- VSM: Value Stream Mapping
- WIP: Work In Progress
- TPT :Total Processing Time

Chapter 1: Introduction

1.1. Background

In Ethiopian footwear industry it is main problem to manufacture based on balanced section wise production inorder to avoid excessive WIP. This thesis is intended to facilitate solutions relative to minimizing WIP as well as identify bottleneck areas. The production of different modeldoes not affect the problem solving process as the production of footwear follows relatively similar value addition process such as design, cutting/clicking ,stitching/closing, lasting/making and finishing of footwear.

These value addition stations described are associated with appropriate man power and machineries that are purposely arranged in department/section based arrangements and such value addition and the overall footwear production process is depicted in a nut shell as below.(see figure 1)

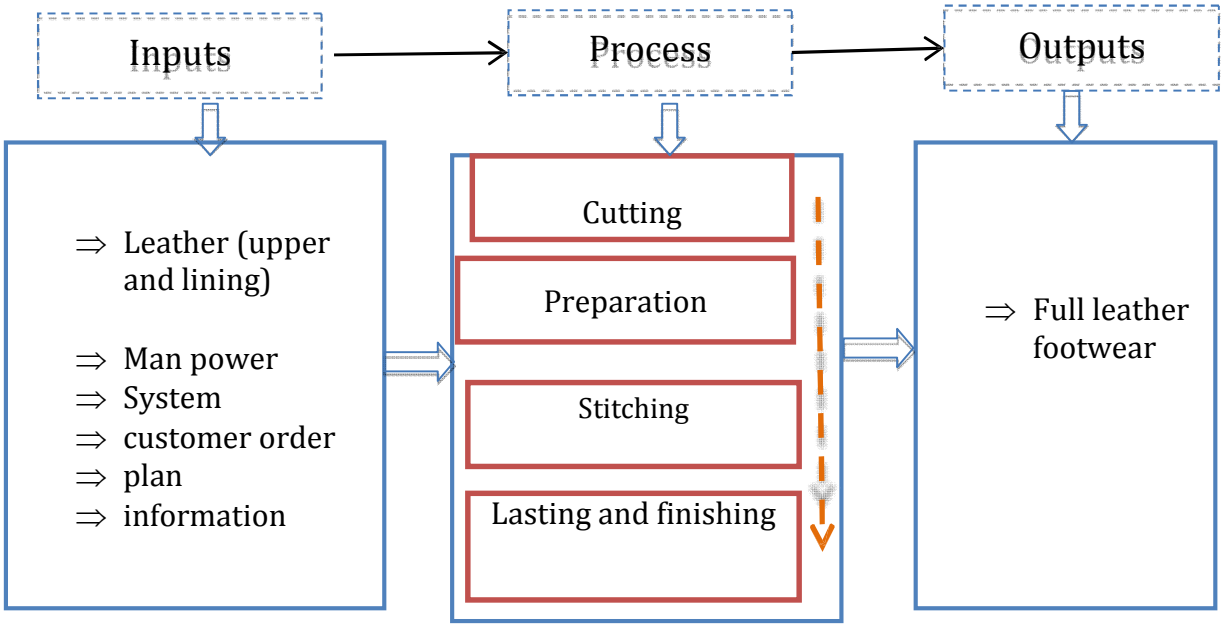


Figure 1. Simplified footwear production process

In the shoe manufacturing, the production line is dynamic, discrete and stochastic. Its randomness is due to variable processing times, as well as random failures and subsequent repairs. Such randomness makes it difficult to control the production process or to predict their behaviour (Altiok and Melamed, 2007). A simulation model which is established to understand and to analyse the structure of manufacturing reveals relationships among the processes and provides to determine the impact on the throughput of the production.

Footwear manufacturing process requires a lot of work which makes shoe making as a typical labour-intensive process, needs high skill and a lot of diverse knowledge in many aspects that may affect the quality, the appearance and the functions of a shoe.

This thesis will concentrate on improving the footwear manufacturing process through implementing appropriate lean tool (VSM and bottleneck analysis) and develop simulation result to facilitate the analysis of to-be system.

1.2. Problem statement

The footwear industry in Ethiopia has shown significant progress in number of manufacturing firms, production capacity and supply of products to both local and global market. However, the industry is not cost competitive as compared to other similar sectors in foreign country. This can be supported by the identified problem in the factory such as an balanced section production output and input, cost ineffective process with a function of time, wastes, under capacity production and unwanted transportation between process lines.

More importantly, the private sectors are unsatisfactorily convinced on how to scale up the benefit gained from the lean manufacturing system and use it for continuous improvement. They have also small contribution for performance measurement system improvement. Despite the fact that the industries hire professionals for their production process facilitation, most are concerned to routine activities than controlling the manufacturing process as it is difficult to inter-relate each unit process to visualize and identify bottlenecks. High WIP product count is also the other problem in the factory that seeks improvement. Effective resource utilization such as machine, man and material is also one of the prominent problems in kangaroo footwear factory.

From the above text it is key to wrap up two issues i.e. way of implementing lean manufacturing system and existence of waste throughout the production of footwear. Therefore, this project will strive to work on implementation of selected packages of lean manufacturing practice that are identified based on those significant problems to enhance efficiency and experience the reflected continuous improvement.

1.3. Thesis objective:

The general objective of this project is to implement lean manufacturing system and develop alternative manufacturing system for further improvement through systematic data collection and simulation of footwear manufacturing processing in Kangaroo shoe factory.

Specific objectives:

- To model and simulate footwear manufacturing process before and after implementation of lean tools.
- To compare the current and the modified footwear manufacturing process.
- To develop alternative process for further improvement using modified VSM as an input data to the arena software.
- To simplify the data analyzing mechanism of input data elements such as section wise processing and value and non- value adding activities.
- To compare the output result of existing and modified VSM status and facilitate the decision making system.
- To simplify the task of measuring process performance within complex and dynamic manufacturing environments.
- To visualize and identify bottleneck area in footwear manufacturing process.

1.4. Scope

The overall activity of the research ranges from understanding of all kinds of footwear manufacturing process, data collection, organization and simulation of the manufacturing processes to develop an alternative processing method for further improvement in Kangaroo shoe factory to quantify the benefits gained from lean package and recommend improvement results for the factory. This project is made in Kangaroo shoe factory as a case study.

1.4. Limitation

Arena simulation software comes in three ways such as commercial, research and student versions. The commercial and research versions are characterized by high simulation capability with huge data analysis ability. Despite the opportunity for enhanced simulation and data analysis, these versions are too costly and are not available for individuals but for organizations. Due to this reason, this thesis has used a student version which limits the simulation processing capacity to smaller data content only.

♦ ♦ ♦

Chapter 2: Literature review

2.1. Concept of lean

Lean manufacturing follows waste minimization mechanism in order to decrease manufacturing or service giving cost of a product or service to result maximum profit. According to Denish and Hemant (2014) Lean manufacturing is a philosophy to provide better Quality of products with lower cost and on time with lesser efforts. Lean Manufacturing is defined as a philosophy based on TPS and other Japanese Management Practices that strives to shorten the time line between the customer order and the shipment of the final product by consistent elimination of waste. Lonnie Wilson (2010) explains the lean and TPS system relation deeply by understanding the TPS creater Ohno (1988) say. He summarises Ohno‘s thought with three key statements. They are;

- The basis of the Toyota Production system is the absolute elimination of waste.
- Cost reduction is the goal.
- After World War II, our main concern was how to produce high-quality goods. After 1955, however, the question became how to make the exact quantity needed.

Based on those ohno‘s thought, Lonnie Wilson could then write a definition by taking those three statements together as, ―the TPS is a production system which is a quantity control system, based on a foundation of quality, whose goal is cost reductions, and the means to reduce cost is the absolute elimination of waste.‖ He was confident to conclude as ―TPS is often used interchangeably with the terms Lean Manufacturing and Lean Production.‖ He also said that ―regarding the technical issues of TPS and Lean, I will frequently use these terms interchangeably. It is called Lean because, in the end, the process can run; using less material, requiring less investment, consuming less space, using less inventory and people.‖

In other side lean manufacturing aims for Identification and elimination of waste in all aspects of a business and there by enriching value from the customer perspective. Lean production cuts costs & inventories rapidly to free cash which is critical. It also supports growth by Improving Productivity & quality, reducing lead times and freeing huge amount of resources.

2.1.1. Lean revolution

The revolution of lean is geared by other philosophy that was developed before it emerges with this named. Shigeo Shingo (Toyota‘s primary consultant and teacher) and Taiichi Ohno are pioneers of lean manufacturing system by developing related philosophy called Toyota production system (TPS). Believes that both are played a significant role and it was though their significant roles and their conceptual genius we reach lean now. As Ohno (1973) said; the president of Toyota Motor Company, Mr. Kiichiro Toyota‘s (1894-1952) speech was the starting point for Toyota production system while I am working in waving plant of Toyota textiles. The

speech was about the productivity difference between three countries Japan, America and German which compares the productivity between Germany and America as 1:3. Japan to America reach 1:9, and comparing to his country Japan, Ohno realised that it means nine Japanese do a job which can be done by one American. ohno couldn‘t stop thinking why and he thought of –had it been we are compared with the automobile industry in America, we would have more gap. Finally he reached with a better reason for this productivity gap. He summarized that the gap is not because of physical work difference; it is just a matter of minimizing waste. This summary was the starting point for the Toyota production system to be born.

Norman Bodek on his interview sheet with pioneers of lean, put Dr.shingo‘s work as –his big breakthrough was to realize the difference between process and operations, *process* being the total flow of manufacturing from the customer‘s order to the finished product and *operations*, a series of machines. By focussing on process he was able to teach us how to smooth out our operations to be more efficient‖.

In today‘s global footwear manufacturing system, key issues that are so important to customers are delivery time; price and quality of the footwear produced by a given producer and are called –customer values‖. Survival of footwear industries mostly depend on the capability to smoothly provide such values determined by the ultimate end users.

Many studies reveal that such customer values are not meet due to that fact that there are wastes related to material, unwanted motions and transportations that consume productive time that lead to delay of delivery of the products to the customers at the right time, excess inventory and overproduction the bring up working capital tied ups.

Despite the fact that these wastes are prevalent to the footwear industry and are proven their existence, there is a mechanism to mitigate and/or eliminate such wastage through a technique called lean manufacturing system.

Lean manufacturing system is strongly associated with waste that the philosophy strives in reduction of such wastes defined as non-value adding activities as perceived from the customer point of view. The overall intention of lean is to reduce cost and enhances product and service delivery by minimizing cycle time of production.

Lean manufacturing will enable manufacturing firms to clearly identify requirements of customers, systematically establish the production flow process that are strongly related to the value addition process and thereby diagnose areas where potential waste exists. Such approach to lean based footwear manufacturing system help the industry to identify the points where improvements are mandatory. The combination of lean tools will be a way for routing increased flexibility and process improvement for any industry.

2.1.2. Lean tools

There are 25 lean tools listed according to Vorne /www.vorne.com/ on its *what is it* and *how does it help* magazine. Those 25 types of lean tools are defined as follows.

VSM:

A value stream is the entire set of activities running from raw material to finished product for a specific product or product family. Value stream maps are powerful visual tool used to identify waste and understand the flow of material and Information. Value stream maps show all actions required to deliver activities required to produce the product, including those in the supply chain, as well as those in internal operations Denish and Hemant (2014).

In this paper also, the VSM will be used as a pictorial representation of all activities required to produce the product, including those in the supply chain, as well as those in internal operations. So as to meet customer values by using lean manufacturing system, there are many tools identified as universal such as VSM where the existing production system is defined and key value adding processes are indicated and analysed based on the real situation of the factory. VSM is a technique for systematically organize and analyse production related aspects such as production data and flow of material along value chain of the production process. In the case of footwear manufacturing processes, VSM will be used to see the level of value adding operations and non-value adding activities there by to eliminate waste in the whole supply chain of the footwear production system.

A predefined set of icons are generally used to construct the value stream map. Simulation models will be developed for the constructed VSM of the related production system in order to simulate the designed models in a dynamic environment to describe the effect of changes on the system performance in movable and quantified terms. Working principle of this research in lined with VSM is to expose the level of non-value activities present in any form by implementing the various tools available in lean. Therefore, value stream map has constructed as a first tool helps to visualize the non-value-added activities.

VSM has a variable block which gives relevant information about the interrelated steps. Using those variables VSM contributes a lot to for the opportunity of improvement. Information to be listed in the block can be selected by user according to its necessity. The following figure 2.1. Shows the variability of variables selected and measured for each step.

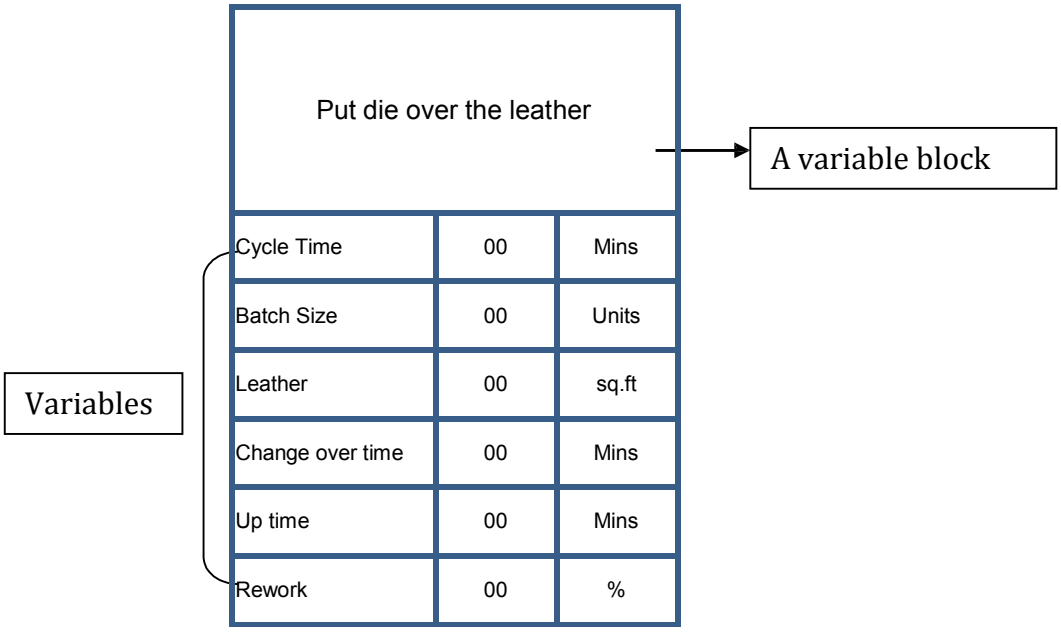


Figure 2.1 The variability of variables selected and measured for each step

All variables may or may not be included inside the variable block rather can be expressed using predefined sequence for the sake of space to display.

On the other hand, there is triangle like images before each process steps which shows the number of queue in terms of units. In VSM, the visualization of non-value adding activity is presented in the form of line which is lined at the bottom of the page and jumped up if and only if there is a value adding or necessary non-value adding activity is recorded. As an example see chapter 4, figure 4.1 existing state cutting section VSM model at Kangaroo shoe.

5S

The ‒many small modifications lead to continuous improvement‖ expresses working mechanism of 5S**.** For process optimization, kaizen or coined in Japanese is a management concept, which focuses on the gradual improvement of processes and on the development of people so that they are able to solve the problems and the desired results can be achieved. It‘s not a project; it is a comprehensive tool and mind set to develop the business. It is used to remove problems and capitalize opportunities for improvement. This work is driven by employees with management support. The industry was the first to use that tool by Toyota and Sony. But it is now also used in the service sector as medical, health and dental care, municipalities, schools, banks and others.

Andon

In English, Andon means **Sign** or **Signal**. It is a visual aid which alerts and highlights where action is required. *Andon* is a principle and is also a typical tool to apply the *Jidoka* principle in Lean Manufacturing which is referred to as ‗automation‘. It indicates the line has been stopped by one of the operators due to some irregularity using alerts like alarms and flashing light.

Bottleneck analysis

A bottleneck is commonly referred to step in a process which limits the total capacity of the process. It is the step, workstation, or stage which causes work in process to build-up because it cannot be processed at the same rate as the other steps or workstations or has the greatest cycle time in a one path process. Bottlenecks should be identified and addressed when planning capacity expansion or planning the capital expenditure budget. Potential process bottlenecks should be investigated in production planning, and new facility planning. This can be achieved through preventive risk thinking and other problem analysis tools. Bottlenecks not only slow or limit the capacity of a process but also cause to other problems in a process which is occupying space (excess storage area)

Continuous flow

It is a one piece flow in which each product is passed or moved along in the production process independently without separating them into lots until it is completed and ready to be delivered ready to be delivered to a waiting customer.

Gemba (the real place)

Genchi means the actual location and genbutsu means the actual materials or products. But genchigenbutsu is interpreted within Toyota to mean going to the place to see the actual situation for understanding. Gemba is a term that has become more popular. It refers to ―the actual place‖ and means about the same thing as genchigenbutsu.

Heijunka (level scheduling)

It is a Japanese word to mean levelling. Heijunka works on levelling the type and quality of production over a fixed period of time (scheduling)to meet customer demands efficiently through avoiding batching and results; minimum inventories, capital costs, man power and production lead time through the whole value stream.

Jidoka (Autonomation)

Jidoka highlights the causes of problems because work stops immediately when a problem first occurs. This leads to improvements in the processes that build in quality by eliminating the root causes of defects. Jidoka sometimes is called automation, meaning automation with human intelligence.

Just-In-Time (JIT)

It is an inventory strategy companies employ to increase efficiency and decrease waste by receiving goods only as they are needed in the production process, thereby reducing inventory costs. This method requires producers to forecast demand accurately.

Kaizen (continuous improvement)

Kaizen is sometimes translated as simply ―continuous improvement‖ but that confuses it with the broader lean pillar of ―continuous improvement‖ and does not capture the full flavour. Kaizen is both a personal mind set and a practice. As a mind-set, it suggests ―My work is to do my work and to improve my work and continuously improve for its own sake. More formally as a practice, kaizen implies:

1. choose and practice techniques the team has agreed to try, until they are well understood—that is, master standardized work
2. experiment until you find a better way
3. repeat forever

Kanban (pull system)

A kanban (kan means visual signal, ban means card or board) is used in to signal a pull event (a replenishment request) in a pull system. It is a card, but sometimes it is a cart, while other times it is just a marked space. In all cases, its purpose is to facilitate flow, bring about pull, and limit inventory. It is one of the key tools in the battle to reduce overproduction‖.

Muda (Waste)

It is a combination of muri and mura. Muda is a Japanese word which represents uselessness or wastefulness. It is a key concept in the Toyota Production System (TPS) as one of the three types of deviation from optimal allocation of resources (the others being mura and muri). Waste reduction is an effective way to increase profitability. Toyota adopted these three words beginning with the prefix **mu-**, which in Japan are widely recognized as a reference to a product improvement program or campaign.

From a customer's point of view, value-added work is a process that adds value by producing goods or providing a service that a customer is willing to pay for. However, muda is any process that consumes more resources than needed, which causes waste to occur.

Muda are broken down into two. These are:

- Muda Type I: non-value added activity, necessary for end customer.

- Muda Type II: non-value added activity, unnecessary for end customer. The aim is to eliminate this type of wastage.

Type-I are usually hard to eliminate because although it is classified as non-value added activity, it is not necessarily muda. For example, the quality inspection process for critical process is needed at car assembly, to ensure the car quality and fulfil safety standards before sending it to the end user; however, from customer point of view, these actions are deemed unnecessary and do not contribute to the assembly process which add values or to the car assembly.

Type-II is non-value added activities which contribute to waste and incur hidden costs. Toyota Production System identifies the wastages that occur and group them into 7 major categories.

KIP (Key Performance Indicator)

a quantifiable measure used to evaluate the success of an organization, employee, etc., in meeting objectives for performance. "Key performance indicators show big improvements and delivery times have been reduced"

Overall Equipment effectiveness

(OEE)Overall equipment effectiveness (OEE) is a term coined by Seiichi Nakajima in the 1960s to evaluate how effectively a manufacturing operation is utilized. It is based on the Harrington Emerson way of thinking regarding labour efficiency.

PDCA (Plan, Do, Check and Act)

PDCA (plan–do–check–act or plan–do–check–adjust) is an iterative four-step management method used in business for the control and continual improvement of processes and products. It is also known as the Deming circle/cycle/wheel, Shewhart cycle, control circle/cycle, or plan–do–study–act(PDSA).

Poka-Yoke (Error proofing)

Poka-yoke refers to mistake-proofing (also error-proofing or fool-proofing). These are creative devices that make it nearly impossible for an operator to make an error. (Liker, 2004)

Root cause analysis

Root cause analysis (RCA) is a method of problem solving used for identifying the **root causes** of faults or problems.

Single-Minute Exchange of Dies

Single-Minute Exchange of Die (SMED) is one of the many lean production methods for

reducing waste in a manufacturing process. It provides a rapid and efficient way of converting a manufacturing process from running the current product to running the next product. This rapid changeover is key to reducing production lot sizes and thereby improving flow (Mura), reducing production loss and output variability.

The phrase "single minute" does not mean that all changeovers and start-ups should take only one minute, but that they should take less than 10 minutes (in other words, "single-digit minute").Closely associated is a yet more difficult concept, One-Touch Exchange of Die, (OTED), which says changeovers can and should take less than 100 seconds. A die is a tool used in manufacturing. However SMED's utility is not limited to manufacturing.

Six big loses:-‖Quality improvement strategy focused on removing variability from a process‖ Is a methodology for improvement, the goal is to achieve savings by reducing the causes of defects and variability in manufacturing and business processes. The method is used primarily by large manufacturing companies for example in manufacturing or automotive industry in order to become even more cost effective. Six-Sigma is statistical methods within the area of quality management with the approach – define –measure – analyze – improve - monitor. It is frequently used in manufacturing processes to increase the quality level. The _Six-Sigma_ methodology requires a special training for the company staff, it means talking about the different roles that staff can fill depending on their level of education. Six-Sigma is a quality improvement strategy focused on removing variability from a process. Although originally developed for manufacturing processes, the Six Sigma methodology has been successfully applied to a wide range of processes. As a tool for process improvement and reduction of defects, Six Sigma compliments Lean and is a component of many Lean programs.

SMART goals

The acronym SMART has several slightly different variations, which can be used to provide a more comprehensive definition of goal setting: S - specific, significant, and stretching. M - Measurable, meaningful, motivational. A - Agreed upon, attainable, achievable, acceptable, action-oriented, R- reliable and T- time bounded.

Standard work

Standardized work is one of the most powerful but least used lean tools. By documenting the current best practice, standardized work forms the baseline for kaizen or continuous improvement. As the standard is improved, the new standard becomes the baseline for further improvements, and so on.

Takt Time

Takt is the German word for the baton that an orchestra conductor uses to regulate the tempo of the music. Takt time may be thought of as a measurable ―beat time,‖ ―rate time‖ or ―heartbeat.

In Lean, takt time is the rate at which a finished product needs to be completed in order to meet customer demand.

Total productive Maintenance

In industry, total productive maintenance (TPM) is a system of maintaining and improving the integrity of production and quality systems through the machines, equipment, processes, and employees that add business value to an organization.

Visual factory

Visual factory is a term to describe how data and information is conveyed in a lean manufacturing environment. In a lean manufacturing environment time and resources dedicated to conveying information, although necessary, are a form of waste.

Kanban

It is a method of regulating the flow of goods both within the factory and with outside suppliers and customers. Based on automatic replenishment through signal cards that indicate when more goods are needed.

2.1.3. Application area of lean

Existence of room for improvement in all process oriented activities such as manufacturing, construction and service industry makes lean be high level structure i.e. can be implemented in all kinds of value adding processes. The need to reduce cost, reduced lead time towards customers and set forth long term profitability is the driving force for application of lean.

Lean, through its principles and identification and elimination of waste, remains an important part of engineering of critical processes so as to minimize production costs, smoothen material flow and customer communication of a given manufacturing process such as footwear production.

Additionally, the definition of application of lean service is a standardizable system of service operations made up only by activities that generate value for customers, focusing on explicit tangibles and aiming to meet the customers‘ expectations for quality and price. It also makes the value-added processes flow and implement customer-driven system. Application of lean tools solve the customers‘ problem completely by ensuring that all services operate and work together thereby leading establishment of situation where activities do not waste the customers‘ time.

Lean principles were created having the final consumer in mind; they are perfectly adaptable for all kinds of customers.

Specifically with footwear manufacturing practices, lean principles should be applied not only in actual footwear manufacturing, but should also be extended to other processes, especially to those more upstream along the production chain, such as the product development process (PDP), which presents great opportunities for the application of these principles. It is important that the product be developed based on lean principles, so that potential wastes from the product development process are avoided in manufacture and product development design stage may suggest the right production rout for the actual production of a given product where the possible waste of movements are reduced and consumption patterns are optimized.

Application of lean can also be core during the value addition produces of footwear manufacturing system such as cutting, closing, lasting, finishing and packing process. At each stage of discreet activities, it is practically observed that issues related to time to perform specific activities, hand and tools movement and consumption of material are concerns for the factory where lean tools are applied for improved productivity and enhanced delivery through proper motion follow up of selected value adding activities only.

Delivery of produced shoe to the ultimate customer will not be guaranteed through application of lean on manufacturing activities but lean-geared supply chain management system (SCM) within the company. with this, lean SCM refers to resource utilization, that is, units of material, chemicals, and components arrive in a manufacturing setting ―just in time‖ for their use. Suppliers deliver their supplies just in time for their use in production, and customers receive finished products just in time for their convenient use. Hence, there is no wasted movement of materials, use of labour or equipment, or idle inventory in lean SCM.

2.1.4. Method of lean implementation

In industry (service giving or manufacturing), system implementation process starts with a commitment and readiness of top management as well as entire employees. There must be a well lean-trained team who can train, control, follow and lead as per the principles. The team strives to make the industry lean primarily through evaluating and analysing current practice of the industry. According to the evaluation result the team develops an implementing plan by selecting tools from lean packages and line how to ground the plan .Implementing as per plan, checking activities as per plan through measuring the progress comparing before and after reports and taking corrective actions are the next successive steps done in lean implementation process. These cyclical activities i.e(plan-do-check-act)will be performed continuously till the company

gets satisfied regarding profit maximizing.

2.2 Lean focus

The main focus of lean is to eliminate waste. Wastes are a non-value adding activities that uses resources like materials, machineries, manpower and also time. There are several types of wastes. Toyota developed its production system, striving for Excellence, with a keen sensitivity to waste. Toyota executive Taiicho Ohno (1912-1990) defined The 7 Deadly Wastes (muda) as shown below.

The seven types of Ohno‘s wastes are:

1. Waste from overproduction
2. Waste from waiting times
3. Waste from transportation and handling
4. Waste related to useless and excess inventories
5. Waste in production process
6. Useless motions
7. Waste from scrap and defects

1. Waste from overproduction

Many companies are producing more than necessary because they lose parts, products and material. Without order, care and discipline in storage, inventories will fill all available space. Temporary storing a batch in a non-defined / dedicated area is risky, as someone could move the batch without care or notice. In such a case, it is likely to lose its track, all ending in a waste of raw material, energy and man power. It may lead to a double waste if the lost batch requires to produce a new one be delivered. Over production can be handled by eliminating the wasted space and valuable surface by excess inventories and it is a potential improvement.

On the other hand 5S can be used to setup rules for storing, define space and places. These rules have to be widely communicated so that everyone knows where is what, why and for how long. While continuously improving the situation, the rules have to be updated and stick to the latest state.

2. Waste from waiting times

Waiting is a consequence of poor synchronization between process stages or bad preparation.

Waiting for parts, material, tools, instructions, and the like can be caused by a lack of rules about storage places, when people have to search everywhere.

A worker should ask that the item he is waiting is really necessary? If they're not or if they do not

add value to the job or the product, it is being wise to try to eliminate them or at least reduce the waiting time and storage distances. Through this, all searches will be reduced if the searcher knows where to search.

3. Waste from transportation and handling

The necessity to move and transport can be caused by the previously mentioned wastes. All transportations may not be eliminated, but they have to be kept to the very minimum. Looking for a pallet truck to move crates or pallets is a common occupation in the workshops. People most often claim for more trucks, but a proper set of rules, parking areas and discipline to bring them back after use is enough to solve availability of this problems.

4. Waste related to useless and excess inventories

"Useless"! The name itself gives the solution. In the 5S way, anything that is useless is to be eliminated. In case of inventories, the gain is the value of the goods stored and the regained spaces, which must be dedicated preferably to value creating activities. For example, paper documents and their numerous copies, catalogues and calendars of previous years, files and data, dry and worn out pens and pencils are all excess inventories.

5. Waste in production process

Procedures and work guides which are not constantly updated are likely to let useless operations be performed in the process. Sorting and ordering applies also in the sequences of the process and the related documents.

This type of waste is also common in administration processes and office work. Old rules still remain even if the causes of their creation disappeared a while ago. As long as nobody will update the set of rules, everyone will carry on, sticking to the olds with wrong application and discipline.

6. Useless motions

Ergonomics of the work place is certainly the most popular and "visible" application of the 5S. The layout and display of the area will follow the 5S logic, favoring availability of necessary items, distance of reach and ease for tending. Among useless motions, do not forget the walks to search for missing items, data, instructions and complementary information.

7. Waste from scrap and defects

Number of defects and quality problems can be directly linked to the work place state:

- Assembly mistakes (parts mismatch) due to jammed work table with parts from different models / series.
- Forgotten parts in assembly, the parts could not be seen in the mess on the table.
- Scratches on parts by scrap form the work table (burrs, dirt and parts.).
- Spoiled parts because of dirty scratched and so on.
- Assembly mistake by not following the right sequence.

There are few more types of waste can be added and analyzed:

8. Waste from confusion

Any goals or metrics that cause uncertainty about the right thing to do leads to confusion.

9. Waste from unsafe or un-ergonomic work conditions

It is office work conditions that cause carpel tunnel, eye fatigue, chronic back pain, or that compromise the health and productivity of workers in any way.

10. Waste from underutilized human potential:

Unused skills, talents, and creativity of human being are a waste. On the other side, restricting employee's authority and responsibility to make routine decisions also hinders to use human potential satisfactorily. As per Ohno‘s interpretation the following are part of Waste from underutilized human potential.

- Having highly paid staff do routine tasks that don't require their unique expertise.
- Not providing the business tools needed to perform and continuously improve each employee's assigned work.
- Not trusting your people to stop production to stop and fix a problem (Jidoka).
- Not trusting your people to be responsible for the cleanliness, maintenance, and organization of their own work area.
- Not trusting people with a flat organization structure of largely self-directed teams. Not expecting (and measuring) every person to contribute.

2.2.1. Lead time

Lead time represents the time laps between customer order and order received.Petri Kärki (2012) expresses lead time combining with different terms and time stamps. He‘s time stamps are order entry date, production started, packing and invoicing started, packing and invoicing finished and shipping date. As shown in figure 2.2.

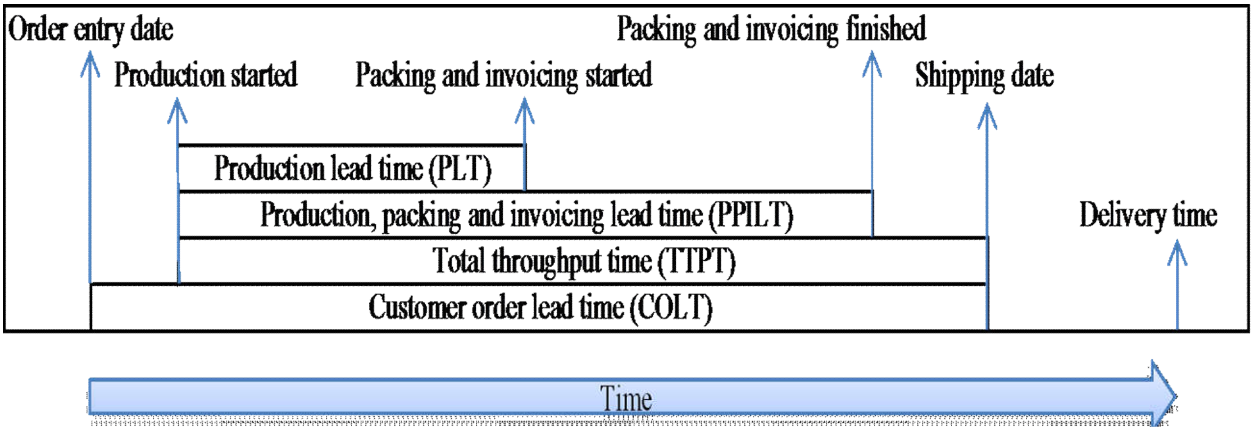


Figure 2.2 Petri's Lead time –time stamps‖ for different lead time terms.

Lead time can be reduced using different mechanism such as better scheduling, redesigning the process and also by organizational means using performance systems that give managers incentive to reduce lead time (Phillip J. et.al.,1996).They also express reduced lead time comparing with Work in progress, forecasting, operation's cost and agency cost. From a cost perspective, lead time is important for four reasons. First, lead time is proportional to work-in-process inventory, which can be a major investment for a firm. Second, because the firm cannot produce instantaneously, lead time forces the firm to forecast needs and to hold safety stock of materials and finished goods. The longer the lead time the longer the firm forecast horizon. If forecasting accuracy decreases with longer horizon, lengthened lead time forces the firm to relay upon more uncertain forecasts, which increases safety stocks of materials and finished goods. Third, short lead time may be favorably related with operations' costs that are time related in such a way that longer lead time in processing stages may increase quality costs for defects only discoverable during final processing stages and testing. The longer the lead time, the longer it may take to detect quality problems, since final assembly and test occur a long time after production may have begun. Fourth, short lead time reduces agency costs (Phillip J. et.al.). Jensen and Meckling (1976) defined agency cost as it is a cost associated with measurement, control and divergence of interest of the manager and the firm.

2.2.2. WIP (work in progress) or buffer

In manufacturing industry inventory can be classified in to three stage. That are raw material, work-in-process (WIP), and Finished goods inventories. The Production process of a product consists of several stages such as raw material inventory; machining (processing), buffer inventory (WIP), and final product inventory (Khalid A. Aldakhilallah, 2002). These stages of a production process are shown in Figure. 2.4. WIP is a form of inventory which exists as neither

incoming material nor finished material but as a part passed through value adding activity/process step or steps.

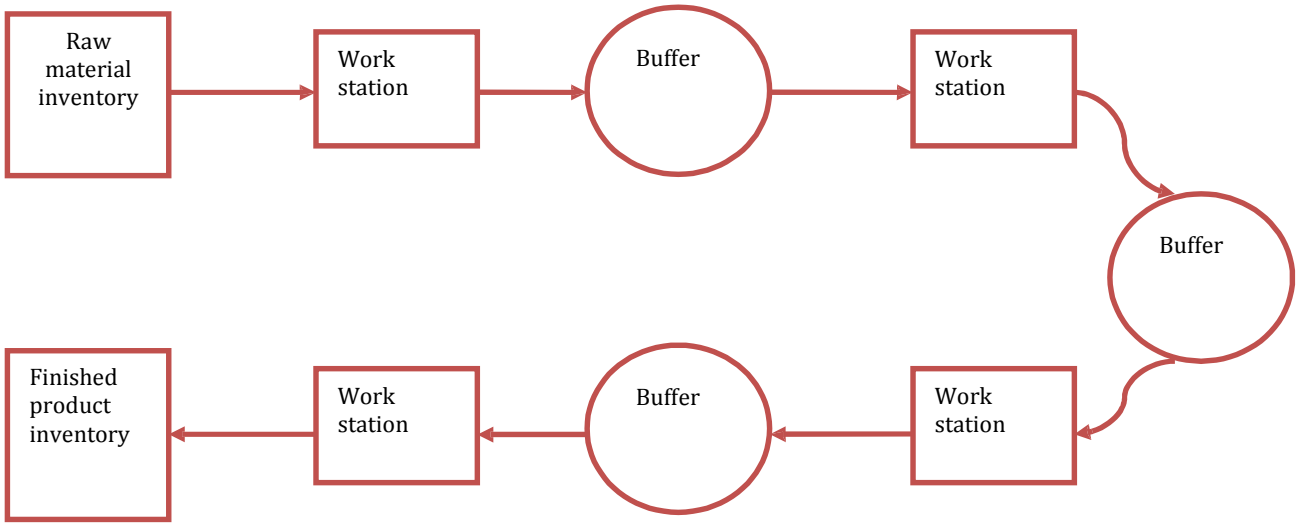


Figure 2.3 Stages of production process

2.2.3. Cost

Cost is all about serving, making or doing expense which can be raised or reduced in terms of time, money or resources. Manufacturers are busy on how to reduce cost over the total price of a product. Those time and resources play great roll in cost reduction process.

As resource/money and time spent to produce a product influence its final price, limitation must be built to expose waste. This limitation is called the standard time where as if the product uses beyond the limitation, it is waste. There are wastes seen easily through observation and also involving in actual process.

There are many ways to minimize waste but this paper focus on lean as a tool for the seen and unseen waste elimination and reduction. The need for continuous profit of manufacturers can be supported if and only if a company could work continuous on cost reduction principle. Marek said that ‑It requires constant effort at cost reduction to maintain continuous profits in manufacturing. The prime way to reduce costs is to produce only those products determined by sales in a timely fashion, to restrain excessive manufacturing and to eliminate all waste in manufacturing methods‖ on his book named basic concepts of lean manufacturing.

Lean appreciates cost reduction policy than the cost plus policy as in cost plus policy product cost is fixed. This can be shown easily as follows.

Cost plus policy: Sales Price = Cost + Profit ……. Eq. 1

Equation 1, concerned about how to set sales price:

Cost reduction policy: Profit = Sales Price– Cost ……. Eq. 2

Cost reduction policy is concerned about how to increase profit by decreasing cost continuously. From the above two equation the cost reduction and cost plus policy can be combined and explained so as to show impact of lean through cost reduction principle.

Let ;

C_f= the fixed cost per product in cost plus policy just to set the sales price

$C_{w1}, C_{w2,\ldots} C_{wn}$= Cost of waste in the company according to their identification step

$C_{1,2,3\ldots\ldots n}$ = reduced newly fixed cost of a product after elimination of waste (C_f- $[C_{w1}+C_{w2,\ldots}+ C_{wn}]$)through manufacturing methods(based on cost reduction policy) but always $C_f > C_1 > C_2 > C_3 \ldots\ldots\ldots > C_n > 0$

P_f = fixed profit set by company per product based on cost plus policy

$P_{1, 2, 3,\ldots\ldots n}$ = continuous profit increment because of continuous cost reduction

P_n= maximum profit

S= Sales price which is fixed value

$C_f - C_{1,2,3,\ldots\ldots n}$ = the unnecessary cost (cost of waste) that will increase in number as we continuously eliminate waste, which is always greater than zero. This continuous waste elimination is explained in terms of 1,2,3 up to n times and C_n represents the minimum cost we use to produce a product.

Using equation 1, $S = C_f + P_f$ ..... Eq. 3

Using equation 2, $p_{1,2,3,\ldots\ldots n} = S - C_{1,2,3\ldots\ldots n}$ ..... Eq. 4

Substituting equation 3 in to equation 4;

$P_1 = P_f + C_f - C_1$ …….. $(C_f - C_1)$ is cost of first identified waste (C_{w1})

$P_2 = P_f + C_f - C_2$ …….. $(C_f - C_2)$ is cumulative cost of identified wastes($C_{w1}+C_{w2}$)

$P_3 = P_f + C_f - C_3$ …..… $(C_f - C_3)$is cumulative cost of identified wastes ($C_{w1}+C_{w2}+C_{w3}$)

.

.

$P_n = P_f + C_f - C_n$ …….. $(C_f - C_n)$ is cumulative identified wastes($C_{w1}+C_{w2}+C_{w3}+....+C_{wn}$)

As $C_{1,2,3,\ldots\ldots n}$ decreases in other words as C_n approaches zero after elimination of all wastes in company, the result of $C_f - C_{1,2,3,\ldots\ldots n}$ will increase which is the additive value for the fixed profit (P_f) set by the company considering the cost plus policy. By this we can increase the profit from P_f to P_n through reducing the unnecessary cost i.e. waste. This all implies a lean approach over cost plus policy and cost reduction principle through continuous improvement.

2.3. Manufacturing Process activities

2.3.1 Process mapping

In manufacturing system there are processes that a part to be produced will passes through in order to add value step by step. A single process is composed of activities in type i.e. value

adding, non-value adding and also necessary value adding activities. Each process can be shown with their interaction in process mapping easily. This helps the factory owner to see or visualize areas that demands improvement.

2.3.2. Activities (VA, NVA & NNVA)

Activities are sub part of the processes in which their sequential arrangement will form a process. Each activity may or may not have contribution for the final output product. All activities in side a process are not necessarily value adding. For that matter they are classified to be value adding, non-value adding, necessary non-value adding activities. Value adding activity is an activity that a customer is willing to pay for plus those which makes change in WIP product to enable to come to end product. The necessary non-value added activity is an activity which cannot be eliminated easily due to the rule of work or processing. They do not add any value on the product but are necessary to pass from one step to another step of value adding activities. Value adding and necessary non-value adding activities must be performed in such a way that they could not be a reason for less productivity in a company. So all activities need to be under control for detail analysis and identified to eliminate the unnecessary one from sequence of activities in each of process.

2.4. Introduction to footwear manufacturing process

Footwear manufacturing is the process of designing, engineering, cutting, stitching and making leathers and man-made materials into an upper, insole, outsole and heel around a wood, plastic or metal last. The last determines the fit and feel of shoes as well as their performance. The units of measurement for shoes sizes differ across countries.

The sport shoe making process can be subdivided into different distinct stages (clicking, preparation and Decoration, closing, lasting, Finishing, and component making) from the point where the raw materials has been prepared and manufactured. See appendix-A footwear manufacturing process:

2.4.1 Footwear manufacturing process

The maximum or probable process steps that shoe manufacturer should follow is cutting, preparation /decoration, closing/stitching, lasting/making, finishing and packing. Each process step has its own value adding mechanism one over the other are explained in the following detail manner.

a. Cutting

The first operations in shoe making take place in the ‗cutting section'. Here the individual shoe

components are cut from the basic materials that will make up the shoe. Traditionally this was performed manually by cutting around the edge of a template with cutting knives. Although there are now some automated systems that implement high pressure water cutting methods, these are expensive and limited in the materials they can cut.

Consequently the majority of component cutting is now achieved by the use of preformed die. Each die is made from a steel strip that has a ground, hardened edge and has been formed in to the shape of the shoe component required. Support plates, or cross-members are then welded into place resulting in a strong, sharp device capable of cutting cleanly through the materials. The material is laid out on the flat bed of a high pressure press, the die is placed onto its surface and the press activated, forcing the knife through the material. For man-mad materials often multiple thicknesses can be cut in one stroke without any degradation in component quality.

In addition to cutting the components from the material, holes can be punched to assist in their alignment during further processes, or simply to give a decorative appearance. For synthetic materials the cutting pattern can be arranged in such a manner as to optimize the material usage by ensuring the shapes to be punched are arranged so that they inter-lock. For leather materials the _clickers' need to be very skilled in order to maintain the quality of the leather from which individual parts of the shoe are cut.

b. Preparation and Decoration

After 'cutting' comes **preparation and decoration** this includes such operations as Stamping Printing, embossing, welding, marking, pasting and skiving. Printing is performed in decoration section in order to print different decoration colour on shoe cut component as per design and colour required using ink and butter paper which the design of print made on it. Figure 2.4 shows decoration using printing. Embossing is done in decoration section which helps to print logo, brand mark, label or other decoration as per design required using embossing machine, temperature and pressure of the machine adjusted according to types of materials, thickness and embossing depth. Welding is the operation of welding or pasting two component together using heat and pressure by welding machine.

Figure 2.4:- Decoration using printing

c. Stitching/Closing

In the `closing section', the flat component parts that will make up the shoe upper are taken and sewn together in such a manner as to produce a three-dimensional part called the 'Closed Upper'. Closing also covers the stitching and attaching of the shoe lining, which can consist of facings, stiffeners, back straps and other components. Before final closing the shoe upper is essentially flat and as such is still relatively simple to manipulate. This then allows for operations such as top-line stitching to be carried out with comparative ease thus finishing off the earlier turned-in skive. This operation has had to wait until this point as the complete top-line encompasses several components which would not have been assembled together until closing.

The closing operation itself is generally performed by sewing along the line of disparate curves at the heel. The main example of this is the closing of the heel which transforms the flat upper into a 3-D work piece ready for lasting. This can either be performed by laying the two parts one on top of the other, grain sides together, and sewing along the curve in the flat, resulting in an tucked join once the closed upper has been turned right side out, or by using a machine, where the sewing head zigzags from one work piece to another forming a 'butt' join. See figure 2.5.

Figure 2.5:- stitched/Closed upper

d. Lasting/Making

This is where the closed upper is lasted and soled. Lasting consists of three operations, toe, side and seat and often includes tacking. In toe lasting the last which has the insole board attached to its base and the shoe upper on it is loaded into a machine by locating the margin around the perimeter of the upper into a series of pincers, typically seven, nine or eleven, which are then gripped. The materials are then tensioned by lifting the last against the pull of the pincers by a pneumatic ram called a last post. The seat and side lasting is achieved in a similar way, with adhesive being applied to the insole board and the upper material being rolled or wiped over the adhesive in order to form the bond.

The shoe then passes on to a heat setter to set the upper material to the last form. Other operations that are common within lasting include tacking. This is where a series of tacks are

driven through the highly tensioned upper into the base of the shoe for added strength. See figure 2.6 lasted upper. Once the upper has been fully lasted the sole has to be attached. Before this can be achieved the bottom of the lasted upper has to be `scoured' in order to flatten any pleats that have been introduced by the folding of the upper material around the curved profile of the last. In order to achieve a good bond surface for the cement the bottom is then `roughed' by using abrasive wheels generally in the form of wire brushes rotating at high speeds. These brushes, when brought into contact, grind away any protrusions and the surface of the leather in order to produce a relatively flat surface for the sole to be bonded to. Adhesive is then applied to the base of the shoe and to the sole. This adhesive is generally of a re-activatable form and is often applied to the soles sometime in advance of actual bonding. The actual attaching of the sole involves a process known as `spotting'. Once the adhesive has been reactivated the sole is presented to the bottom firstly at the toe and then at the heel as these are the most important areas from a cosmetic viewpoint. The shoe is then placed into a press which forces the sole onto the bottom of the shoe under high pressure. Finally the shoe is passed through a chiller in order to ensure a good bond.

Figure 2.6:- Lasted upper

e. Finishing and packaging

Before the shoes are packaged and sent to the retailers they are `finished'. This process includes the removal of any loose threads that may have resulted from earlier stitching processes and the polishing of the shoes. The shoes are then inspected to ensure they are of sufficient quality and presentation

After shoe passed the final quality checking standard it go for packing, packing method and system may differ from customers to customers as well as from organizations to organizations, but in general packing could provide information like size assortment, color, materials, article number, customers, company address, and others information.

2.4.2. Footwear production Input

As it is mentioned above, production of footwear involve series of value addition process. The manufacturing process mainly involves three key elements stated as follows.

- Input materials used for upper and bottom part making.
- Machinery infrastructure arranged in accordance with steps for proper value addition process different skill level workers.
- Input materials used for upper and bottom part making.
- Machinery infrastructure arranged in accordance with steps for proper value addition process.
- Different skill level workers and some of them are listed below.

A. Material:

- **Leather:** the top most visible part of footwear is made from assembling of different components and is called upper. Leather is one of the most used upper materials in Ethiopian footwear industry and is made up of tanning process of sheep/goat skin or cow hide infusing number of chemical process for enhanced value addition.
- **Sole:** the outer most bottom component of the footwear where the leather upper is fixed and that provide safety for our foot is called sole. Sole is part of the shoe where the overall load of a person is concentrated and brings balance for the wearer. It can be made of natural rubber, plastic rubber, EVA,
- **Insole:** the middle layer made of a special cellulose cardboard sheet cut to fit with the inner part of the sole the periphery of the lasted upper and the surface of the insole is used to apply glue for permanent bonding with the sole.
- **Fabric**: fabrics are woven or non-woven textile materials used in the footwear upper making process. The various purpose of using fabric differs from model to model of the footwear. Fabrics thus can be used as a reinforcement of thin leather material or as a lining.
- **Stiffeners**: the upper material made form leather and fabric materials as an assembled upper of footwear does not guaranty the shoe to maintain the natural shape or contour of a human foot. Therefor stiffeners are used as part of hard material to enable the upper open space for the foot maintaining the form of smooth shape of the footwear.
- **Thread**: As welding is for joining two steel materials, thread a highly twisted cylindrical, flexible polyester material used for stitching purpose so as to join two components of the upper material of the footwear such as Vamp, quarter and heel grip and so on that are made of leather or fabric material.
- **Accessories**: accessories are small materials used as an input for footwear production with functional and decorative purpose. Laces to tighten loose fitting, eyeleting for

insertion of laces, tags for brand name pasting and many others can accordingly be used as an accessory.

- **Foams:** most of the time such materials are used to enhance comfort around the ankle of footwear and are used to create pipe like structure on the top line of the footwear.
- **Glue**: viscous materials used to bring strong bond among the edge of components for proper stitching operation. The main purpose of glue pasting is to bring the two most important part of the shoe i.e. the upper and the sole is through two phase application of glue
- **Neoprene**: are chemicals used for cleaning of dust from the sole material to increase bonding between the sole and upper.

B. Machine

- **CAD/CAM:** is a technology for design and footwear pattern engineering activities including sizing, grading, allowances and consumption related aspects
- **Swing beam cutting press:** this machine is used to cut light components such as leather and lining for upper preparation. It is composed of both hydraulic and electrical components that can work accordingly to bring precise cut components such as Vamp, Quarter and various straps.
- **Skiving machine**: this machine will shave leather materials up on the periphery of the cut component for reducing leather thickness so that overlapping components during stitching will be easier.
- **Splitting machine** : as the name indicate this machine is meant to reduce the thickness of the leather . The difference with skiving machine is that skiving machine will remove excess material at the edge of the component while splitting machine will minimize the thickness of the whole area of the component and make it in two pieces.
- **Binding machine**: where the supplied leather/upper material is below the expected thickness, additional reinforcement is applied. Binding machine will make the upper material and heat reactivated reinforcement material by applying heat and pressure.
- **Flatbed stitching machine**: ftalbed machines are commonly used stitching machines used to assemble two components by using tread. It is electrically powered machine that comes in different brand and performance and mostly used for components that can easily be joined together.
- **Post bed stitching machine**: post bed closing machines are specially designed stitching machines that can handle stitching operation where curves and excess material prevail. Post bed machines are helpful when assembly is made around the back side of the shoe where difficulty is common due to shape and visibility complexity of the upper.

- **Eyeleting machine**: this machine is pneumatically operating machine for the formation of wholes for letting shoe laces. Application of die is must to fit the various eyelets designed as an accessory.
- **Embossing machine**: Where required to place text and company logo on the shoe as a permanent mark, selected text and logos are embossed through application of a die and heat so that the message will remain permanent on the leather upper.
- **Back part moulding machine**: maintaining the natural curve of human foot is important for comfort and this shape is created by using moulding machine to bring the right shape around the heel.
- **Fore part lasting machine**: lasting is fixing the upper part to the insole through creating space for the foot to be inserted and free movement of toes. Forpart lasting will stretch the upper and apply polyuterine glue for bonding purpose and will secure the upper at the bottom of the insole.
- **Back part lasting machine:** as is for part lasting this machine will also secure the upper at the bottom back side of the foot resulting the balance of points to be fixed at the back side of the shoe.
- **Roughing machine**: during design stage the designer will make lasting allowance so that bonding material will be applied and secured both at the insole and outer most sole. These allowances will create thick material at the bottom of the lasted upper and are not ready for cementing/glue application. Roughing machine will reduce the excess material and provide fibre like structure that can easily absorb cementing materials.

- **Wrinkle chesser**: are used to create smooth curve around the front and back side of lasted shoe through application of steam and roller tool
- **Chiller**: the lasted shoe upper temperature is relatively hot due to the heat applied by the chesser and lasting machines and need to be cooled for further process and this machine will provide the upper to cool.
- **Sole press machine**: pressing machine is used for application of high pressure force to create permanent bonding between the upper and the sole.
- **Delasting machine:** this machine will assist the lasted upper to be removed from the last/form up on completion of its lasting operation.
- **Spray machine:** so as to bring extra look and shinning effect, spraying machine will evenly spread lacquers, cream or black dye on the wearable shoe.
- **Polishing machine:** this shoe shinning, machine will apply rotary fibres and make the applied cream or dye to shine so that the finishing will appear acceptable and inviting to wear

the footwear.

c. Man power:

Footwear manufacturing needs the required qualified worker to perform at its best productivity and quality. By its nature the manufacturing process of footwear need different skill level according to the easiness of the operation and complexity required.

There is also a need for appropriate professional expertise to establish proper production planning, execution and monitoring activity to ensure the factory as a whole and the sections as a team are working properly. Analytical and mathematical approaches are also applied for corrective measures.

With the skill level specifically for those operations directly relevant for value addition, it is recommended to have all level operators such as skilled, semi-skilled and unskilled labour. Among the total operations in the closing department 25% of the work can be done by the unskilled labour type work force.

The number of man power required for footwear production is determined by the complexity of the work, the work order on hand and the urgency to meet delivery date and companies are most of the time free to deploy labours in accordance with their need but still has a permanent staffs at crucial point of value addition stations.

2.5. Significance of simulation in lean manufacturing process

Detty and Yingling (2000) described several studies where simulation identified the values for specific parameters of the lean system. Simulations enabled decreases in inventory, order lead time, and system flow times as well as reduced variability in supplier demand in an assembly process for a consumer electronic production H. Marvel & Charles R. Standridge (2009). Schroer (2004) showed that simulation techniques could be used to facilitate understanding of the basic concepts of lean manufacturing such as inventory control and process variability reduction.

Detty and yingling also said that it assists in the decision to implement lean manufacturing principles. This implies that, Simulation have ability to show the behavior of variability in a given process steps to support decision making process. Variability influences faithfulness on benefit of lean implementation as it refers instability of result. In this paper, simulation techniques are used as a facilitator to understand the basic concepts of lean manufacturing such as, push versus pull manufacturing and also to support process variability reduction.

There are too many simulation modelling soft wares in the world. One of them applied in this paper is Arena.

Arena plays a significant role in manufacturing as well as service giving industries by capturing the existing situation and facilitating alternative possible scenarios for further improvement. Arena is a true Microsoft ® Windows ® application which is fully compatible with other windows software, like word processors, spreadsheets and CAD packeges.

Arena uses SIMAN one of process oriented simulation language which makes is time saving and develop time persistent statistics while constructing complex model. Arena software has 5 easy steps to be followed. They are:

1. **Create a basic model: -** Arena provides an intuitive, flowchart-style environment for building an "as-is" model of your process. Simply drag Arena's modules (the shapes in the flowchart) into the model window and connect them to define process flow.
2. **Refine the model: -** Add real-world data (e.g., process times, resource requirements, and staff levels) to your model by double-clicking on modules and adding information to Arena's data forms. To create a more realistic picture of your system, replace the animation icons that Arena automatically supplies with graphics of your own (e.g., from ClipArt or other drawing packages).
3. **Simulate the model: -** Run the simulation to verify that the model properly reflects the actual system. Identify bottlenecks and communicate with others through the dynamics of Arena's graphical animation.
4. **Analyze simulation results: -** Arena provides automatic reports on common decision criteria, such as resource utilization and waiting times. Augment the built-in statistics with your own, so that Arena reports what's important for your decision-making needs.
5. **Select the best alternative: -** Make changes to the model to capture the possible scenarios you want to investigate, and then compare the results to find the best "to-be" solution.

To build models with Arena, will be using modeling shapes, called modules, from the Basic Process panel (and perhaps other model-building panels) to define your process. There are two types of modules on a panel: Flowchart modules and Data modules.

a) Flowchart module shapes are placed in the model window and connected to form a flowchart, describing the logic of your process.
b) Data modules are not placed in the model window. Instead, they are edited via a spreadsheet interface.

2.5.1. Replication and run length of simulation

Replication is one of the basic elements of simulation software which simplify long calculation steps of hand simulation. It is a recalculating process with the same input parameters and different random input numbers for each performance measures outputs. In arena simulation software

replication plays an important role regarding time consumption and precise result even if there is an error which can be calculated based on sample average, sample standard deviation and estimated percent value of user confidence level for having true output of total production after replication result.

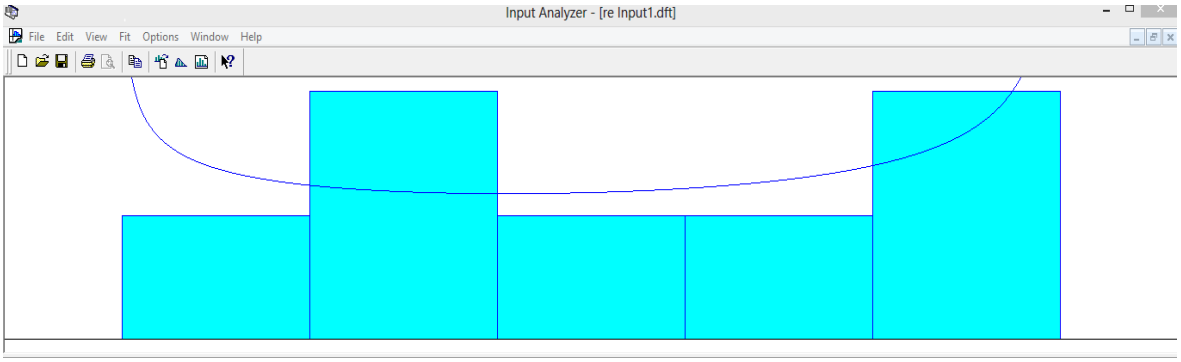
The specified time that the simulation is going to run is called run length which is equal to one replication. Therefore number of replications will be a number of each run with independent value of random inputs (inter-arrival and service time)and different statistical distribution with its own parameter value(relative to fixing the probability function). This results different values for all performance measures under each number of replications. Table 2.1 shows an example concerned about the relation between run time, number of replication and its average and standard deviation calculation using input analyzer part of Arena.

Table 2.1 Performance measurements replication average and standard deviation result using Arena input analyzer.

Run length	**Performance**	**Performance**								**Sample standard deviation**
		Measurements result for each number of Replications (7)							**Sample mean**	
20 min	Total production	3	2	5	6	6	4	3	4.14	1.57
	Average waiting time in queue	3.33	1.43	0.5	2.69	1.11	2.9	3	2.14	1.1
	Maximum waiting time in queue	12.1	4.05	1.1	6.89	3.33	6.02	5.15	5.52	3.47
	Average total time in system	9.61	6.1	2.23	12	4.14	8.03	7.29	7.06	3.29
	Maximum total time in system	16.7	7.7	4.7	13.8	5.55	10.1	7.5	9.44	4.41
	Time- average number of parts in queue	2.3	1	0.23	1.82	1.2	2.4	2.54	1.64	0.861
	Maximum number of parts in queue	2	3	2	1	2	3	1	2	0.816
	Machine utilization	2.72	1.12	0.9	2	1.8	2.8	3	2.05	0.833

** Note: For each replication 20 minutes run time is used

Using Arena input analyzer *Total production* sample average and standard deviation is calculated accordingly. See Figure 2.7.




```
          Distribution Summary

Distribution:    Beta
Expression:      1.5 + 5 * BETA(0.801, 0.715)
Square Error:    0.021286


          Data Summary

Number of Data Points    = 7
Min Data Value           = 2
Max Data Value           = 6
Sample Mean              = 4.14
Sample Std Dev           = 1.57

          Histogram Summary

Histogram Range          = 1.5 to 6.5
Number of Intervals      = 5
```

For Help, press F1

Figure 2.7 *Total production* sample mean and sample standard deviation result screen shot taken from input analyzer-Arena software.

Likewise; for *Maximum waiting time in queue,* sample mean and sample standard deviations calculated using arena's input analyzer. See figure 2.8 a and b.

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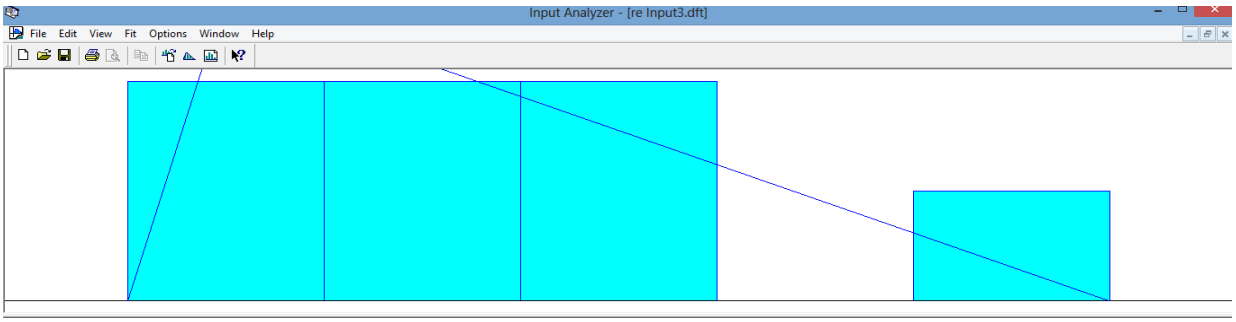

Figure 2.8 a) *Maximum waiting time in queue* sample mean and sample standard deviation Graph screen shot

```
      Distribution Summary

Distribution:   Triangular
Expression:     TRIA(1, 2.2, 13)
Square Error:   0.032149


Kolmogorov-Smirnov Test
  Test Statistic       = 0.145
  Corresponding p-value > 0.15

      Data Summary

Number of Data Points   = 7
Min Data Value          = 1.1
Max Data Value          = 12.1
Sample Mean             = 5.52
Sample Std Dev          = 3.47

      Histogram Summary
```

For Help, press F1

Figure 2.8 b) *Maximum waiting time in queue* sample mean and sample standard deviation result screen shot

The number of replications estimated on table 2.1 is an initial value (replication number=7) to get sample mean and sample standard deviation. But this may not be the exact replication number to get the approximate true value with less error. Therefore we should measure the reliability of number of replication of giving true value.

After sample mean and sample standard deviation are calculated for all replications of performance measures, half width from the sample mean value will be manipulated to enable to know the range that covers true value depending on estimated confidence level. Equation 5 gives the range that the true mean value will be available based on the sample mean value.

$$\bar{x} \pm h_o = \bar{x} \pm t_{n-1,\frac{1-\alpha}{2}} \frac{s}{\sqrt{n}} \quad \text{.....Eq. 5}$$

Where; $\bar{x}$=sample Mean and h_o = initial half width

t= taken from ‘t’ distribution table at n-1 and (1-α)/2 coordinate

n= number of replication

α= confidence interval in percent to have true value with in half width

s= standard deviation

As an example, let’s set the half width interval for *Total production*’s sample average value and fix replication count. All values are taken from table 2.1except for ‘t’. See Appendix-G for ‘t’ distribution.

Given: $\bar{x}$= 4.14

$t=t_{(6,0.025)}$= 2.447

n=7

α=95%

s= 1.57

Substituting the above values in to equation 5,

$4.14 \pm 2.447\frac{1.57}{\sqrt{7}} = 4.14 \pm 1.452$, where 1.452 is the 95% half width

This implies that subtracting 1.452 and adding 1.452 from 4.14 samples mean value results the true mean interval 2.688 to 5.592. See figure 2.9 probability distribution density

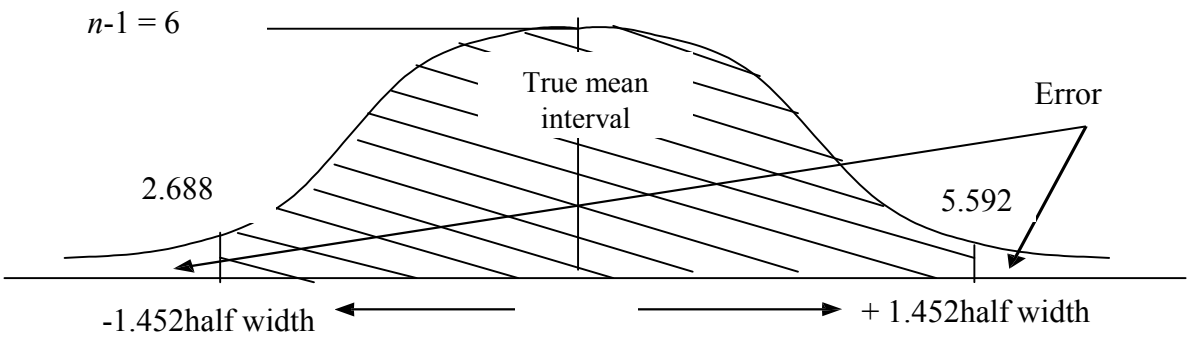

Figure 2.9 probability distribution density with 6 degree of freedom

When degree of freedom approach ∞ error area as well as true mean interval/half width decreases. This implies that the outcome of increasing number of replication is minimizing error. Likewise, for the rest performance measures listed in table 1.1, 95% half width value and there true mean interval are coded in table 2.2 as follows.

Table 2.2 Performance measurements true mean interval.

Performance measurements selected to be calculated	Sample Average	Sample standard deviation	95% half width	True mean Interval	
				lower	upper
Total production	4.14	1.57	1.452	2.688	5.592
Average waiting time in queue	2.14	1.1	1.017	1.123	3.157
Maximum waiting time in queue	5.52	3.47	3.209	2.311	8.729
Average total time in system	7.06	3.29	3.043	4.017	10.103
Maximum total time in system	9.44	4.41	4.079	5.361	13.519
Time- average number of parts in queue	1.64	0.861	0.796	0.844	2.436
Maximum number of parts in queue	2	0.816	0.755	1.245	2.755
Machine utilization	2.05	0.833	0.770	1.28	2.82

Now the 95% confidence initial half width have been known which may not be the intended one since it affects most acceptable replication number calculation. Therefore, it is necessary to fix the half width value (assumption) for each performance measurements which gives low and acceptable error level.

2.5.2. Interval and service time (random inputs)

Inter-arrival time resembles the time gap between the two arrivals of individual consecutive parts. Size of batch to be transferred from station to station, means of transportation adopted to make it ready for the immediate value addition process and the amount of time required to process a part are some of factors that affect the inter-arrival time value between two successive parts on the same station as well as from station to station.

Service time is a time required to transform a parts, components, and semi-finished product in to immediate value adding process where they get assembled. The amount of process time needed to perform specific operation can mostly be affected by the complexity of the work, the skill and experience of the personnel taking care of the part and machine performance. The speeds of service at which each station perform determine the speed of part, components, and semi- finished products flow towards the next required value adding stage.

As a manufacturing process is mostly performed by more than two work stations, the higher service rate of station A will create accumulation of part to be processed at next station B that is, at station B parts are arriving at faster rate than station A and this will create a queue of parts to be processed at station B.

2.5.3. Events and process oriented simulation

As explained earlier, events like arrivals, departure and process end are essential parts which makes inter-related process with continuity behavior to visualize simulation. In process oriented simulation the whole part is about calculation with the time value when events occur and what happened when they occur. This enables to control, increase flexibility by using variables, attributes as well as logic flow and also to know the general stage at any time interval. Once events get their equivalent value inside processes, it is somehow easy to develop a process oriented simulation. In Arena software all event values of process will be written in SIMAN language from newly created typical entity/part arrival up to its dispose.

This can be also used to develop a simulation model for complex process by using event oriented program for each independent process stages.

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Chapter 3: Methodology

With an intention to reach the research objective, factory assessments has been made to identify and formulate problem. On the area that the problem is identified, data have been collected using different methods that are; time study and visual recognition which are primary and secondary. Based on this, a model will be constructed using VSM in order to identify value adding, non-value adding and necessary non-value adding processes of current manufacturing process. The modelled current manufacturing process will be simulated and analysed using arena software to calculate and verify that the collected data that are especially took from those stochastic processes are correct. Verification process takes place at this stage in such a way that the output result of actual process and the simulated one will be compared. This increases the reliability of the final conclusion of the thesis result as it is verified that it is based on correct data.

If the result of verification is not correct, proper data collection will be made again and passes all steps until it results similar with the output result of actual process. After being verified and got positive result, implementation of VSM, and bottlenecks analysis will take place to improve lead time (increase final production output), reduction of WIP and cost. Newly developed manufacturing process again will be modelled using VSM to visualise all activities and simulated using arena to show how the manufacturing process is improved relative to the former arena simulation result. Based on the newly developed manufacturing process, documentation and implementation step takes place accordingly to improve the manufacturing processes. See figure 3.1 Methodology diagram.

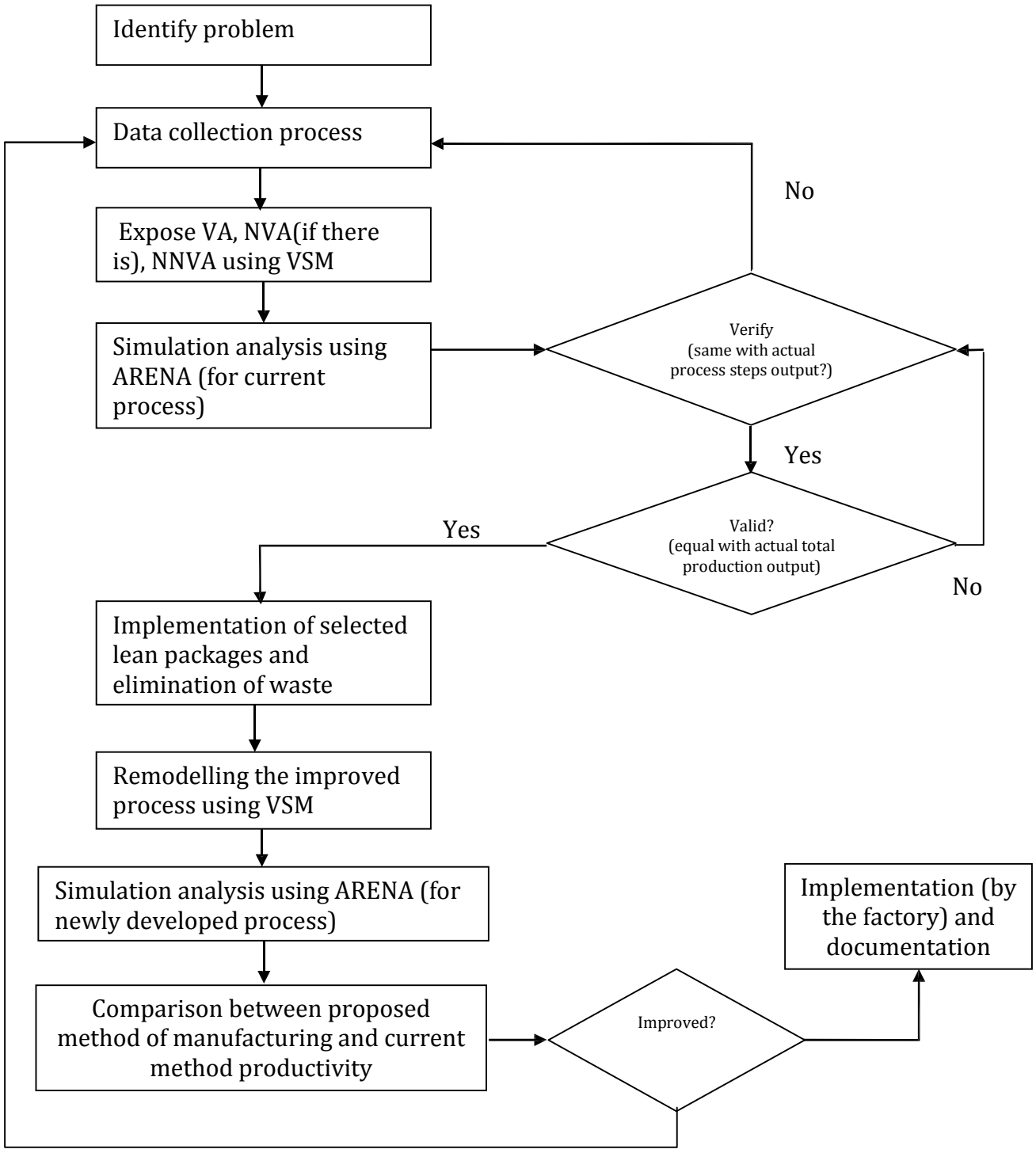

Figure 3.1 Methodology diagram

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Chapter 4: The case study

4.1 Kangaroo shoe factory background

Kangaroo shoe factory is one of the renowned shoe manufacturing unite established in 1982 as a private company in Ethiopia, Addis Ababa around Gerji Industrial area. During its establishment, it was installed with an average actual production capacity of 1000 pairs of shoe per day in different model. With its investment since 2015 the factory has made an expansion phase to increase its production capacity by 60% to reach its existing capacity which is 1600.The actual production capacity of the factory is 800 pairs of different models per day if and only if input is fulfilled.

In the factory working days are fixed to be from Monday to Friday 8 hour per day and Saturday 4 hour per day except on holydays(14 days) and weekend(half day of Saturday and Sunday). Therefore, total working days will be 273 per year.

4.2 System development status

To enhance customer satisfaction and delivery of its product to its target, Kangaroo shoe manufacturing has implemented the new international system standard ISO 9001:2015 by 2017. There is also an effort to meet requirements for competition of Ethiopian Quality Award (EQA) where possible activities lead to enhanced within the factory. The factory has started a joint activity to take-off a first stage kaizen philosophy as a tool for lean manufacturing system to reduce waste and enhance cost competitiveness at its infant stage where activities are sorted and implementation is due to begin.

With regard to long term strategic issues, 2 years marketing and communication program is crafted for smooth demand generation and market share achievement is developed. Moreover, the plan to maintain production activities and human resource activities are also in place. Such strategic documents and plans ensure the potential of the company where local competitions are prevailing.

4.3 Man power

One of the key elements in a given manufacturing firm is availability and the right composition of all the required man power at each point of manufacturing activity and management related works. With this regard kangaroo shoe is composed 60 men and 236 women total of 296 staffs

for its production of footwear unit. To further disintegrated there are about 42% skilled, 45% semi-skilled and 5.4 % are professional staffs to support production related activities.

The labour characteristic is known for its multi-skilled composition and of high turnover which account an average rate 0f 14.5%. Most of its staffs are concentrated at its production line where the most value addition work takes place. The standard for healthy staff turnover is 7% but in the case of kangaroo shoe it is much higher than the expected standard. to minimize the drain of skilled man power, the factory has implemented an incentive mechanism where Employee of the Month in Cutting Dep't is approved via Minutes that ultimately approved by 3 Factory Top Management based on Material saving & Cutting standard achievement. There is also reward mechanism for Supervisors Reward program at every 3 month of 500birr and document base reward for professionals based on performance evaluation in every 6 months.

To meet system standard requirement of ISO9001:208 there is regular based annual training plan that linked with LIDI, Kaizen & ISO training packages for all staffs which is monitored & followed by HR department

4.4 Marketing activities

As the data collection date, the company is engaged in executing local market of corporate customers & retailing business through marketing & production setup. The company is also ready for export order whenever it is on hand and is capable in human resource & merchandizing technologies that ultimately synchronized with the availability of machine & experience in exporting.

With its more than 9 retail outlets in Addis Ababa for local market, the company is responding for its order through personal contact, Fax & means of telephoning where customers place an order for a given model. For export order, the company is responding to its ultimate buyers through internet based communication such as E- mail as well as of the buyer means of communication like sample confirmation through Skype or photo sample & so on.

Kangaroo shoe factory is initiating customers demand through presenting itself into Local & foreign exhibitions, reaching through means of Radio, Online sales, social media &Website as well as in referring magazines to takeover local market via tendering. Additionally, marketing research practice for the purpose of knowing its customer behaviour and important aspects of marketing elements such as price, quality & competitors are regularly conducted.

4.5 Product development practices

Among the key firm level activities Product Development Centre is one of it serving as a section for interpretation of marketing research information to real and tangible product. this section also

work as a means for external communication centre where buyers samples and designed and counter sampling is done. Here, after the actual product development and sampling work is over, other activities such as consumption calculation, Bill of material, technical specification, production routs are determined for each style/model. PDC is responsible for sending trail production samples before mass production is started, there is practice of trial production for each graded patterns and is minimum 60 pairs from each size i.e. 10 pairs/size.

4.6 Production planning and controlling

This section is organized & equipped with 2 industrial engineering graduates with activities such as material planning & capacity planning, aggregate planning , preparation of Bill of materials & MRP (material requirement plan) , regular recording of WIP. NAT-JNLP software is implemented that ultimately carried out material planning interfaced with finance department. There is a trend of analysing plan against actual production in every month so as if the problem is occurring due to unavailability of material & immediately informing to the respective management. If it is due to power cut, machine breakdown & employee turnover it is postponing to next month plan. There is also a trend to tie 12 similar parts of same size number together in order to minimize size mismatch after some value adding process.

4.7 Cutting section

Through an intensive coordination of quality team, incoming inspection of Leather & other input materials are carried out at this point before the leather is cut for the given article. on the basis of the amount of order , manually & clicking machine. Cutting production method is used accordingly. Currently the factory has reached on an average of 1150 stroke per clicker accounting for actual cut capacity of 800-1000 pairs/day. For achieving such quantity of cut components, the require infrastructure and proper die management system is used.

With regard to section specific performance measurement tools, kangaroo shoe factory is evaluating the cutters performance daily through material saving, meeting cutting standard & efficiency. So as daily cutters incentive report can be compiled as of their performance. Even if there is turn over, the company is managing new cutters in providing on job training through supervisors & LIDI support.

important graphical representations for quality cut component production for the next production activity is facilitated through wall mounted Show boards .The company is performing intensive in process quality control, capacity building & performing root-cause analysis to manage the rejection or rework. Due to unavailability of Machine spare parts 17 out of 19 are currently working.

4.8 Stitching section

Stitching section is meant for permanent attachment of footwear components to result completed ready upper for lasting. The components in line for stitching however need to be go through preparation called prefabrication. In this section, Prefabrication machineries are available for all intended purposes for preparation. All the required tools & equipment are also available for upper making.

Important machineries like single & double bed machineries, zigzag, chuchane, stroble so on are used for stitching of various construction uppers. Trolley& conveyor are used as a means of transportation from one point of value addition to the next station.. There is hourly feeding &packing report that ultimately controlling the production. In-process quality checking practices with comprehensive quality checking parameters are rigorously done but still there is 0.78% rejection specific with stitching defects. Line balancing for similar models through standard time calculation & update is carrying out to enhance the overall productivity improvement program. Currently 1600 pairs/day production capacity is maintained with 4 lines. it has been observed that the average capacity utilization of the section is around 73% and the most likely capacity to produce specific model per line ranges from 250 to 320 pairs of shoe. The variation comes from the characteristic of the model that complex models take time for completion.

4.9 Lasting and finishing section

Lasting section at kangaroo shoe is known for its Cemented, strobe & moccasin methods footwear constructions of various models. Completely checked and ready upper & last is loaded on dedicated conveyor where the upper is transported to different stations of value adding activities depending on the type of the model.

The company is controlling lasting activities through planning & controlling unit via WIP, Final QC & quality check lists directly reported from QC team. Lasting section production status is maintained through hourly feeding report, hourly packing report & daily work order. Using 64% of machineries available in this section an average of 512 pairs of shoe are being produced using two identical lines that leads to the total section capacity to be around 1024 pairs per day. Kangaroo has established skill inventory matrix specifically required for lasting section for improved man power assignment and skill up gradation program in the future. The following table 4.1 shows the consolidated information of all section about the installed production capacity.

Table 4.1: Instoled production capacity of all section in kangaroo shoe factory

Production capacity per day in pair				
Cutting section	Preparation section	Stitching section 73% capacity utilization	Mocassine section	Lasting and finishing section 64% capacity utilization
1000 -1600 two types of model	600-700 one line	250-320 one line	300 no line	Up to 512 one line

Source: Kangaroo shoe factory

4.10 Inventory management system

The section is organized by 11 skilled staffs for efficient movement of material to and from store for both finished shoe and raw material. Finishing goods store where Incoming leather inspection system for thickness, shade, feel, colour fastness inspection are carried out for all materials as per the sample. Separate store for leather, sole, chemicals & other accessories is also organized in proper manner. There is a practice of leather sorting but regarding & cost variance calculation is not carried out There is no dead stock policy but eliminating stock material through selling & recycling for different purpose.

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Chapter 5: Data collection and analysis to implement selected lean packages

In this chapter data collection, data organization and analysis of both VSM and Arena result of the current and future model will be presented in a manner to enable to draw a better conclusions and recommendations based on the problem identified in kangaroo shoe factory.

The main purpose of the study will be reflected in this chapter which is tackling aforementioned problem statements in section 1.2. The followings are systematically used problem solving approaches.

- Data collection.

- Identify non-value adding activities current state shoe manufacturing process in kangaroo using VSM.
- Analyse the current state VSM by simulating with Arena and verify by comparing with each process step. If it is the same, then ensure that the simulation model is ready to represent real or existing manufacturing system (validity test)before further modification done on the model to improve current manufacturing system. If it fails, it goes to the verification and also to the data collection stage accordingly.
- Eliminate identified non-value adding activities using Kanban supported by pull system and to construct future VSM based on it.
- Model and evaluate the future state VSM (after elimination of non-value adding activities) with Arena.
- Ensure that through applying selected lean manufacturing principle the company could minimize waste and recommend them better solution for productivity according to the analysis result.

Due to the fact that footwear manufacturing process steps are too vast to be displayed in VSM and also Arena even for one product model, the study will be conducted on systematically selected one model footwear. The manufacturing process itself invites the manufacturer to produce verity of products which will pass different process steps. But there are products categorized in the same product family with slight difference in their production process flow. Even though it is necessary to evaluate each step that the product model passes in numerical value, conducting the study for one product family will disturb the accuracy of the end result which will lead for wrong interpretation and recommendation.

5.1 data collection

The data collection process has been performed for about 8 months and also this paper have used the past data from the factory profile for the sake of having appropriate final result of study. Points listed below are investigated first as a base line of having strong data collection process gradually.

I. Sections‘ process steps (current state)

II. Machine availability

I. sections‘ current process steps (See figure 5.1 a to e)

a) Cutting section processes

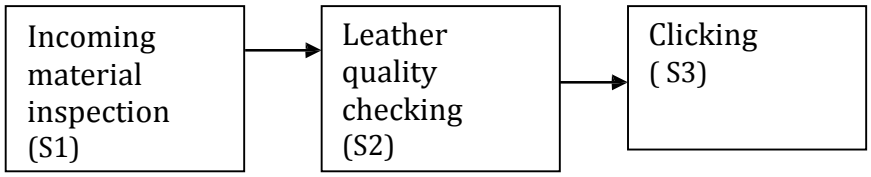


Figure 5.1 a: process steps for cutting section

b) Preparation section processes

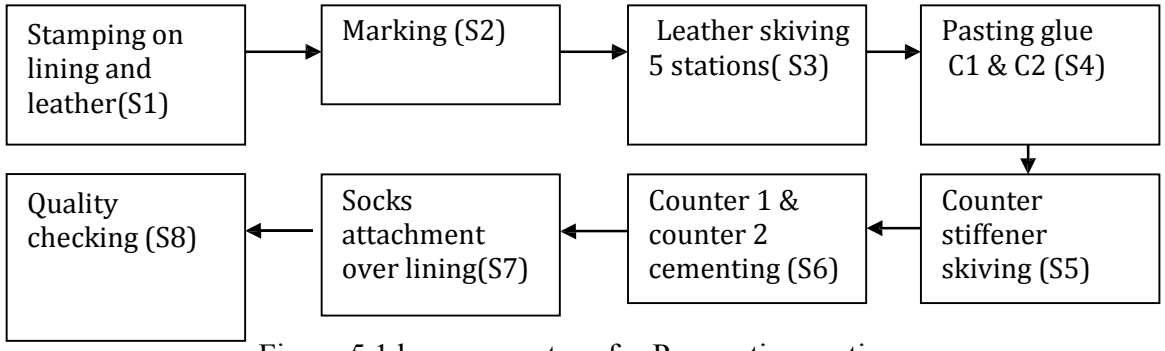
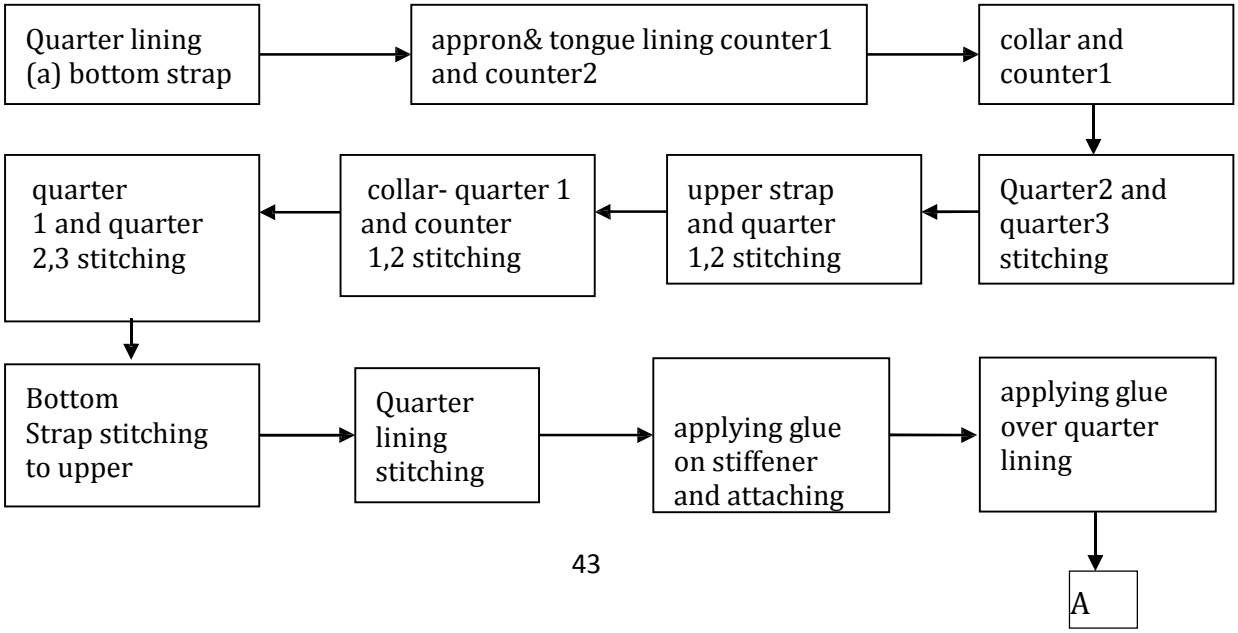


Figure 5.1 b: process steps for Preparation section

c) Stitching section processes



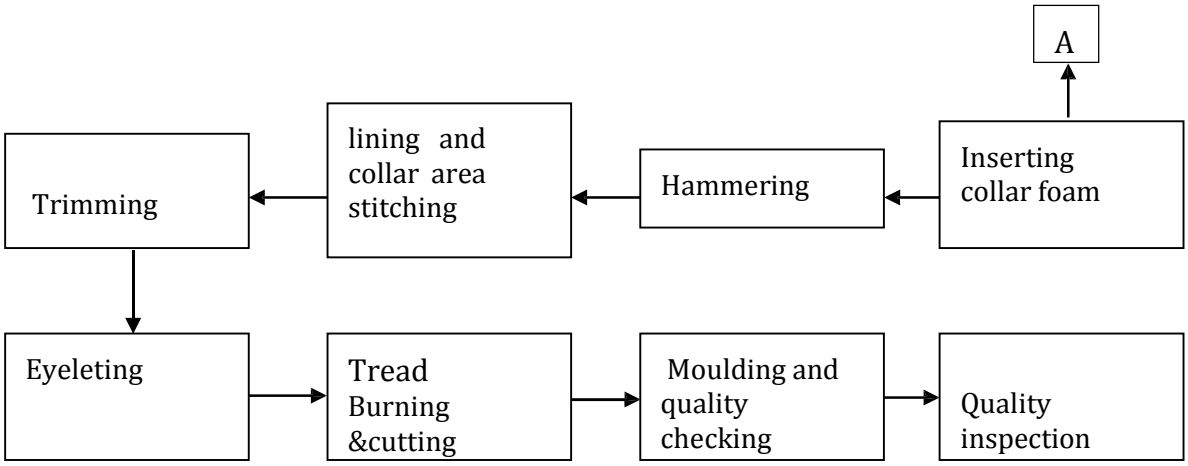


Figure 5.1 c: process steps for stitching section

d) Lasting and finishing section processes

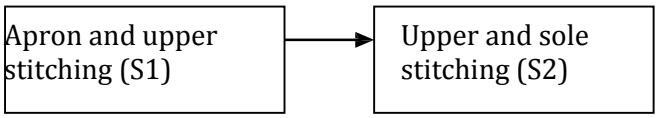


Figure 5.1 d: process steps for mocasine stitching section

e) Lasting and finishing section processes

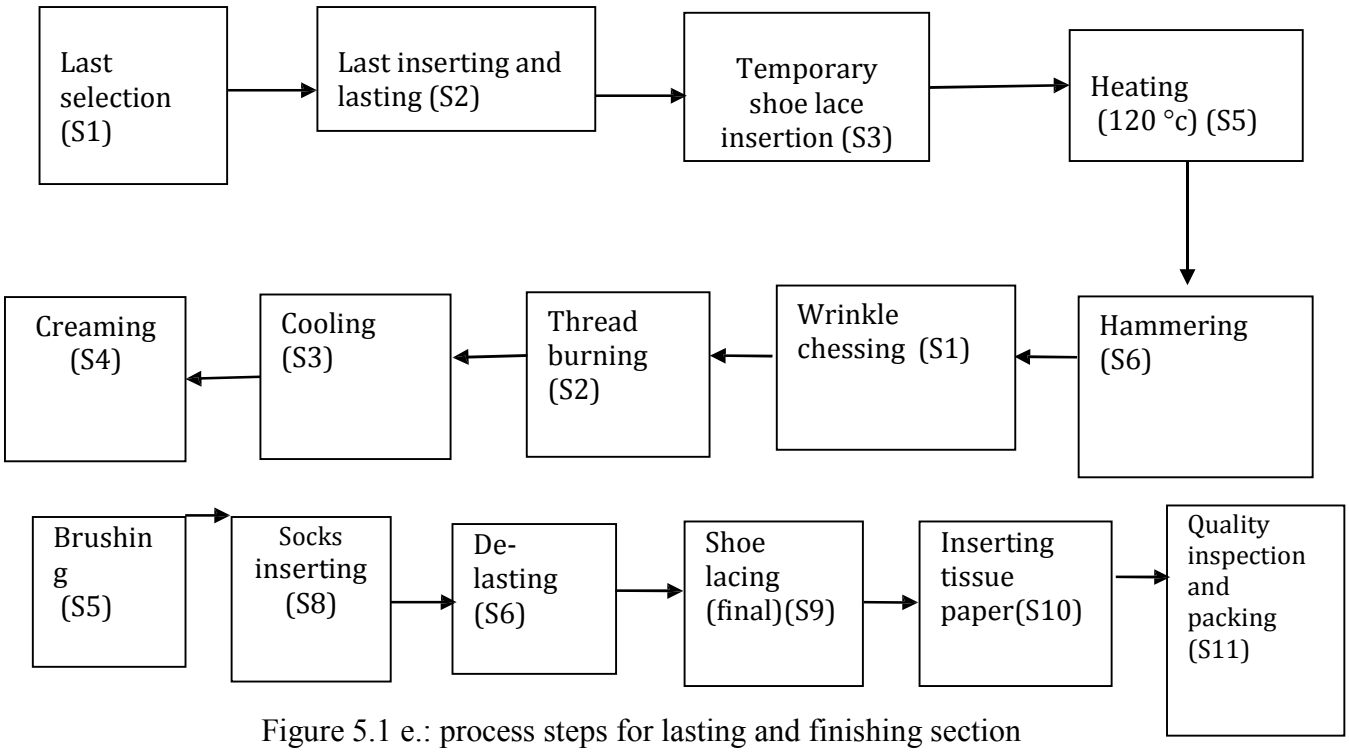


Figure 5.1 e.: process steps for lasting and finishing section

II. Working machine availability

Generally, the summary of machine availability at each section is shown in table 5.1below. Table 5.1. Section wise machine availability of Kangaroo shoe

Cutting	
M/C TYPE	**QTTY**
Leather cutting	15
Leather splitting	1
Reinforcement cutting	4

preparation	
M/C TYPE	**QTTY**
Logo Stamping	1
Number Stamping	3
Skiving	8
Ironing	2
Insole and counter skiving	2

Stitching	
M/C TYPE	**QTTY**
Flat bed single needle	15
Post bed single needle	15
Post bed double needle	50
Zigzag stitching	3
Trimming	4
Eyeleting	4
Back part moulding	3
Strobe/insole stitching	2
Tongue stitching	2

Lasting	
M/C TYPE	**QTTY**
Toe lasting	2
Side lasting	3
Back part lasting	2
Hammering and moccasin	1
Heating conveyor	2
Ironing	4
Roughing	2
Sole attaching	4
Cooling	2
Brushing	4
De-lasting	2
Heal cantering and attaching	2
Insole moulding	1
Toe puff ironing	

5.1.1 Product Model selection

In product model selection process, three important considerations are taken in to account. The first one is based on the tendency of company‘s product model specialization and the second is customer order quantity for the product model. The third point is based on number of processes steps of the product model (easiness) and small number of components. Based on the first criteria, product model selection result is known to be Model C1 as per company‘s product model specialization tendency. The second and third criteria needs company‘s past data on each product model order quantities to be analyzed to select the correct one. Table 5.2 and 5.3 shows list of product models in terms of customer order quantity from March, 2016 to January, 2017 and list of product models with their corresponding number of processes steps and components in the same time interval respectively.

Table 5.2 product models in terms of customer requirements (from April, 2016 - March, 2017 respectively)

S.No.	Product models	Order quantity	Rank
1	C2	2730	
2	C9	6825	
3	C11	13650	
4	C1	25550	1
5	C12	4095	
6	BANKER 1	9828	
7	BANKER BOTS	4095	
8	TIMBERLAND 900T	7098	
9	Model 908	1638	
10	KONTEE01 02	6279	
11	BOOK1 02	3549	
12	MOETO 01 02	8190	
13	COMFORT 01	4368	
14	COMFORT 02	5460	
15	COMFORT 03	6825	
16	DIVA 1	3549	
17	DIVA 2	4641	
18	ATLAS	10920	
19	ATLAS PUMA	8190	
20	ATLAS EXINA	9555	
21	ATLAS BOOTS	4914	

Source: kangaroo shoe factory planning section

Summarizing the above two tables (Table 5.2 and 5.3), product model called C1 with moccasin construction has scored high value of customer order quantity and also total production number with in the specified year. According to the above criteria and steps for product model selection, model type C1 will be used as centre for the case study analysis of the paper. C1 is characterized by its comfort, high demand, with medium number of components, partially made with hand stitch construction. C1 follows the basic footwear value addition process to meet customer and quality requirements. The daily instoled production capacity of the factory with this model ranges from

250 to 400 pairs per day with one line and its average selling price is set to ETB 550.

Table 5.3 Product model's number of process steps with their components

S.No.	Product models	Number of process steps (cutting, stitching & lasting)	Number of components	Rank
1	C2	51	14	8
2	C9	51	10	14
3	C11	48	12	13
4	C1(Classic 1)	46	10	1
5	C12	48	12	5
6	BANKER 1	56	12	7
7	BANKER BOTS	48	10	3
8	TIMBERLAND 900T	51	10	14
9	Model 908	51	16	6
10	KONTEE01 02	48	14	4
11	BOOK1 02	48	10	2
12	MOETO 01 02	51	12	16
13	COMFORT 01	51	12	18
14	COMFORT 02	51	12	19
15	COMFORT 03	48	12	20
16	DIVA 1	48	10	17
17	DIVA 2	48	14	11
18	ATLAS	56	12	10
19	ATLAS PUMA	56	16	9
20	ATLAS EXINA	56	16	12
21	ATLAS BOOTS	56	16	15

Source: kangaroo shoe factory product development centre

The current daily production quantity produced in each section is deduced from monthly gathered data in table 5.4 below and the current intake capacity of each section will be recorded as following.

Table 5.4. Existing production quantity produced in each section

Observation per month (8	Working days in month	Production capacity per month of Classic 1 model (C1) in				
		Cutting section	Preparation section	Stitching	Mocassine section	Lasting and finishing
January	23	1989	17020	5934	5520	5566
February	21	1562	13461	4452	5313	4830
March	24	2148	15840	6000	5904	5856
April	18.5	14707.5	12894.5	4828.5	4458.5	4421.5
May	24	2133	14736	6072	5832	5736
June	23	1961	17135	5083	5221	5658
Average production capacity per day		**843.9**	**682.3**	**242.5**	**241.6**	**240.2**

Table 5.5 current intake capacity of each section

Observation per month (8 hr/day)	Working days per month	Intake capacity per month of Classic 1 model (C1) in pair				
		Cutting section	Preparation section	Stitching section	Mocassine section	Lasting and finishing section
January	23	1710 sq.ft	19435	12466	7222	5750
February	21		15624	11529	6384	5628
March	24		21168	13488	7056	5928
April	18.5		13190.5	10045.5	5124.5	5143
May	24		21048	12936	7392	5640
June	23		19619	12167	6946	7245
Production capacity per day			**824.6**	**544.06**	**300.6**	**264.7**

5.1.2. Process related data collection

The observed processing and inter arrival time data under all sections are gathered in different days. Sample size for data collection process is taken to be 15 and displayed as follows.

a) Cutting section

The input mainly used here is upper leather for the upper part and lining leather for the inner lining as a component. The arrival characteristic here is different as compared to the other sections in that the received materials are not in the form of piece by piece components to be cut rather bundle of sheet finished leather. Cutters/clickers are issued the sum total of the pairs to be cut for one full day and the output of all cutting station is transferred to the next value adding operation. In addition to this, modelling cutting process have no significant value as it can be checked or verified indirectly while preparation section current status simulation is made. Hence, such gathering of information about an inter arrival of components or materials in cutting section is not performed. Cutting processing time observed in terms of minute recorded on table 5.6 and within 451 minutes average 806 pairs are cut. (See three examples about how pair cut per clicker is calculated in component bases Appendix-B)

Table 5.6 Processing time observed in cutting section

Number of stations with different clicking skill owners	Operations name	Number of workers	Number of processing time Observed per each station (in Munites)																											
			1		2		3		4		5		6		7		8		9		10		11		12		13		14		15	
			pair cut	time	pair cut	time	pair cut	time	pair cut	time	pair cut	Time	pair cut	time	pair cut	time	pair cut	time	pair cut	time	pair cut	time	pair cut	time	pair cut	time	pair cut	time	pair cut	time	pair cut	time
1	Cutting	1	5.1	30	5.0	28	5.5	31	4.5	25	5	28	4.6	26	5.2	29	5.2	29	4.7	28	5.6	30	5.8	31	5.3	29	5	28	5	28	5.3	29
2		1	3.7	30	4.6	32	4.7	32	3.8	26	4	29	3.7	27	4.1	30	4.1	30	3.8	27	4.4	31	4.8	32	4.2	30	3.6	27	4.8	33	4	29
3		1	2.4	29	3.0	30	3.2	33	2.7	28	3	30	3	30	3.3	32	3.3	31	3	29	3.1	30	3.1	33	3.5	32	3.1	30	3.5	32	2.7	27
4		1	3.2	27	3.6	28	4.2	32	3.8	29	4.4	32	4.4	32	3.8	29	3.8	29	3.6	28	3.8	29	4.2	31	4.6	33	4.4	32	3.8	29	4.4	32
5		1	4.9	32	4.3	29	4.4	29	4.8	31	4.8	31	5.7	35	4.2	28	4.2	28	4.7	30	4.7	30	5.6	34	4.9	31	5.4	33	4.2	28	5.6	34
6		1	4.9	31	4.6	30	4.4	28	5.1	32	5.3	33	4.4	29	4.4	29	4.6	30	5.1	32	4.4	29	4.8	31	4.6	30	4.4	29	3.9	27	5.3	33
7		1	4.7	19	4.5	27	5.7	30	6.9	36	5	29	5.3	30	5.3	30	4.8	28	5	29	4.8	28	5.3	30	5.6	31	5	29	4.2	26	6.9	36
8		1	4.5	30	3.6	25	5.2	33	4.7	30	4.5	29	4.7	30	5.2	32	4.2	28	4.9	31	4.9	31	4.5	29	4.5	29	5.2	32	4.5	29	5.4	33
9		1	4.6	30	4.4	28	4.9	31	4.4	28	5.4	32	5.6	33	6.4	36	4.9	30	5.4	32	4.9	30	4.4	28	4.4	28	4.4	28	4.2	27	5.4	32
10		1	5.0	31	5.0	32	5	35	3.9	27	4.5	30	4.1	28	5	32	4.5	30	5.5	34	4.3	29	4.3	29	4.5	30	4.3	29	3.9	27	4.1	28
11		1	4.9	32	4.8	30	5.4	34	4.8	30	5	31	4.6	29	5	31	4.6	29	4.6	29	5.3	32	5.3	32	5.3	32	4.1	27	4.8	30	5.3	32
12		1	3.8	32	3.6	30	3.4	29	3.4	29	4.5	35	3.6	30	4.1	33	3.1	27	3.6	30	4.1	33	3.6	30	3.4	29	3.2	28	3.8	31	3.4	29
Total sum of pair cut and time used			52	29	51	29	56	31	53	29	55	31	54	30	56	31	51	29	54	30	54	30	56	31	55	30	52	29	50	29	58	31

** Since single operation (only clicking) is performed in cutting section, the obsetvation was made across each similar stations and differently skilled clicker.

b) Preparation section For preparation section, input material is taken from cutting. The material arrives the first station of preparation section according to table 5.7 and the processing time on the bases of operation is recorded on table 5.8 below.

Table 5.7 Inter-arrival time of input cut components observed data in preparation section (in second)

Observation days	Number of observation															Average Inter-arrival time
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Day1	35	38	27	33	29	40	31	35	20	25	30	24	37	35	34	35 Second
Day2	34	53	31	45	36	35	39	37	44	23	33	41	35	26	42	
Day3	45	39	48	31	44	39	44	48	32	30	38	50	39	22	31	
Day4	36	49	25	37	51	43	35	31	42	28	23	25	38	37	35	
Day5	29	22	35	49	33	30	28	22	50	40	31	29	33	25	27	

Table 5.8 Processing time observed in preparation section

Number of operations	Operation name	Number of workers	Number of processing time observed per operation (in seconds)														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Stamping on lining and leather	1	21.74	13.71	16.00	19.91	15.70	17.28	16.34	16.78	13.68	13.40	17.21	15.93	16.40	13.87	15.80
2	Marking	1	7.74	10.08	11.77	10.37	10.09	9.47	10.90	7.73	7.32	10.85	5.87	11.29	11.87	7.33	8.67
3	Skiving 1	1	3.00	3.90	4.00	4.20	3.00	3.00	4.00	2.00	3.50	4.00	3.20	4.10	2.90	3.00	3.60
4	Skiving 2	1	4.00	2.50	2.70	3.40	3.10	3.00	2.20	3.10	2.80	3.00	2.60	4.00	4.00	3.90	3.00
5	Skiving 3	1	2.50	3.20	3.25	3.40	2.13	2.25	2.55	1.78	2.23	2.50	2.25	3.05	2.45	2.73	2.55
6	Skiving 4	1	3.00	3.84	3.90	4.08	2.55	2.70	3.06	2.13	2.67	3.00	2.70	3.66	2.94	3.27	3.06
7	Skiving 5	1	3.26	4.12	4.15	4.33	2.38	2.67	2.51	2.43	2.18	2.39	2.50	3.60	3.23	3.79	2.86
8	Skiving 6	1	3.33	2.40	3.20	3.40	2.75	2.85	4.27	2.30	3.30	4.17	3.17	4.30	3.17	3.47	3.66
9	Pasting glue	1	5.67	4.80	5.01	4.80	5.37	5.60	4.60	4.55	4.79	5.07	4.52	5.06	5.00	4.80	5.41
10	Counter 1 and counter 2 cementing	1	21.76	19.00	18.96	19.78	17.13	22.31	20.32	14.80	17.67	20.95	21.64	18.47	16.25	19.30	20.87
11	Socks attachment over lining	1	19.97	21.70	26.67	22.80	26.03	17.65	27.46	19.88	26.58	20.07	23.00	24.24	25.69	24.82	19.74

c) Stitching section

For stitching section, input material is taken from preparation. The material arrives the first station of stitching section according to table5.9 and the processing time on the bases of operation is recorded on table 5.10.below.

Table 5.9 Inter-arrival time per entity observed data in stitching section (in second)

Observation days	Number of observation															Average Inter-arrival time
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
Day1	53	45	60	48	42	53	50	54	49	57	43	51	50	46	60	53 Second
Day2	66	60	52	46	60	49	52	54	43	49	48	50	51	54	58	
Day3	55	61	52	51	42	62	50	53	54	50	54	45	61	51	49	
Day4	59	53	62	50	49	55	54	52	55	62	89	51	53	54	53	
Day5	55	54	51	53	50	49	57	51	54	53	55	51	47	50	51	

Table 5.10 Processing time observed data in stitching section

Number of Operations	Operation name	number of workers	Number of Processing time Observed per operation (in seconds)														
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Quarter lining and bottom strap stitching	1	60	53	50	58	57	62	57	55	66	54	57	57	65	56	57
2	Apron Tongue Lining and counter1 and counter2	1	58	62	55	52	60	57	58	56	63	59	61	57	58	56	58
3	Collar and quarter1 attaching	1	44	50	42	46	49	53	46	52	45	40	38	48	46	41	46
4	Quarter2 and quarter3 stitching	1	50	47	56	46	50	60	55	45	56	52	50	51	53	48	50
5	Upper strap and quarter1 with quarter2 stitching	1	54	60	52	58	54	57	65	55	63	53	56	58	58	64	57
6	Collar quarter1 and counter1 with2 stitching	1	52	61	59	60	57	63	56	65	54	55	59	59	53	59	61
7	Quarter1 and quarter 23 stitching	1	15	16	18	15	21	22	14	13	15	20	13	15	17	12	12

Number of Operations	Operation name	number of workers	Number of Processing time Observed per operation (in seconds)														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
8	Bottom strap attaching	1	23	22	29	25	24	31	33	28	25	23	22	25	32	21	21
9	Quarter lining stitching	1	26	31	30	32	35	27	33	30	28	30	28	27	34	30	29
10	Applying glue on stiffener and attaching on counter	1	12	15	11	15	13	15	18	12	14	18	15	16	17	15	11
11	Apply Glue over quarter lining	1	17	21	15	17	20	14	16	18	16	17	19	21	17	4	18
12	Inserting collar foam	1	24	23	26	22	21	24	22	20	21	25	24	24	27	23	24
13	Hammering	1	65	59	61	59	63	60	62	59	62	60	60	60	59	60	63
14	Lining and collar area stitching	1	55	63	50	50	62	55	50	48	58	55	59	49	55	55	55
15	Trimming	1	12	11	10	13	13	13	14	12	12	14	12	12	14	12	13
16	Thread burning and cutting	1	12	12	11	9	12	9	6	5	9	10	9	9	8	7	11
17	Eyeleting	1	19	23	21	20	20	21	20	22	20	23	19	24	19	20	20
18	Molding	1	12	12	14	13	14	12	10	9	10	12	12	12	10	13	9
19	Quality Inspection	1	17	14	12	14	11	13	14	11	14	15	12	14	17	14	16

d) Moccasin section

In this section only two operations are done, that are:

1) Aprone and upper hand stitching
2) Upper and sole stitching

These processes are done only after clothing process is finalized to produce upper. As one of the main reason we are constructing VSM for sections is in order to identify multy processes‘ VA, NVA, and NNVA in terms of time as well as smooth simulation input, constructing VSM model for Moccasin stitching is not as such mandatory and influential for the objective of the paper. Worker with an average skill of hand stitch (mocassine) stitches aprone and upper to the average of 32 pair per day. Average capacity of a worker to stitch upper and sole per day is 20 pair. The number of workers currently exists in this section is 25 i.e. (15 for upper and sole stitching and 10 for aprone and upper stitching). The total

production capacity of this section is 300 pair per day. (See current production quantity produced in mocassine section from table 5.4. in titled existing production quantity produced in each section

e) Lasting and finishing section

For lasting and finishing section, input material is taken from stitching. The material arrives the first station of lasting section according to table 11and the processing time on the bases of operation is recorded on table 5.12.

Table 5.11 Inter-arrival time per entity observed data in lasting section

Observation days	Number of observation															Average Inter-arrival time
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
Day1	110.0	104.0	112.0	104.0	96.0	115.0	103.0	114.0	97.0	102.0	94.0	100.0	106.0	110.0	116.0	110.34 Second
Day2	120.0	134.0	105.0	111.0	117.0	106.0	115.0	112.0	109.0	93.0	102.0	113.0	107.0	101.0	122.0	
Day3	120.0	121.5	122.0	102.0	104.0	123.0	114.0	129.0	114.0	120.0	113.0	117.0	120.0	94.0	97.0	
Day4	115.0	123.0	115.0	106.0	121.0	129.0	109.0	97.0	119.0	110.0	133.0	98.0	111.0	114.0	110.0	
Day5	104.0	97.0	108.0	130.0	105.0	101.0	105.0	94.0	126.0	113.0	107.0	107.0	100.0	96.0	112.0	

Table 5.12 Processing time observed data in lasting and finishing section

Number of Operations	Operation name	Number of workers	Number of Processing time Observed per operation (in seconds)														
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Last selection	1	6	5	5	8	5	6	6	6	8	8	6	6	7	7	5
2	Last insertion and lasting	1	7	6	6	7	6	8	8	6	7	7	6	6	7	6	8
3	Temporary shoe lace insertion	1	5	7	5	6	6	8	6	7	4	6	7	6	6	7	8
4	Heating	1	11	11	10	10	11	13	9	12	11	10	11	11	9	10	9
5	Hammering	1	11	10	9	10	10	8	9	8	10	10	9	9	10	12	8
6	Wrinkle chasing	1	7	9	6	7	7	6	8	9	7	8	7	6	8	8	9

7	Thread burning	1	5	5	6	4	6	5	4	4	5	6	5	5	4	6	6
8	Cooling	1	6	8	7	7	8	10	8	8	9	10	8	7	5	8	9
9	Creaming	1	10	11	12	11	11	12	9	12	10	11	10	12	11	13	11
10	Burning	1	13	14	14	15	13	10	12	13	14	13	10	11	14	13	15
11	Delasting	1	10	11	11	9	10	10	9	10	9	11	10	10	9	10	10
12	Shoe lacing Final	1	9	9	6	7	8	8	9	10	10	11	7	9	9	11	6
13	Sockes insertion	1	11	9	11	10	10	9	10	11	9	11	10	10	10	9	11
14	Inserting tissue paper	1	9	7	10	9	11	10	9	8	10	9	8	8	9	12	11
15	Quality inspection	1	19	21	18	18	20	17	18	16	17	20	18	16	18	17	17

5.1.3. Current state VSM model construction

All types of activities with their numerical value are explained in VSM based on the collected data which is categorised in to 3 sections (preparation, stitching, and lasting & finishing). Cutting and mocassine sections are exceptionals that are not suitable to construct VSM model as each section has 2-3 processes only. The rest will be discussed in detail below.

a) Preparation section current VSM for model C1 in stitching section:

The starting activity of model C1 is marking on leather to enable to sew over the marked line. It guides the operator not to lose the path of stitching. Skiving activity is the next step which adds value on the part by reducing the thickness of the leather for the purpose of sewing parts together in level without up and down. Reinforcement attaching is another value adding activity to strengthen the upper toe area of the shoe. The rest are attachment activities to enable to sew leather, lining and reinforcement together. The whole activities that one pair of model C1 passes is summarized using VSM. See figure 5.2

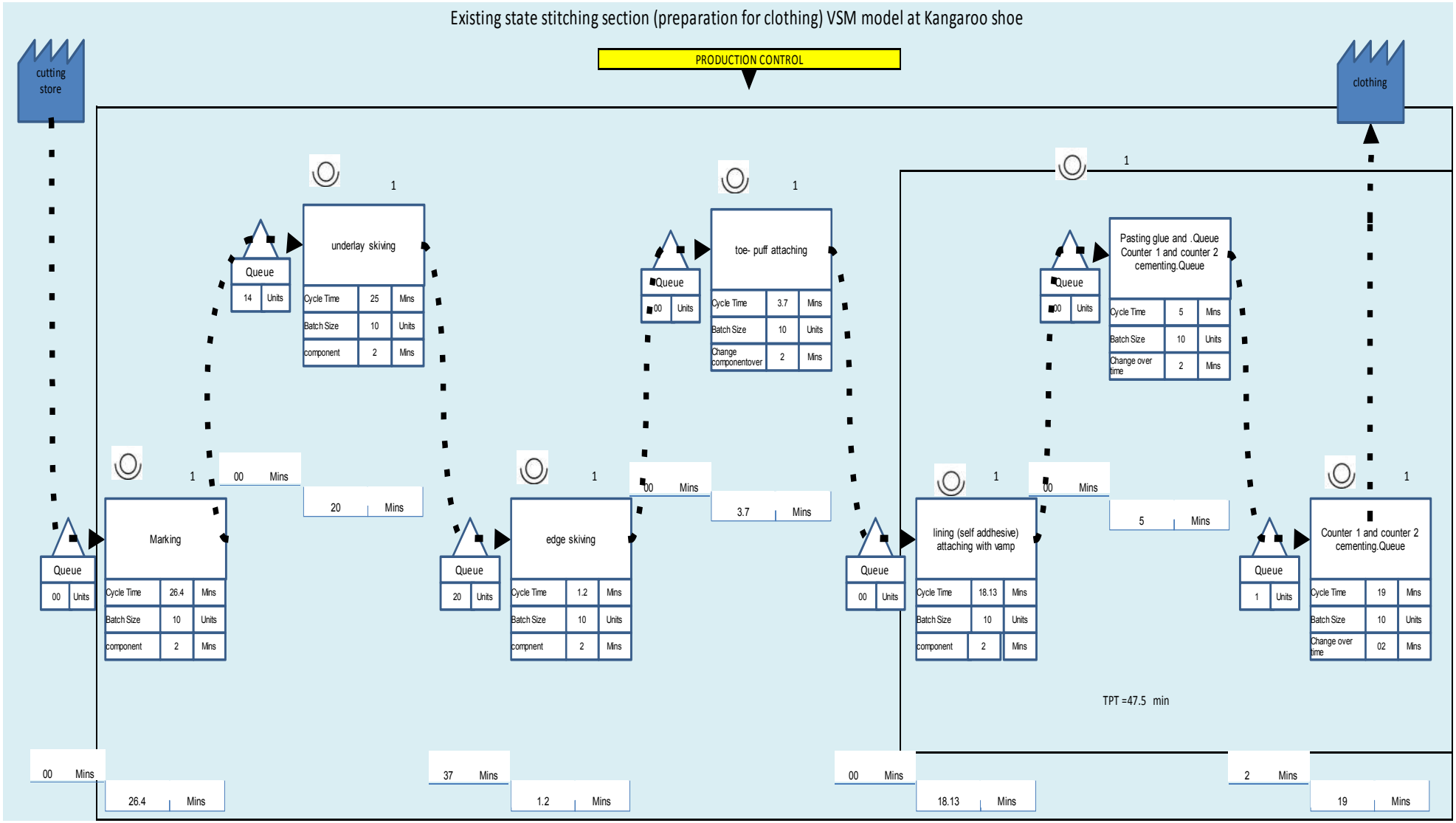


figure 5.2 preparation VSM model for C1

b) Stitching section current VSM for model C1

In this part of stitching section, the main process that the model passes is stitching or inter-relating all parts cut in to pieces together which is called Upper. The whole activities that one pair of model C1 passes is summarized using VSM. See figure 5.3.

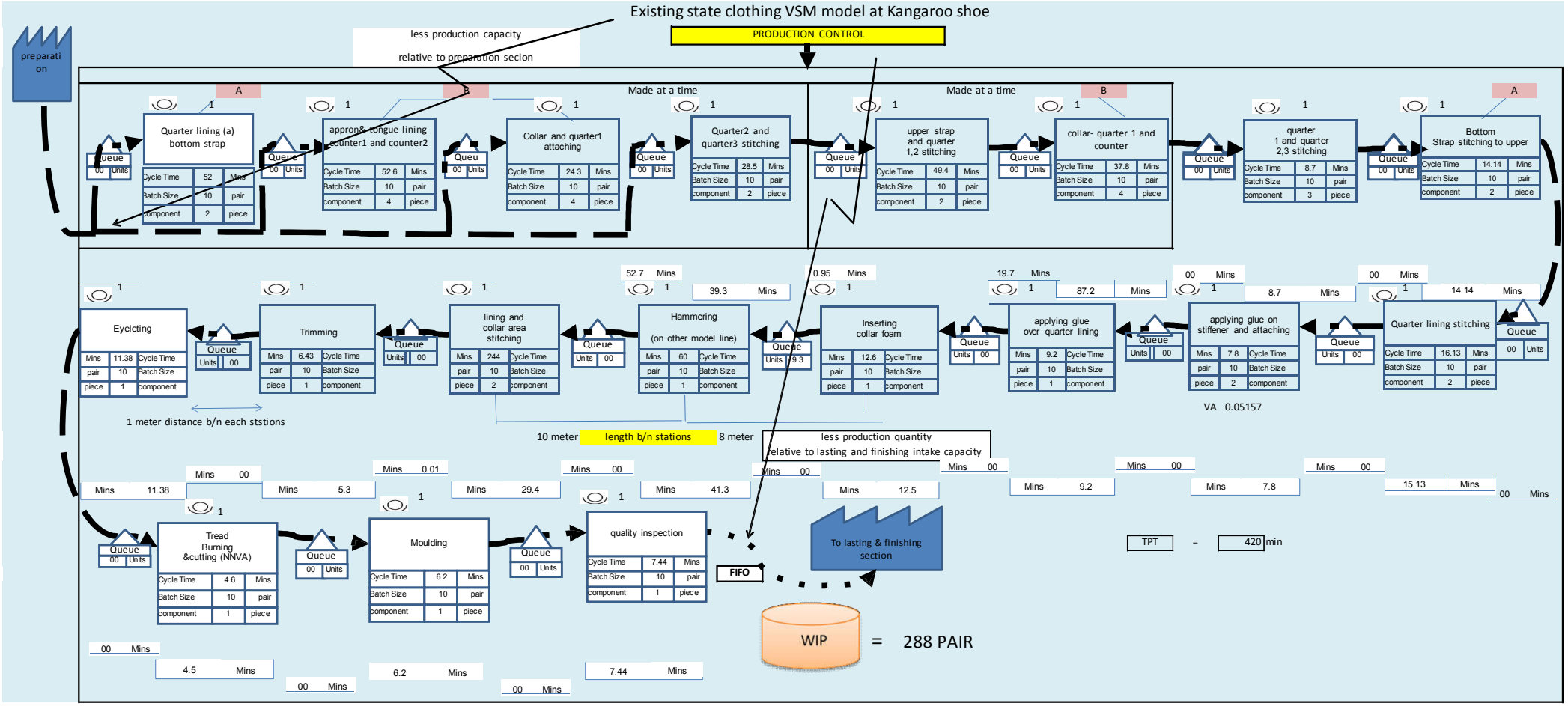


Figure 5.3 stitching section current VSM for model C1

5.1.4. Identified VA and NNVA activities from current VSM of all section processes:

Identified VA and NNVA activities are explained on appendix- D in titled –Current and modified simulation result comparison based on controlling parameter and Key performance indicators in terms of processes‖. All are processes that are classified in to value adding and necessary value adding activities and are part of stitching, preparation as well as lasting and finishing section. cutting and mocassine section ware not explained(not simulated) there as they are not influencing the improvement process for this kind of improvement step.

5.1.5. Arena simulation model based on current VSM model:

The simulation model is constructed for stitching section first for the sake of logical and smooth improvement. As stitching and lasting sections have multy process steps, they are considered on VSM by part. Next to stitching lasting –finishing and preparation sections are followed. The assumptions and conditions took place while processing all simulation model are the following points.

- 1 entity arrives at a time
- The simulation process uses student version of Arena software which allow only 150 entities to be simulated at a time. This limits infinite simulation to run that produces more than 150. For this reason number of entities as an input per day may be deduced in to appropriate amount. eg. if 200 pair is the daily production (8 hour working time per day) amount which uses more than 150 entities, one can use simulation length as 4 hour to simulate 100 pairs at a time.
- All simulations uses 8 working hour
- the number of entity per arrival is taken to be 1pair
- .rework is taken as a part of simulation output as it is redone by supervisors exceptionally.
- overlap process is expected between sections as all are on process to be input to each other.
- all section‘s input data are taken in the form of expression according to section 2.5.1. Replication and run length of simulation. See appendix-C.
- the process flow discipline in each section is FIFO (first in first out)

a) Stitching section current simulation model

The current Arena simulation model bases the existing VSM of the section as shown in figure 5.9

As we can see from the figure, the input number of entities entered in the line are 17 pairs. Based on section 5.1.2. Process related data collection, the average inter arrivals between two consecutive arrival of input is used 53 second for simulation purpose with selected replication length 900 second. The output production (number out) also displayed on the figure as 8 pair per one forth of an hour as it must be similar to the current production output i.e. 256 pair per day (see table 5.4 **current production quantity produced in each section**.). The intake capasity is simulated to be 544 pair in order to approach the real system at the final result. In general the simulation process uses the following points to get the reachable level of reality relative to the existing one.

1. average production per day = 256 pair
2. average input per day = 544 pair
3. selected replication length = ¼ of an hour = 900 sec
4. input entity with in replication length:
   900sec * 544 pair/8*3600 sec = 17 pair

Figure 5.4 and 5.5 is the main stitching section current simulation model and sub-model respectively which are constructed with the above conditions.

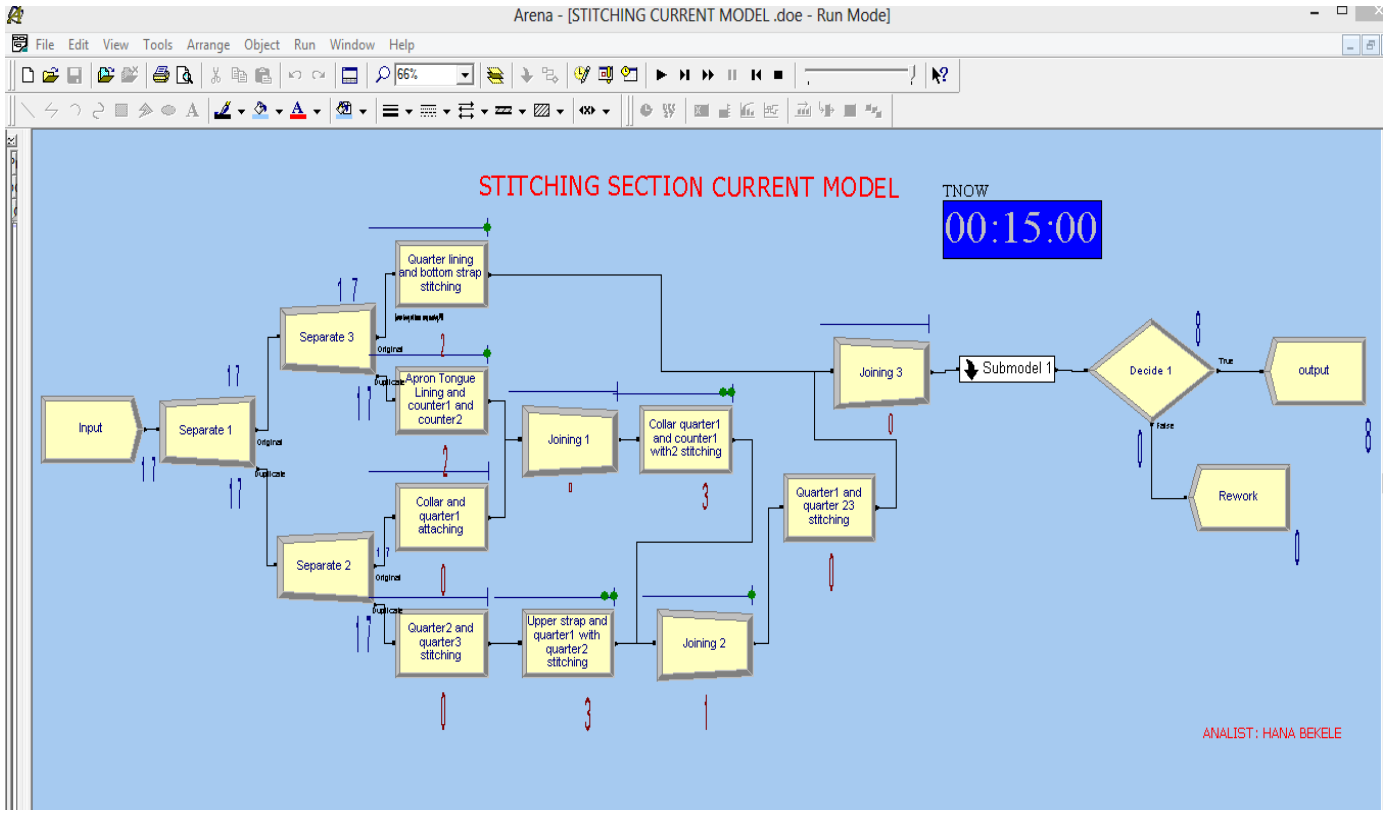


Figure 5.4 Stitching current Arena simulation model

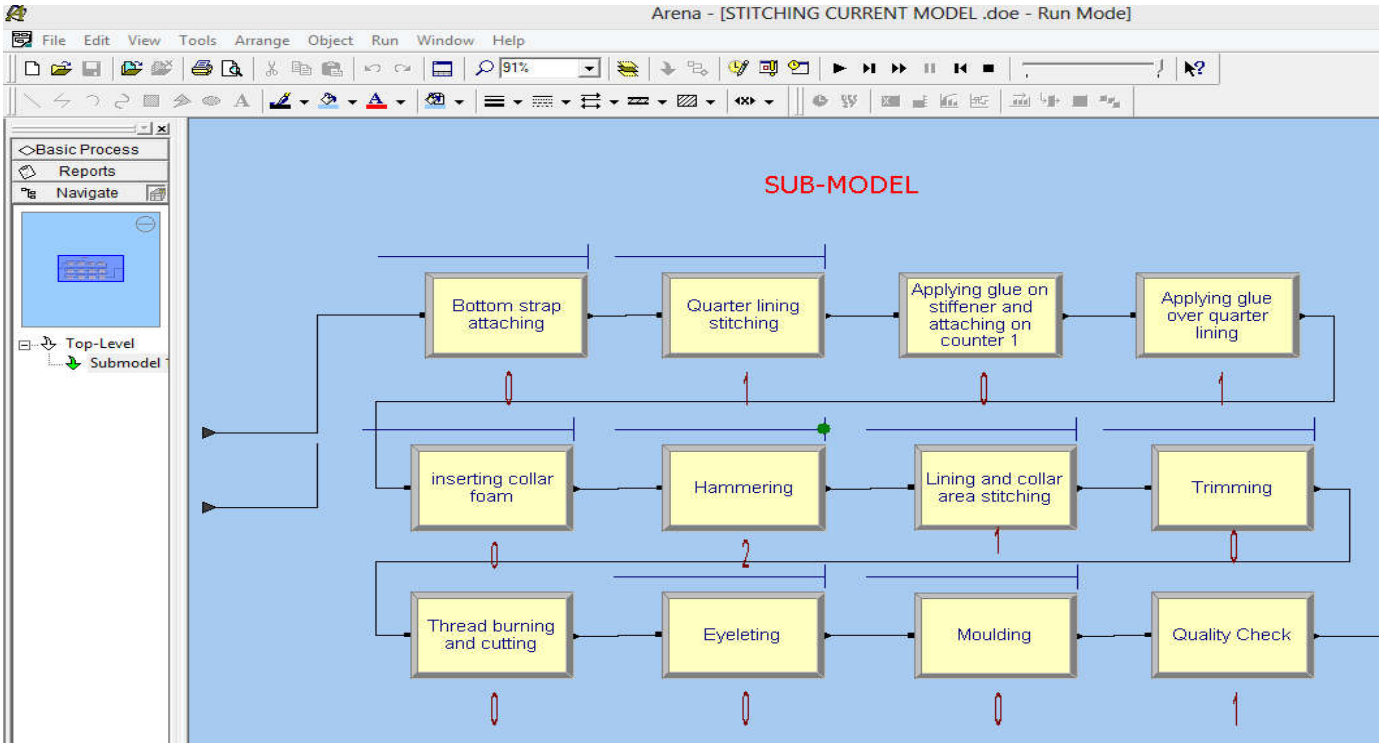


Figure 5.5 Stitching current Arena simulation sub-model

b) Lasting and finishing section current simulation model

The current Arena simulation model bases the existing VSM of the Lasting and finishing section is shown in figure 5.6. As we can see from the figure, the input number of entities entered in the line are 33 pairs. Based on section 5.1.2, Process related data collection (table 5.12), the average inter arrivals between two consecutive arrival of input is used 110 second for simulation purpose with selected replication length 3600 second. The output production (number out) also displayed on the figure as 31 pair per hour as it must be similar to the current production output i.e. 248 pair per day (see table 5.5 for current production quantity produced in each section.). The intake capasity is simulated to be 264 pair in order to approach the real system at the final result. In general the simulation process uses the following points to get the reachable level of reality relative to the existing one.

1. average production per day = 248 pair
2. average input per day = 264 pair
3. selected replication length = one hour = 3600 sec
4. amount of input entity with in replication length:

264pair/8 = 33 pair

Figure 5.6 is the main Lasting and finishing section current simulation model which is constructed with the above conditions.

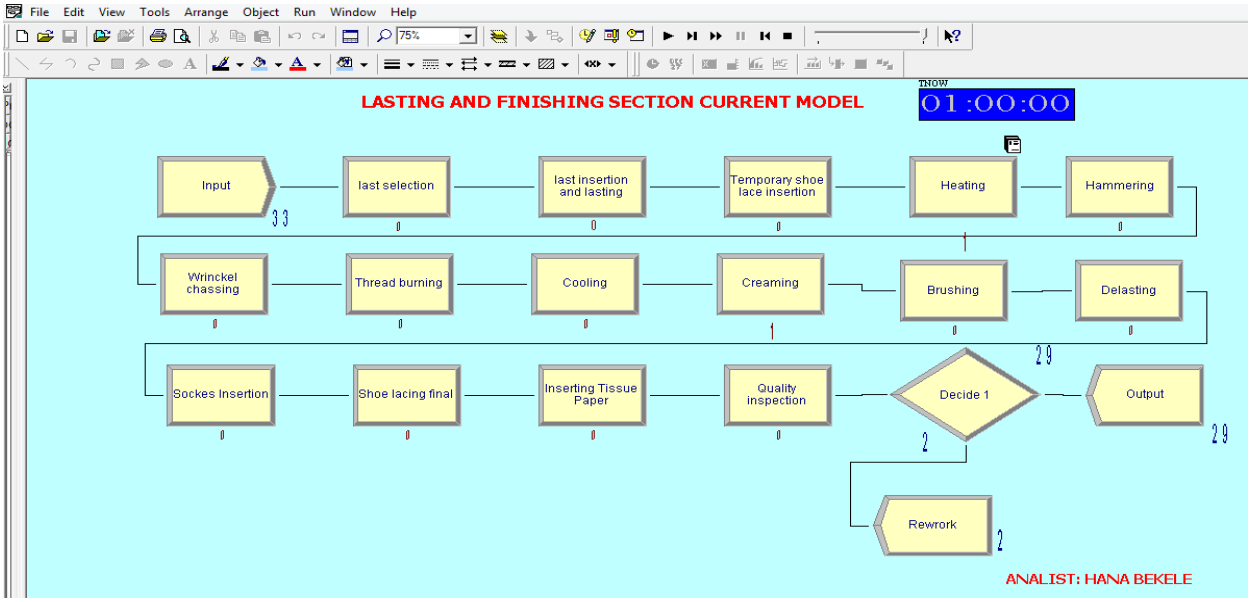


Figure 5.6: Lasting and finishing current Arena simulation model

c) Preparation section current simulation model

The current Arena simulation model bases the existing VSM of the preparation section as shown in figure 5.7. As we can see from the figure, the input number of entities entered in the line are 103 pairs. Based on section 5.1.2. Process related data collection (table 5.8), the average inter arrivals between two consecutive arrival of input is used 35 second for simulation purpose with selected replication length 3600 second. The output production (number out) also displayed on the figure as 86 pair per hour as it must be similar to the current production output i.e. 688 pair per day (see table 5.4 current production quantity produced in each section.). The intake capacity is simulated to be 824 pair in order to approach the real system at the final result. In general the simulation process uses the following points to get the reachable level of reality relative to the existing one.

1. average production per day = 688 pair
2. average input per day = 824 pair
3. selected replication length = 3600 sec
4. amount of input entity with in replication length:

   824 pair/8sec = 103 pair

Figure 5.7 (a) and (b) is the main preparation section current simulation model and sub-model respectively which are constructed with the above conditions.

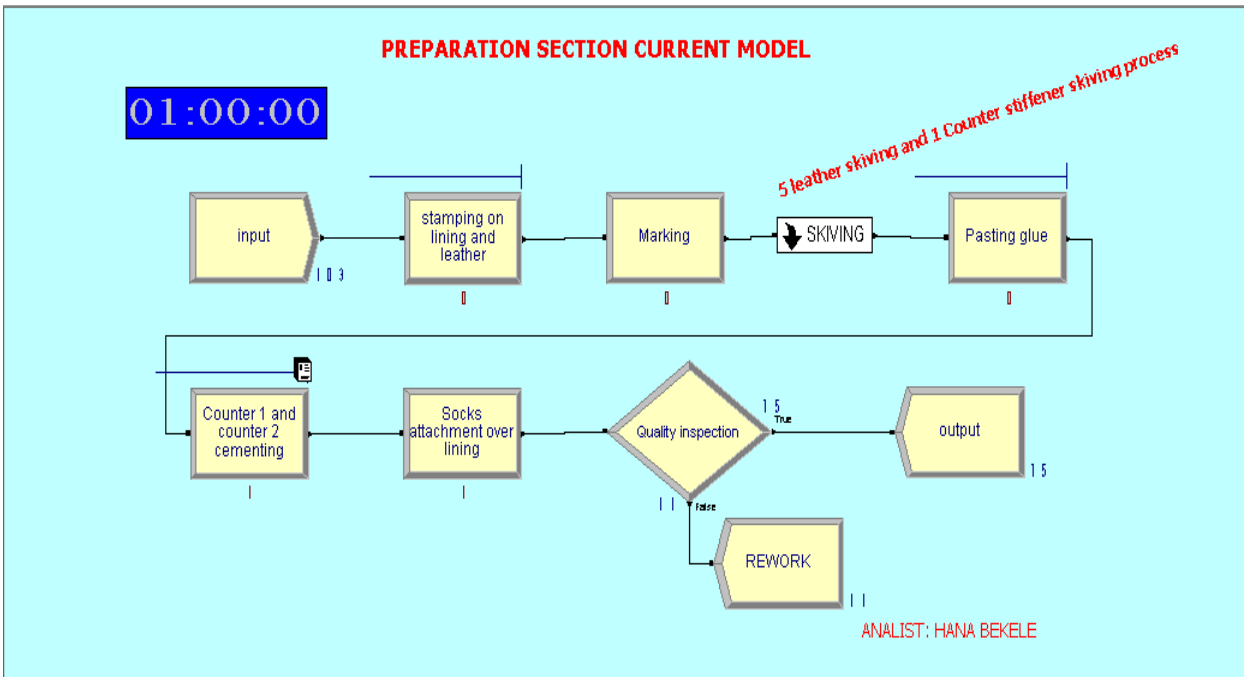


Figure 5.7.a) Preparation current Arena simulation model

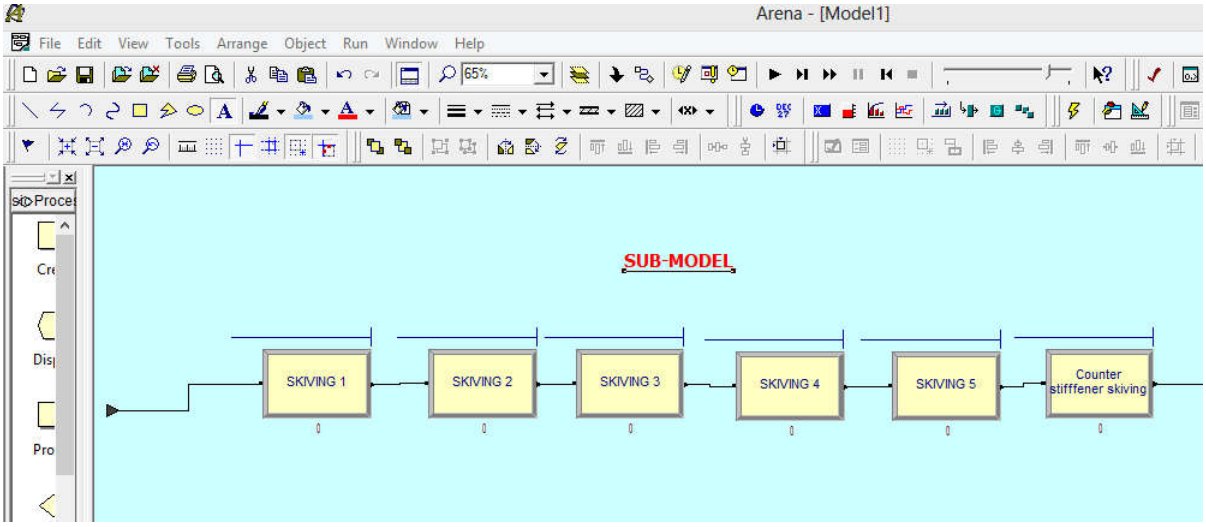


Figure 5.7.b) Preparation current Arena simulation sub-model

5.1.6. Verification and validation of Current state arena simulation model result

All processes are compared to the existing live system in order to verify that the simulation almost approaches the real one. After so many step of verification process it is found that the simulation approaches the existing (real) system with error of 0.008% in preparation, 0.056 % in

stitching section and 0.032% in lasting and finishing. This can be also checked finally by validation process through comparing the simulation output made using the above all section processes (including error measured) with the existing production outcome. 0.032% is deviation from the real system in this case study. See appendix – F existing Vs. current simulation result Production capacity of Classic 1 model (C1) in pair.

5.2. Data analysis of current and proposed production system

5.2.1. Simulation model per process result and analysis for current state

The simulation result is taken from the software directly as per the condition took to simulate in section 5.1.5 the current system data. The controlling parameters selected for all sections to evaluate the simulation result are **process** and **queue time** which are classified as the following key performance indicators:

1. Process
    - Time per entity.
    - Accumulated time (accumulated VA time, accumulated other time/NNVA time, accumulated NVA time and accumulated wait time).
    - Number in and number out.
2. Queue
    - Waiting time in queue.
    - Number waiting.

For a better understanding, see their definition on appendix- F. Simulation model result and analysis for all sections; stitching, lasting/ finishing and preparation are organized below.

a) Simulation model result and analysis for current stitching section

The following figure 5.8(a) to (d) and table5.13 (a) to (g) shows an inter-related simulation result according to the selected controlling parameter.

Table 5.13 a) Stitching section current simulation model *time per entity* result

Process

Time per Entity

Other Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Tread burning and cutting	0.00240365	0.00	0.00214786	0.00262907	0.00145720	0.00328673

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Applying glue on stiffener and attaching on counter 1	0.00406517	0.00	0.00390325	0.00420938	0.00315451	0.00493309
Applying glue over quarter lining	0.00480182	0.00	0.00458912	0.00504844	0.00394899	0.00581060
Apron Tongue Lining and counter1 and counter2	0.02741274	0.00	0.02552545	0.02885904	0.01536481	0.04132402
Bottom strap attaching	0.00736408	0.00	0.00690523	0.00789458	0.00585899	0.00907622
Collar and quarter1 attaching	0.01267854	0.00	0.01230660	0.01308347	0.01068033	0.01448123
Collar quarter1 and counter1 with2 stitching	0.01969712	0.00	0.01756827	0.02195679	0.01487754	0.03037361
Eyeleting	0.00592846	0.00	0.00570142	0.00630277	0.00531564	0.00689606
Hammering	0.02151111	0.00	0.01863875	0.02421504	0.01640069	0.02943629
Inserting collar foam	0.00658121	0.00	0.00630713	0.00679928	0.00567293	0.00735221
Lining and collar area stitching	0.01529162	0.00	0.01462056	0.01594277	0.01340725	0.01727621
Moulding	0.00323293	0.00	0.00306098	0.00341382	0.00252153	0.00387646
Quality Check	0.00387904	0.00	0.00366241	0.00411157	0.00306599	0.00470151
Quarter lining and bottom strap stitching	0.02708112	0.00	0.02373680	0.03050444	0.01507771	0.04292945
Quarter lining stitching	0.00840010	0.00	0.00804093	0.00872141	0.00725074	0.00968728
Quarter1 and quarter 23 stitching	0.00452641	0.00	0.00427464	0.00484409	0.00340941	0.00599289
Quarter2 and quarter3 stitching	0.01483195	0.00	0.01398696	0.01704385	0.01254618	0.01902207
Tread burning and cutting	0.00240365	0.00	0.00214786	0.00262907	0.00145720	0.00328673
Trimming	0.00334835	0.00	0.00322580	0.00348235	0.00282376	0.00384462
Upper strap and quarter1 with quarter2 stitching	0.02573944	0.00	0.02137832	0.03095929	0.01457107	0.04313281

Table5.13 b) Stitching section current simulation model *accumulated VA time* result

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Applying glue on stiffener and attaching on counter 1	0.05157333	0.00	0.04702099	0.05441306
Applying glue over quarter lining	0.05884484	0.00	0.05506943	0.06562976
Apron Tongue Lining and counter1 and counter2	0.2447	0.00	0.2417	0.2474
Bottom strap attaching	0.0987	0.00	0.08976801	0.1084
Collar and quarter1 attaching	0.2155	0.00	0.2092	0.2224
Collar quarter1 and counter1 with2 stitching	0.2273	0.00	0.2147	0.2323
Eyeleting	0.05335613	0.00	0.05131281	0.05672491
Hammering	0.1716	0.00	0.1672	0.1858
Inserting collar foam	0.07897449	0.00	0.07568558	0.08159131
Lining and collar area stitching	0.1419	0.00	0.1316	0.1562
Moulding	0.02849078	0.00	0.02501303	0.03072434
Quality Check	0.03162699	0.00	0.02954341	0.03659118
Quarter lining and bottom strap stitching	0.2435	0.00	0.2334	0.2490
Quarter lining stitching	0.1092	0.00	0.1045	0.1134
Quarter1 and quarter 23 stitching	0.06081653	0.00	0.05570480	0.06629839
Quarter2 and quarter3 stitching	0.2350	0.00	0.2256	0.2482
Trimming	0.03023740	0.00	0.02903219	0.03273158
Upper strap and quarter1 with quarter2 stitching	0.2270	0.00	0.2235	0.2341

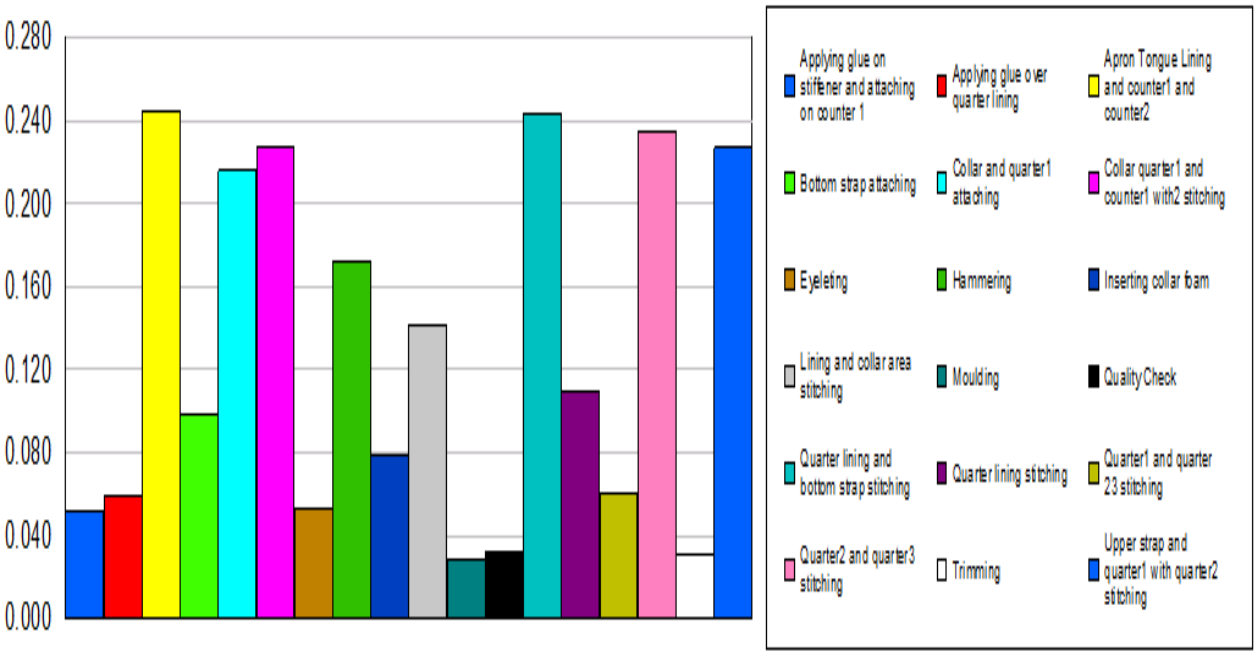


Figure 5.8 a) Stitching section current simulation model *accumulated VA time* result interms of graph

Table5.13 c) Stitching section current simulation model *accumulated wait time* result

Accum Wait Time	Average	Half Width	Minimum Average	Maximum Average
Apron Tongue Lining and counter1 and counter2	0.1665	0.00	0.1412	0.1857
Bottom strap attaching	0.00	0.00	0.00	0.00
Collar and quarter1 attaching	0.00	0.00	0.00	0.00
Collar quarter1 and counter1 with2 stitching	0.04781913	0.00	0.02273199	0.07599135
Eyeleting	0.00	0.00	0.00	0.00
Hammering	0.04483476	0.01	0.01671667	0.07171055
Inserting collar foam	0.00	0.00	0.00	0.00
Lining and collar area stitching	0.00005329	0.00	0.00	0.00078710
Moulding	0.00	0.00	0.00	0.00
Quarter lining and bottom strap stitching	0.1618	0.01	0.1165	0.1937
Quarter lining stitching	0.00	0.00	0.00	0.00
Quarter2 and quarter3 stitching	0.00781734	0.00	0.00057688	0.03347436
Trimming	0.00	0.00	0.00	0.00
Upper strap and quarter1 with quarter2 stitching	0.1333	0.01	0.07452298	0.1993

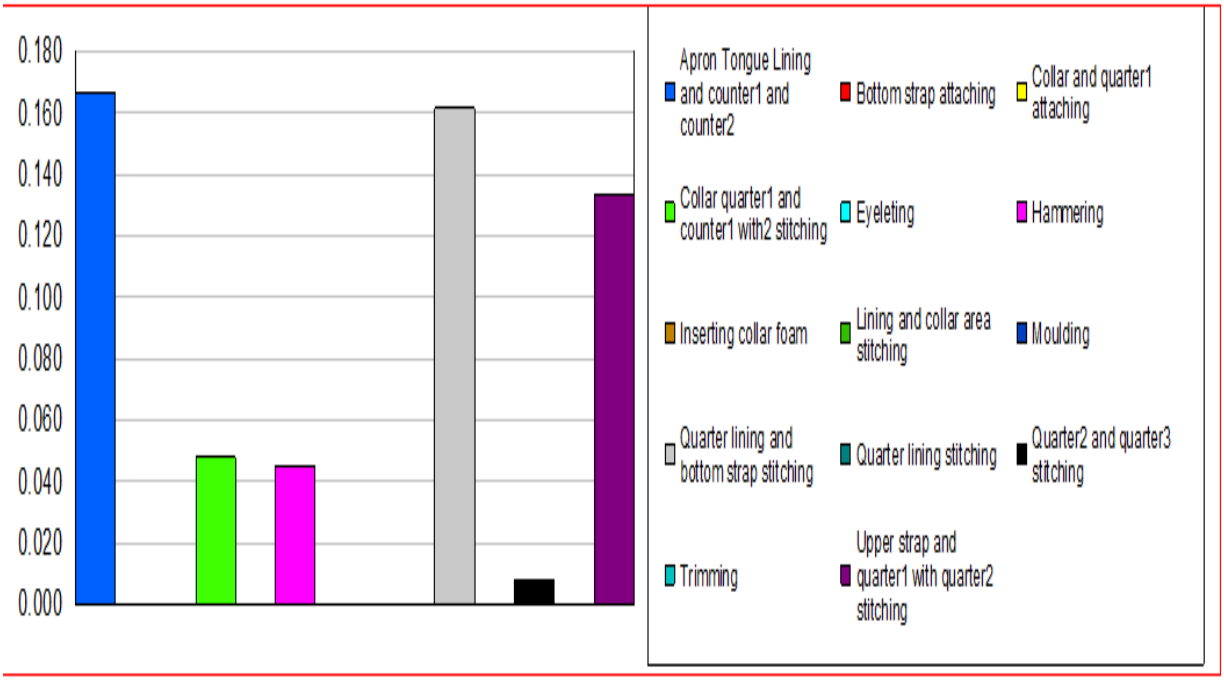


Figure 5.8 b) Stitching section current simulation model *accumulated wait time* result interms of graph

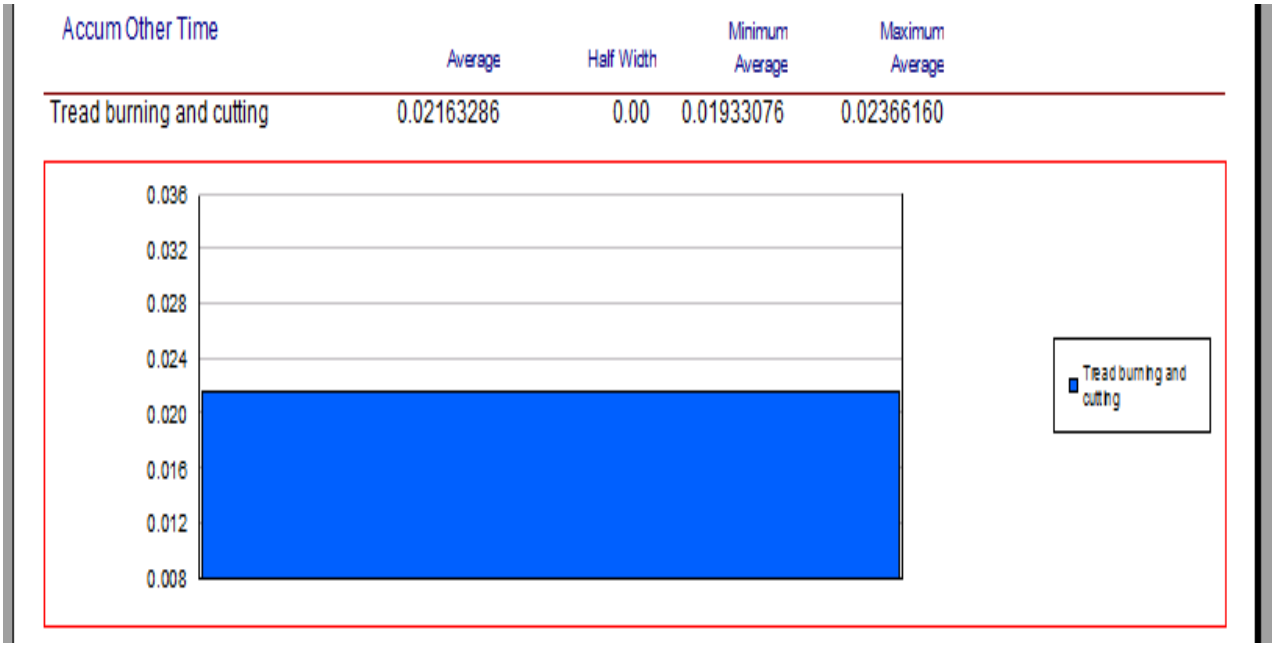


Figure 5.8 c) Stitching section current simulation model *accumulated other time/NNVA* time result interms of graph

Table 5.13 d) Stitching section current simulation model *number in per process* result

Number In	Average	Half Width	Minimum Average	Maximum Average
Applying glue on stiffener and attaching on counter 1	13.0000	0.00	13.0000	13.0000
Applying glue over quarter lining	12.6875	0.17	12.0000	13.0000
Apron Tongue Lining and counter1 and counter2	17.0000	0.00	17.0000	17.0000
Bottom strap attaching	13.9688	0.06	13.0000	14.0000
Collar and quarter1 attaching	17.0000	0.00	17.0000	17.0000
Collar quarter1 and counter1 with2 stitching	16.0000	0.00	16.0000	16.0000
Eyeleting	9.0313	0.06	9.0000	10.0000
Hammering	12.0000	0.00	12.0000	12.0000
Inserting collar foam	12.2500	0.16	12.0000	13.0000
Lining and collar area stitching	10.0625	0.09	10.0000	11.0000
Moulding	9.0000	0.00	9.0000	9.0000
Quality Check	8.8125	0.14	8.0000	9.0000
Quarter lining and bottom strap stitching	17.0000	0.00	17.0000	17.0000
Quarter lining stitching	13.4063	0.18	13.0000	14.0000
Quarter1 and quarter 23 stitching	13.9688	0.06	13.0000	14.0000
Quarter2 and quarter3 stitching	17.0000	0.00	17.0000	17.0000
Tread burning and cutting	9.0000	0.00	9.0000	9.0000
Trimming	9.2813	0.16	9.0000	10.0000
Upper strap and quarter1 with quarter2 stitching	16.3750	0.18	16.0000	17.0000

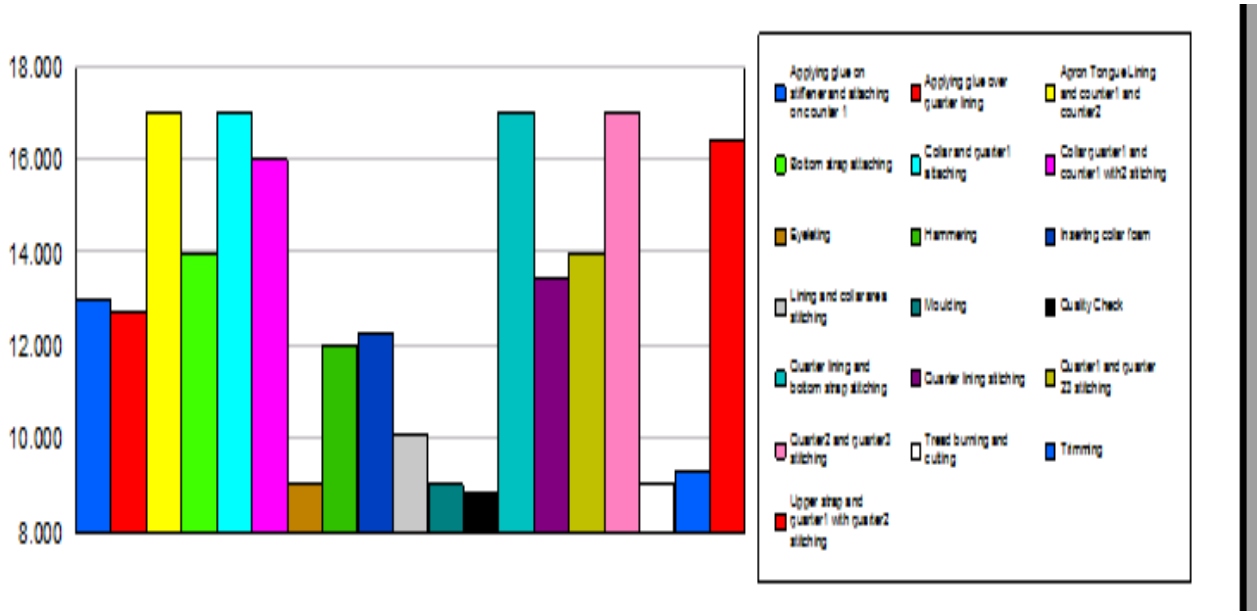


Figure 5.8 d) Stitching section current simulation model *number in per process* result graph

Table 5.13 e) Stitching section current simulation model *number out per process* result

Number Out	Average	Half Width	Minimum Average	Maximum Average
Applying glue on stiffener and attaching on counter 1	12.6875	0.17	12.0000	13.0000
Applying glue over quarter lining	12.2500	0.16	12.0000	13.0000
Apron Tongue Lining and counter1 and counter2	15.0000	0.00	15.0000	15.0000
Bottom strap attaching	13.4063	0.18	13.0000	14.0000
Collar and quarter1 attaching	17.0000	0.00	17.0000	17.0000
Collar quarter1 and counter1 with2 stitching	13.9688	0.06	13.0000	14.0000
Eyeleting	9.0000	0.00	9.0000	9.0000
Hammering	10.0625	0.09	10.0000	11.0000
Inserting collar foam	12.0000	0.00	12.0000	12.0000
Lining and collar area stitching	9.2813	0.16	9.0000	10.0000
Moulding	8.8125	0.14	8.0000	9.0000
Quality Check	8.1563	0.13	8.0000	9.0000
Quarter lining and bottom strap stitching	14.9688	0.06	14.0000	15.0000
Quarter lining stitching	13.0000	0.00	13.0000	13.0000
Quarter1 and quarter 23 stitching	13.4375	0.18	13.0000	14.0000
Quarter2 and quarter3 stitching	16.3750	0.18	16.0000	17.0000
Tread burning and cutting	9.0000	0.00	9.0000	9.0000
Trimming	9.0313	0.06	9.0000	10.0000
Upper strap and quarter1 with quarter2 stitching	14.0000	0.00	14.0000	14.0000

Table 5.13 f) Stitching section current simulation model *waiting time in queue* result

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Apron Tongue Lining and counter1 and counter2.Queue	0.01189736	0.00	0.01012803	0.01325327	0.00	0.02660180
Bottom strap attaching.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Collar and quarter1 attaching.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Collar quarter1 and counter1 with2 stitching.Queue	0.00398429	0.00	0.00196209	0.00613157	0.00	0.01598227
Eyeleting.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Hammering.Queue	0.00483777	0.00	0.00162813	0.00774203	0.00	0.01367474
inserting collar foam.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Joining 1.Queue	0.00445584	0.00	0.00388528	0.00486435	0.00	0.01667755
Joining 2.Queue	0.00175070	0.00	0.00034010	0.00377433	0.00	0.01027825
Joining 3.Queue	0.00541838	0.00	0.00307015	0.00665133	0.00	0.01802184
Lining and collar area stitching.Queue	0.00000533	0.00	0.00	0.00007871	0.00	0.00078710
Moulding.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Quarter lining and bottom strap stitching.Queue	0.01158441	0.00	0.00845116	0.01473007	0.00	0.02820723
Quarter lining stitching.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Quarter2 and quarter3 stitching.Queue	0.00049242	0.00	0.00003393	0.00218506	0.00	0.00429985
Trimming.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Upper strap and quarter1 with quarter2 stitching.Queue	0.01025766	0.00	0.00620268	0.01520210	0.00	0.02869476

Table 5.13. g) Stitching section current simulation model *number waiting in queue* result

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Apron Tongue Lining and counter1 and counter2.Queue	0.8192	0.02	0.7060	0.9060	0.00	2.0000
Bottom strap attaching.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Collar and quarter1 attaching.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Collar quarter1 and counter1 with2 stitching.Queue	0.2482	0.02	0.1222	0.3800	0.00	2.0000
Eyeleting.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Hammering.Queue	0.2397	0.03	0.08745103	0.3833	0.00	1.0000
inserting collar foam.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Joining 1.Queue	0.5703	0.01	0.4973	0.6226	0.00	2.0000
Joining 2.Queue	0.1966	0.04	0.03809089	0.4227	0.00	2.0000
Joining 3.Queue	0.6103	0.03	0.3439	0.7497	0.00	2.0000
Lining and collar area stitching.Queue	0.00021316	0.00	0.00	0.00314839	0.00	1.0000
Moulding.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Quarter lining and bottom strap stitching.Queue	0.8010	0.04	0.5987	1.0582	0.00	2.0000
Quarter lining stitching.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Quarter2 and quarter3 stitching.Queue	0.03348442	0.01	0.00230753	0.1486	0.00	1.0000
Trimming.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Upper strap and quarter1 with quarter2 stitching.Queue	0.6731	0.04	0.4350	0.9744	0.00	2.0000

b) Simulation model result and analysis for current lasting and finishing section

The following figure 5.9 and table5.14 (a) to (h) shows an inter-related simulation result according to the selected controlling parameter.

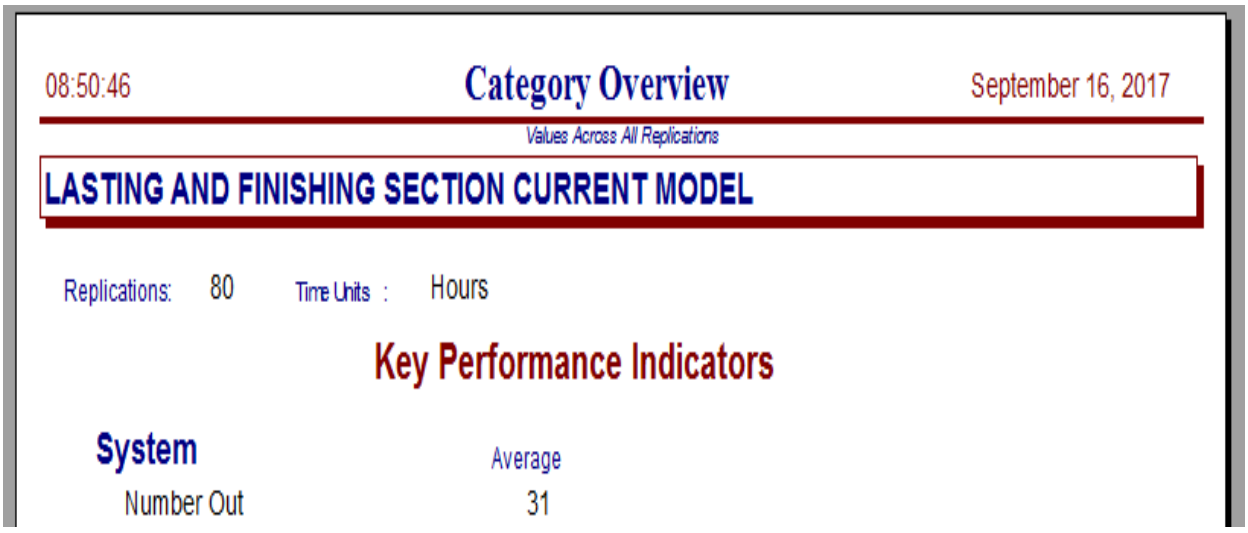


Figure 5.9 lasting and finishing section *current simulation model number out page*

Table 5.14. a) lasting and finishing section current simulation model *time per entity* result

Process

Time per Entity

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Brushing	0.00526113	0.00	0.00454690	0.00632114	0.00284251	0.01285591
Cooling	0.00330181	0.00	0.00251444	0.00404163	0.00168239	0.01020348
Creaming	0.00524897	0.00	0.00393003	0.00668480	0.00251405	0.01213665
Delasting	0.00472779	0.00	0.00407374	0.00527269	0.00250672	0.00782689
Hammering	0.00457971	0.00	0.00360109	0.00598664	0.00250924	0.01245772
Heating	0.00523869	0.00	0.00389907	0.00681422	0.00252377	0.01242408
Inserting Tissue Paper	0.00258931	0.00	0.00248651	0.00273075	0.00195615	0.00331464
last insertion and lasting	0.00443236	0.00	0.00360493	0.00526749	0.00168183	0.01161723
last selection	0.00385827	0.00	0.00319612	0.00483277	0.00142451	0.01027433
Quality inspection	0.00679893	0.00	0.00603854	0.00765439	0.00453140	0.01196509
Shoe lacing final	0.00240882	0.00	0.00231326	0.00254791	0.00170377	0.00304441
Sockes Insertion	0.00277866	0.00	0.00272742	0.00282219	0.00250743	0.00304098
Temporary shoe lace insertion	0.00391686	0.00	0.00310476	0.00464709	0.00112871	0.01109324
Thread burning	0.00298708	0.00	0.00203134	0.00402796	0.00111917	0.00868933
Wrinckel chassing	0.00381175	0.00	0.00265410	0.00492069	0.00167719	0.00815725

Table 5.14. b) lasting and finishing section current simulation model *accumulated VA time* result

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Brushing	0.1093	0.00	0.1058	0.1127
Cooling	0.07094642	0.00	0.06807829	0.07446214
Creaming	0.0956	0.00	0.0914	0.0993
Hammering	0.0919	0.00	0.0902	0.0940
Heating	0.0980	0.00	0.0950	0.1010
last insertion and lasting	0.06423113	0.00	0.06253645	0.06609836
Shoe lacing final	0.07467357	0.00	0.07171115	0.07898536
Sockes Insertion	0.08613853	0.00	0.08455009	0.08748786
Temporary shoe lace insertion	0.05469227	0.00	0.05073325	0.05823660
Thread burning	0.04439176	0.00	0.04264238	0.04635828
Wrinckel chassing	0.06502417	0.00	0.06196861	0.06730526

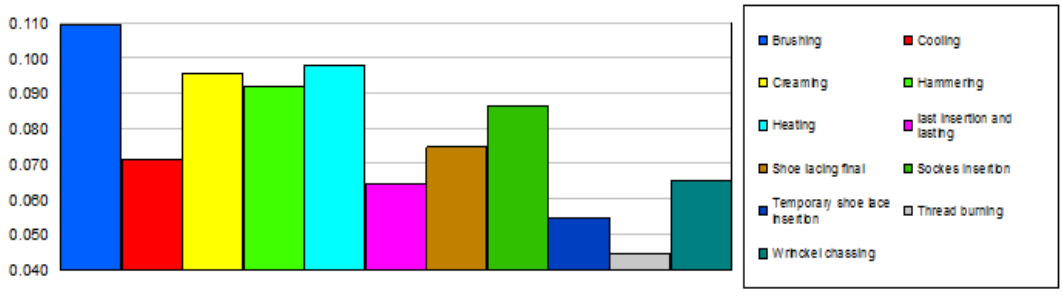


Table 5.14 c) lasting and finishing section current simulation model *accumulated wait time* result

Accumulated Time

Accum Wait Time	Average	Half Width	Minimum Average	Maximum Average
Brushing	0.05419910	0.00	0.03277225	0.08427743
Cooling	0.03436700	0.00	0.00901881	0.06078897
Creaming	0.06889359	0.00	0.02930582	0.1149
Delasting	0.06042301	0.00	0.04142676	0.07708306
Hammering	0.05468360	0.00	0.02237080	0.0988
Heating	0.06959547	0.01	0.02762011	0.1181
last insertion and lasting	0.08203665	0.00	0.05431022	0.1088
last selection	0.06929467	0.00	0.04763435	0.1023
Quality inspection	0.05220181	0.00	0.03069444	0.07522965
Temporary shoe lace insertion	0.07456426	0.00	0.05066550	0.0995
Thread burning	0.05119495	0.00	0.02196235	0.08380852
Wrinckel chassing	0.05695171	0.00	0.02008501	0.0919

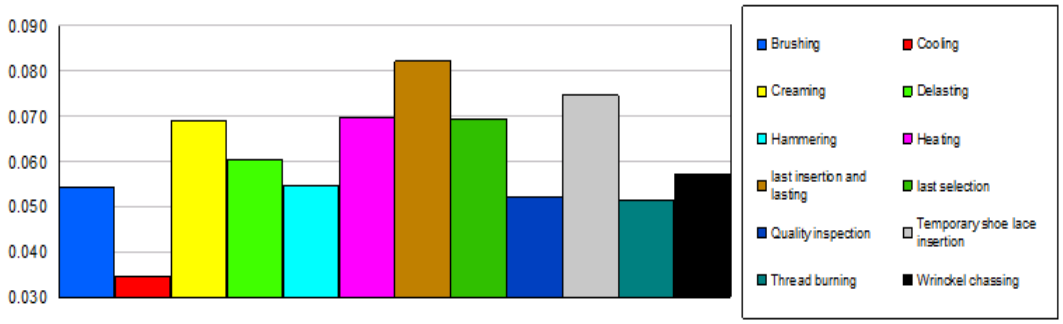


Table 5.14 d) lasting and finishing current simulation model *accumulated other time/NNVA* time result

Accum Other Time	Average	Half Width	Minimum Average	Maximum Average
Delasting	0.08613845	0.00	0.08468022	0.08743200
Inserting Tissue Paper	0.08000859	0.00	0.07591044	0.08465326
last selection	0.05802822	0.00	0.05666606	0.06042413
Quality inspection	0.1555	0.00	0.1503	0.1622

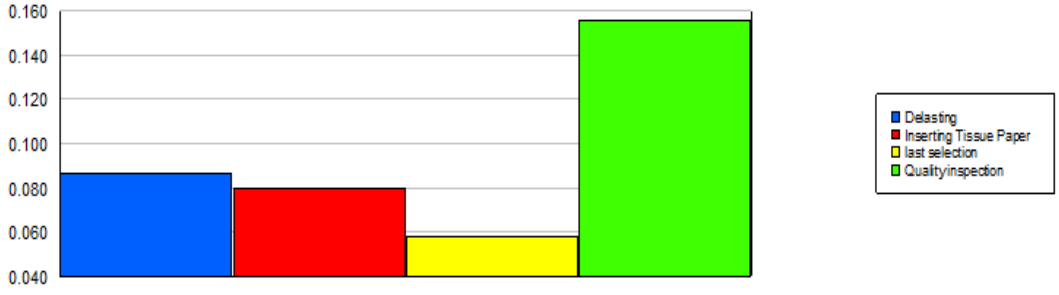


Table 5.14 e) lasting and finishing current simulation model *number in per process* result

Number In	Average	Half Width	Minimum Average	Maximum Average
Brushing	31.3750	0.11	31.0000	32.0000
Cooling	32.0000	0.00	32.0000	32.0000
Creaming	31.9000	0.07	31.0000	32.0000
Delasting	31.0750	0.06	31.0000	32.0000
Hammering	32.0000	0.00	32.0000	32.0000
Heating	33.0000	0.00	33.0000	33.0000
Inserting Tissue Paper	31.0000	0.00	31.0000	31.0000
last insertion and lasting	33.0000	0.00	33.0000	33.0000
last selection	33.0000	0.00	33.0000	33.0000
Quality inspection	30.9000	0.07	30.0000	31.0000
Shoe lacing final	31.0000	0.00	31.0000	31.0000
Sockes Insertion	31.0000	0.00	31.0000	31.0000
Temporary shoe lace insertion	33.0000	0.00	33.0000	33.0000
Thread burning	32.0000	0.00	32.0000	32.0000
Wrinckel chassing	32.0000	0.00	32.0000	32.0000

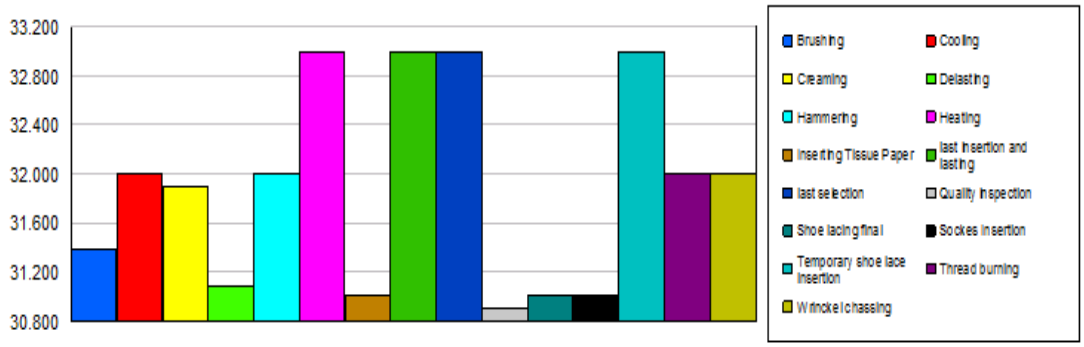


Table 5.14 f) lasting and finishing current simulation model *number out per process* result

Number Out	Average	Half Width	Minimum Average	Maximum Average
Brushing	31.0750	0.06	31.0000	32.0000
Cooling	31.9000	0.07	31.0000	32.0000
Creaming	31.3750	0.11	31.0000	32.0000
Delasting	31.0000	0.00	31.0000	31.0000
Hammering	32.0000	0.00	32.0000	32.0000
Heating	32.0000	0.00	32.0000	32.0000
Inserting Tissue Paper	30.9000	0.07	30.0000	31.0000
last insertion and lasting	33.0000	0.00	33.0000	33.0000
last selection	33.0000	0.00	33.0000	33.0000
Quality inspection	30.5625	0.11	30.0000	31.0000
Shoe lacing final	31.0000	0.00	31.0000	31.0000
Sockes Insertion	31.0000	0.00	31.0000	31.0000
Temporary shoe lace insertion	33.0000	0.00	33.0000	33.0000
Thread burning	32.0000	0.00	32.0000	32.0000
Wrinckel chassing	32.0000	0.00	32.0000	32.0000

Table 5.14 g) lasting and finishing section current simulation model *waiting time in queue* result

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Brushing.Queue	0.00174572	0.00	0.00105717	0.00271863	0.00	0.00910514
Cooling.Queue	0.00108092	0.00	0.00028184	0.00189966	0.00	0.00769402
Creaming.Queue	0.00223384	0.00	0.00091581	0.00360877	0.00	0.00901195
Delasting.Queue	0.00194931	0.00	0.00133635	0.00248655	0.00	0.00499464
Hammering.Queue	0.00170886	0.00	0.00069909	0.00308884	0.00	0.00951530
Heating.Queue	0.00220385	0.00	0.00088730	0.00366847	0.00	0.00911267
last insertion and lasting.Queue	0.00248596	0.00	0.00164576	0.00329771	0.00	0.00952017
last selection.Queue	0.00209984	0.00	0.00144347	0.00309967	0.00	0.00837271
Quality inspection.Queue	0.00171720	0.00	0.00099014	0.00250766	0.00000039	0.00669424
Temporary shoe lace insertion.Queue	0.00225952	0.00	0.00153532	0.00301424	0.00	0.00941004
Thread burning.Queue	0.00159984	0.00	0.00068632	0.00261902	0.00	0.00712435
Wrinckel chassing.Queue	0.00177974	0.00	0.00062766	0.00287304	0.00	0.00594408

Table 5.14 h) lasting and finishing section current simulation model *number waiting in queue* result

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Brushing.Queue	0.05458180	0.00	0.03277225	0.08427743	0.00	1.0000
Cooling.Queue	0.03465153	0.00	0.00901881	0.06078897	0.00	1.0000
Creaming.Queue	0.07135600	0.00	0.02930582	0.1149	0.00	1.0000
Delasting.Queue	0.06053105	0.00	0.04142676	0.07708306	0.00	1.0000
Hammering.Queue	0.05468360	0.00	0.02237080	0.0988	0.00	1.0000
Heating.Queue	0.07410536	0.01	0.03077530	0.1211	0.00	1.0000
last insertion and lasting.Queue	0.08203665	0.00	0.05431022	0.1088	0.00	1.0000
last selection.Queue	0.06929467	0.00	0.04763435	0.1023	0.00	1.0000
Quality inspection.Queue	0.05310210	0.00	0.03069444	0.07522965	0.00	1.0000
Temporary shoe lace insertion.Queue	0.07456426	0.00	0.05066550	0.0995	0.00	1.0000
Thread burning.Queue	0.05119495	0.00	0.02196235	0.08380852	0.00	1.0000
Wrinckel chassing.Queue	0.05695171	0.00	0.02008501	0.0919	0.00	1.0000

c) Simulation model result and analysis for current preparation section

The following figure 5.10 and table 5.15 (a) to (g) shows an inter-related simulation result according to the selected controlling parameter.

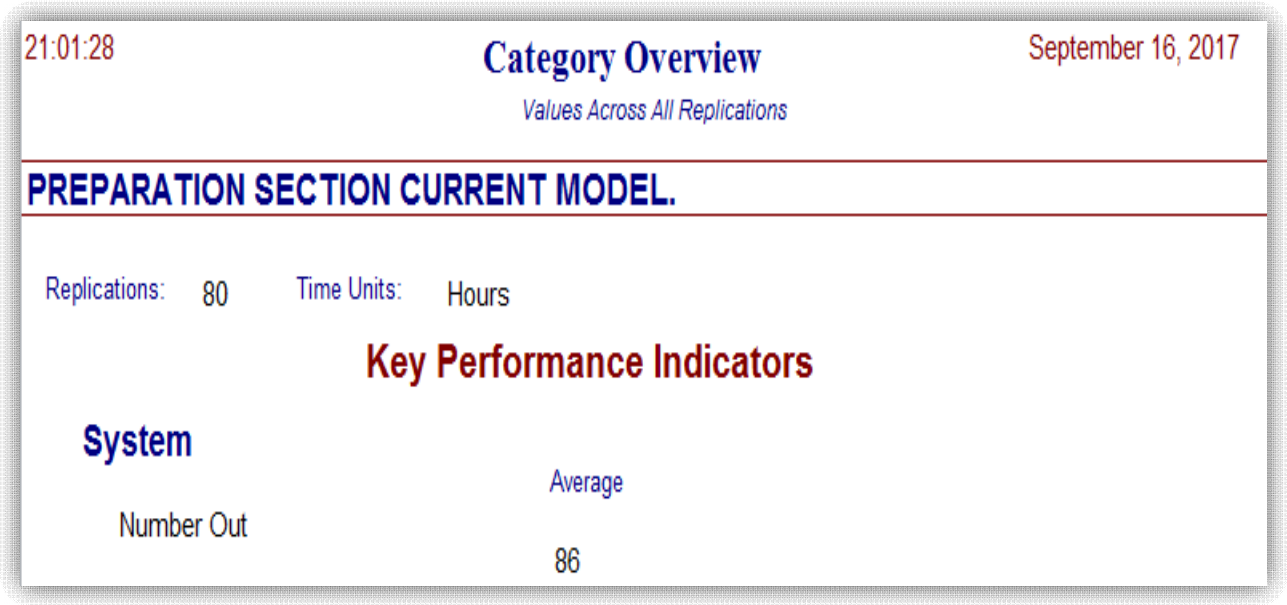


Figure 5.10 Preparation section current *simulation model number out page*

Table 5.15 a) Preparation section current simulation model time per entity result

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Counter 1 and counter 2 cementing	0.00534577	0.00	0.00528765	0.00548824	0.00402229	0.00631696
Counter stifffener skiving	0.00092425	0.00	0.00089953	0.00095518	0.00061170	0.00147821
Marking	0.00260362	0.00	0.00255285	0.00266706	0.00149581	0.00333116
Pasting glue	0.00138358	0.00	0.00137023	0.00139313	0.00125833	0.00156785
SKIVING 1	0.00094797	0.00	0.00091745	0.00098199	0.00057266	0.00122717
SKIVING 2	0.00090521	0.00	0.00088338	0.00093077	0.00056141	0.00111111
SKIVING 3	0.00070071	0.00	0.00068649	0.00072181	0.00046308	0.00098035
SKIVING 4	0.00083528	0.00	0.00081740	0.00085143	0.00056830	0.00117621
SKIVING 5	0.00086201	0.00	0.00083142	0.00088833	0.00057434	0.00399116
Socks attachment over lining	0.00636839	0.00	0.00621886	0.00649893	0.00472692	0.00777630
stamping on lining and leather	0.00449451	0.00	0.00443830	0.00456078	0.00362079	0.00769371

Table 5.15 b) Preparation section current simulation model *accumulated VA time* result

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Counter 1 and counter 2 cementing	0.4645	0.00	0.4600	0.4775
Counter stifffener skiving	0.08096897	0.00	0.07825913	0.08310105
Marking	0.2679	0.00	0.2629	0.2722
Pasting glue	0.1212	0.00	0.1192	0.1235
SKIVING 1	0.0969	0.00	0.0945	0.1002
SKIVING 2	0.08636335	0.00	0.08303790	0.08935390
SKIVING 3	0.06642877	0.00	0.06511418	0.06929379
SKIVING 4	0.07901996	0.00	0.07683595	0.08088619
SKIVING 5	0.07560034	0.00	0.07255360	0.07817321
Socks attachment over lining	0.5483	0.01	0.5348	0.5589
stamping on lining and leather	0.4629	0.00	0.4571	0.4698

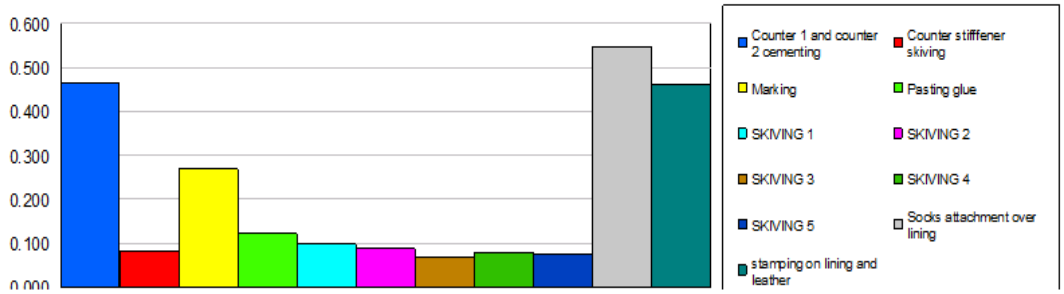


Table 5.15 c) Preparation section current simulation model *accumulated wait time* result

Accumulated Time

Accum Wait Time	Average	Half Width	Minimum Average	Maximum Average
Counter 1 and counter 2 cementing	0.2206	0.01	0.1957	0.2433
Pasting glue	0.0990	0.01	0.08555282	0.1111
SKIVING 1	0.3388	0.01	0.3143	0.3599
SKIVING 2	3.0931	0.06	2.9673	3.3031
SKIVING 3	0.1376	0.01	0.1273	0.1521
SKIVING 4	0.2593	0.02	0.2261	0.2996
SKIVING 5	2.7919	0.07	2.6460	2.9453
stamping on lining and leather	0.00	0.00	0.00	0.00

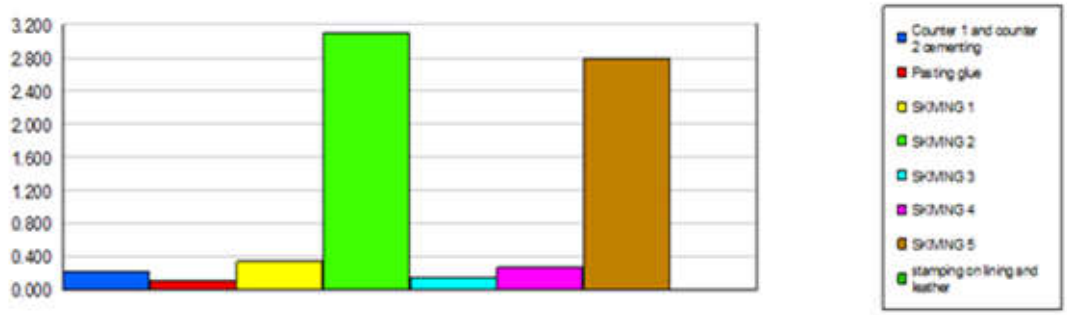


Table 5.15 d) Preparation section current simulation model *number in per process* result

Number In	Average	Half Width	Minimum Average	Maximum Average
Counter 1 and counter 2 cementing	87.6000	0.50	87.0000	89.0000
Counter stifffener skiving	87.7000	0.48	87.0000	89.0000
Marking	103.00	0.00	103.00	103.00
Pasting glue	87.6000	0.50	87.0000	89.0000
SKIVING 1	102.90	0.23	102.00	103.00
SKIVING 2	102.20	0.45	101.00	103.00
SKIVING 3	95.4000	0.60	94.0000	96.0000
SKIVING 4	94.8000	0.45	94.0000	96.0000
SKIVING 5	94.6000	0.37	94.0000	95.0000
Socks attachment over lining	86.9000	0.41	86.0000	88.0000
stamping on lining and leather	103.00	0.00	103.00	103.00

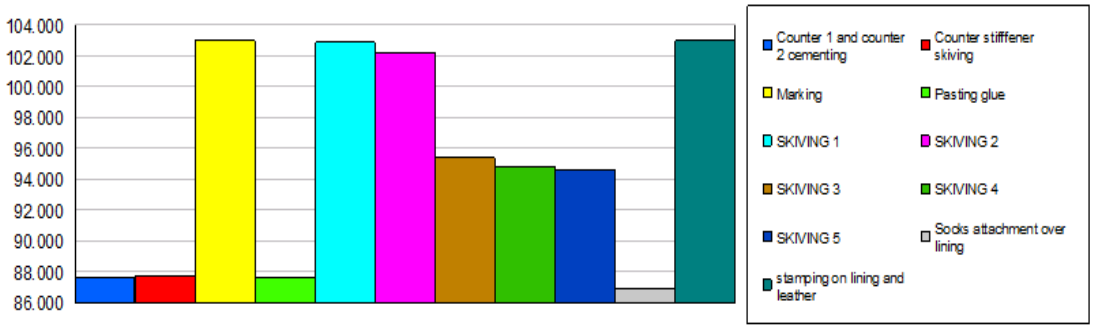


Table 5.15 e) Preparation section current simulation model *number out per process* result

Number Out	Average	Half Width	Minimum Average	Maximum Average
Counter 1 and counter 2 cementing	86.9000	0.41	86.0000	88.0000
Counter stifffener skiving	87.6000	0.50	87.0000	89.0000
Marking	102.90	0.23	102.00	103.00
Pasting glue	87.6000	0.50	87.0000	89.0000
SKIVING 1	102.20	0.45	101.00	103.00
SKIVING 2	95.4000	0.60	94.0000	96.0000
SKIVING 3	94.8000	0.45	94.0000	96.0000
SKIVING 4	94.6000	0.37	94.0000	95.0000
SKIVING 5	87.7000	0.48	87.0000	89.0000
Socks attachment over lining	86.1000	0.41	85.0000	87.0000
stamping on lining and leather	103.00	0.00	103.00	103.00

Table 5.15 f) Preparation section current simulation model *waiting time in queue* result

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Counter 1 and counter 2 cementing.Queue	0.00254806	0.00	0.00224987	0.00289603	0.00	0.01246561
Pasting glue.Queue	0.00113032	0.00	0.00097219	0.00124805	0.00	0.00531251
SKIVING 1.Queue	0.00331156	0.00	0.00305135	0.00352891	0.00	0.01577622
SKIVING 2.Queue	0.03242450	0.00	0.03090910	0.03440687	0.00	0.08044425
SKIVING 3.Queue	0.00145336	0.00	0.00135457	0.00159802	0.00	0.00745351
SKIVING 4.Queue	0.00274178	0.00	0.00237970	0.00318702	0.00	0.01277171
SKIVING 5.Queue	0.03200817	0.00	0.03041386	0.03349186	0.00	0.08102125
stamping on lining and leather.Queue	0.00	0.00	0.00	0.00	0.00	0.00

Table 5.15 g) Preparation section current simulation model *number waiting in queue* result

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Counter 1 and counter 2 cementing.Queue	0.2222	0.01	0.1957	0.2549	0.00	2.0000
Pasting glue.Queue	0.0990	0.01	0.08555282	0.1111	0.00	3.0000
SKIVING 1.Queue	0.3405	0.01	0.3143	0.3619	0.00	2.0000
SKIVING 2.Queue	3.3173	0.08	3.1451	3.4847	0.00	9.0000
SKIVING 3.Queue	0.1384	0.01	0.1273	0.1534	0.00	1.0000
SKIVING 4.Queue	0.2594	0.02	0.2261	0.2996	0.00	2.0000
SKIVING 5.Queue	3.0387	0.07	2.9147	3.1913	0.00	9.0000
stamping on lining and leather.Queue	0.00	0.00	0.00	0.00	0.00	0.00

5.2.2. Remodelling of improved production system using VSM

The re-modeling process is also made for preparation and stitching section as direct modification is made for those sections. see Figure 5.11 and 5.12

The remodelling process focuses on merging the process, using alternative means of processing time reduction, WIP reduction and production according to the intake capacity of section.

a) Modified state preparation section VSM model

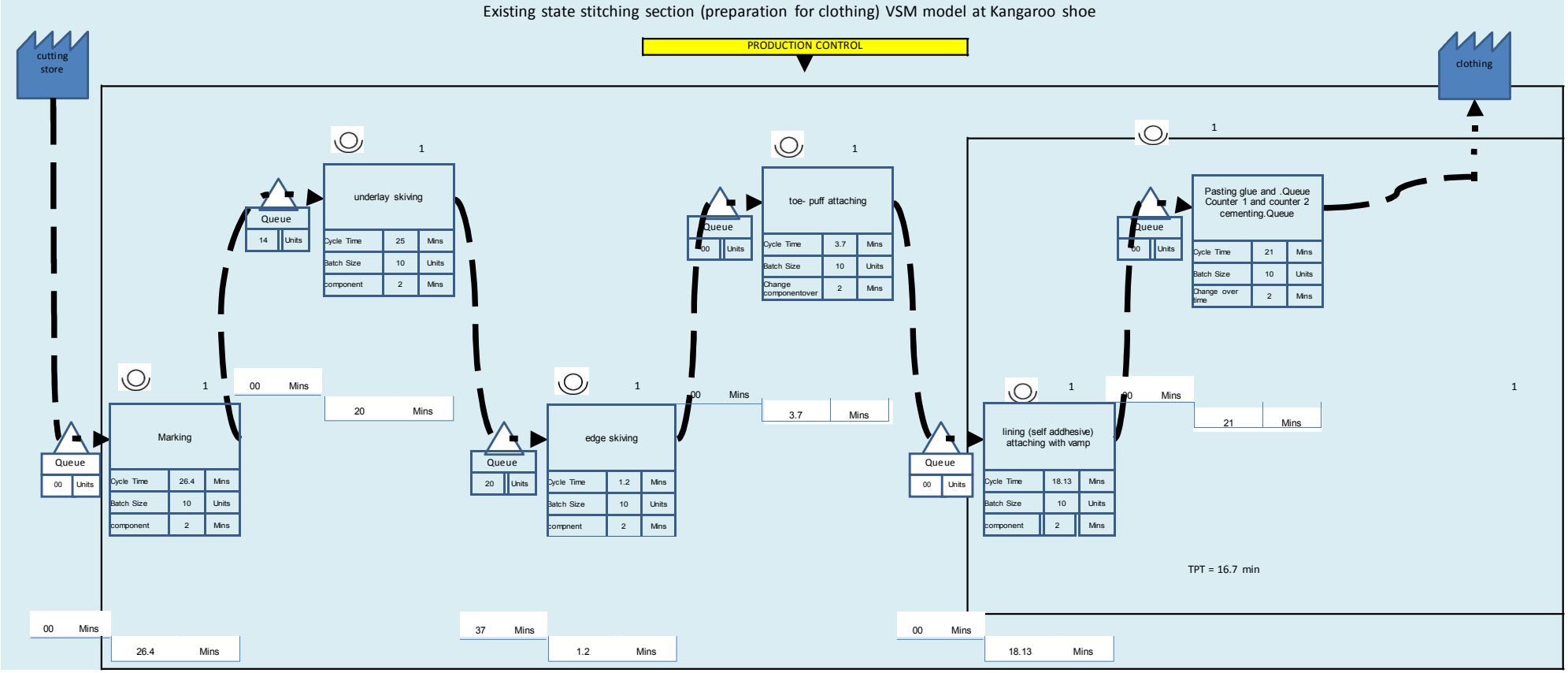


Figure 5.11 Modified state preparation section VSM model

b) Modified state stitching section VSM model

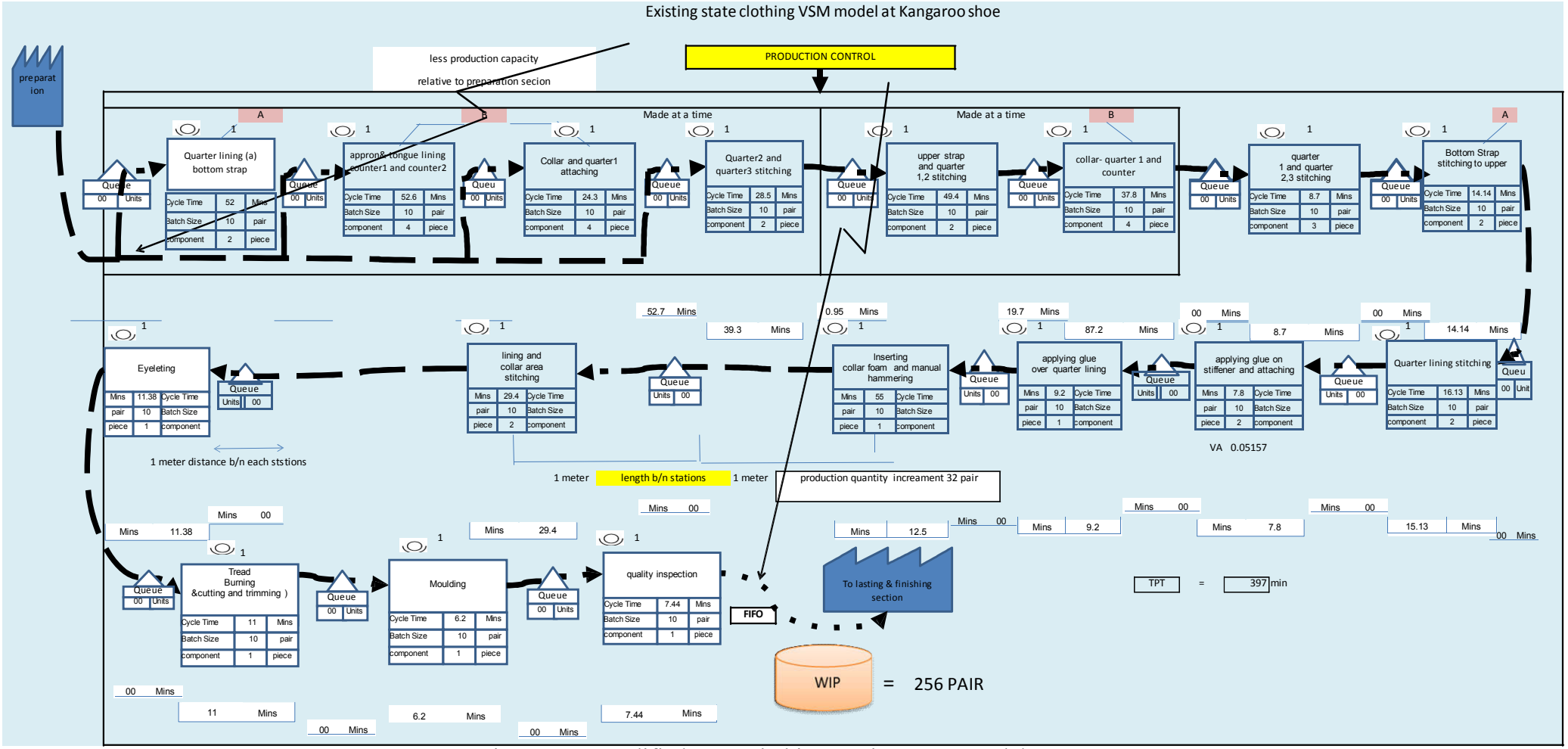


Figure 5.12 Modified state stitching section VSM model

5.2.3. Arena simulation for improved/proposed production system VSM

There are two main changes made while constructing modified simulation model relative to the current one.

1. A section that demands input quantity modifications (depending on excess WIP count between sections) need other inter arrival time logical calculation in alternate manufacturing system changing process. Inter arrival time of input for the modified model will be calculated as; **Number in(for 1st process)** will be;

$$\frac{\text{Replication length} * \text{intake capacity of the station}}{\text{working hour}}$$

Inter arrival time = **Replication length** / **Number in(for 1st process)**

2. In addition to this, data input that are directly related to the improvement area are changed and used in simulation in terms of expression listed on appendix-C. 2.

Both changes are considered depending on improvement types.

a) Arena simulation for modified production system in stitching section:

The highlighted part indicates the improvement area of processes in order to minimize time as well as unnecessary cost related to workers. See table 5.16

Figure 5.13 illustrates the modified model of stitching section based on table 5.16

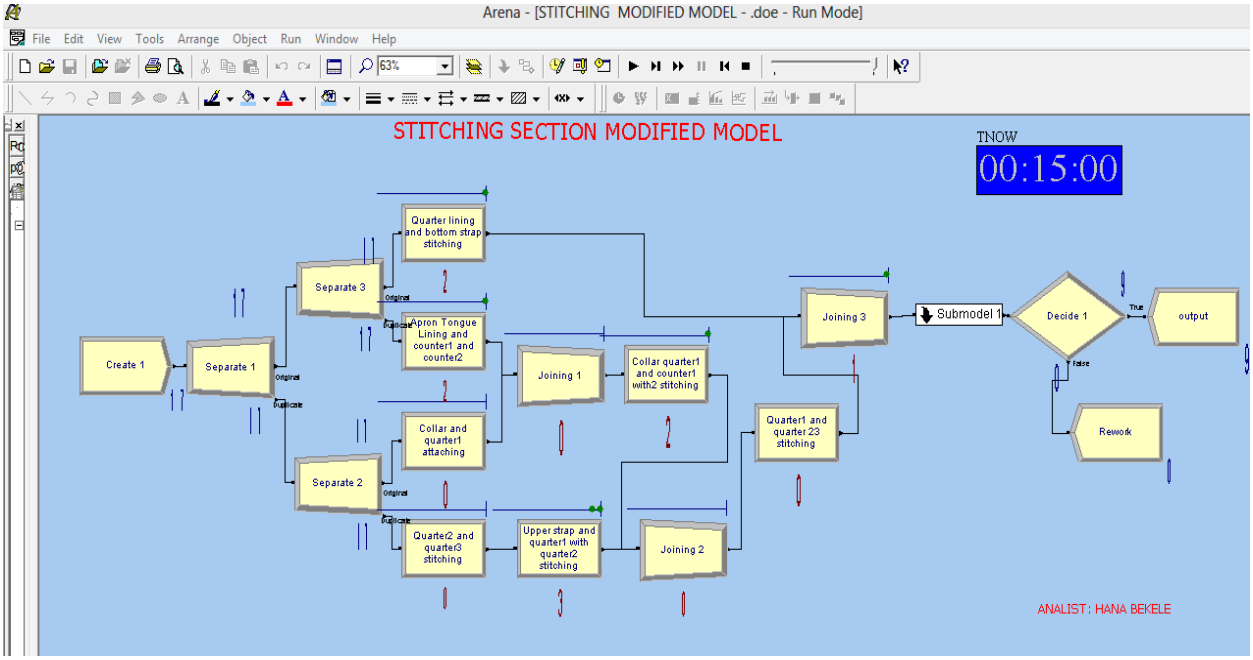


Figure 5:13 stitching section modified model

Table 5.16 Modified Input data with highlighted improvement area of processes in stitching section.

Number of Operations	Operation name	number of workers	Number of Processing time Observed per operation (in seconds)														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Quarter lining and bottom strap stitching	1	60	53	50	58	57	62	57	55	66	54	57	57	65	56	57
2	Apron Tongue Lining and counter1 and counter2	1	58	62	55	52	60	57	58	56	63	59	61	57	58	56	58
3	Collar and quarter1 attaching	1	44	50	42	46	49	53	46	52	45	40	38	48	46	41	46
4	Quarter2 and quarter3 stitching	1	50	47	56	46	50	60	55	45	56	52	50	51	53	48	50
5	Upper strap and quarter1 with quarter2 stitching	1	54	60	52	58	54	57	65	55	63	53	56	58	58	64	57
6	Collar quarter1 and counter1 with2 stitching	1	52	61	59	60	57	63	56	65	54	55	59	59	53	59	61
7	Quarter1 and quarter 23 stitching	1	15	16	18	15	21	22	14	13	15	20	13	15	17	12	12
8	Bottom strap attaching	1	23	22	29	25	24	31	33	28	25	23	22	25	32	21	21
9	Quarter lining stitching	1	26	31	30	32	35	27	33	30	28	30	28	27	34	30	29
10	Applying glue on stiffener and attaching on counter 1	1	12	15	11	15	13	15	18	12	14	18	15	16	17	15	11
11	Apply Glue over quarter lining	1	17	21	15	17	20	14	16	18	16	17	19	21	17	4	18
12	Inserting collar foam and hammering	1	51	55	59	53	55	55	56	60	63	52	54	55	56	61	55
13	Lining and collar area stitching	1	55	63	50	50	62	55	50	48	58	55	59	49	55	55	55
14	Triming ,Thread burning and cutting	1	24	16	23	21	26	21	20	17	17	19	21	21	18	24	21
15	Eyeleting	1	19	23	21	20	20	21	20	22	20	23	19	24	19	20	20
16	Molding	1	12	12	14	13	14	12	10	9	10	12	12	12	10	13	9
17	Quality Inspection	1	17	14	12	14	11	13	14	11	14	15	12	14	17	14	16

The modified simulation result viewed by the software is displayed below. See figure 5.14 to 5.16 and table 5.17 (a) to (g).

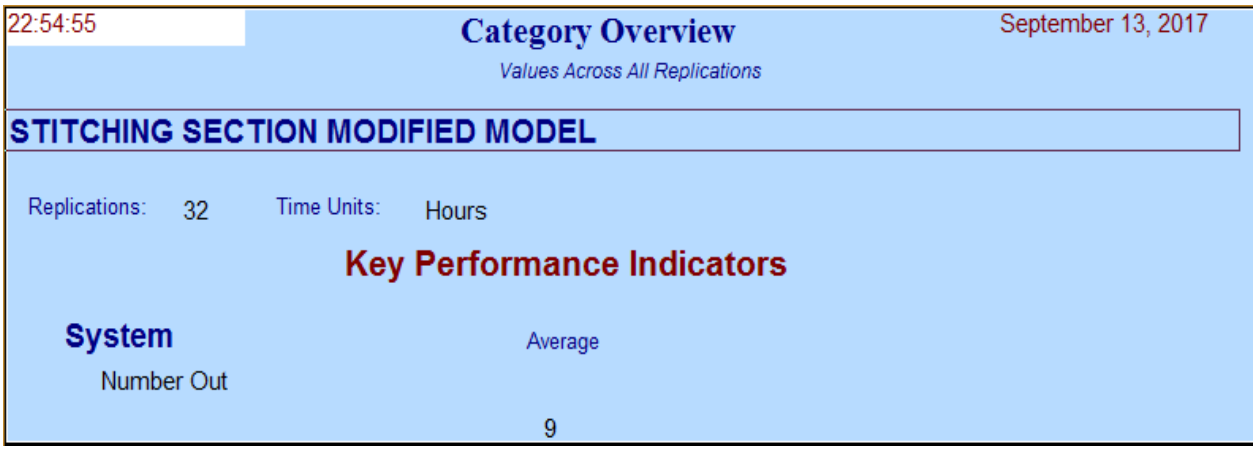


Figure 5.14 Stitching section *modified simulation model number out page*

Table 5.17 a) Stitching section current simulation model *time per entity* result

Process

Time per Entity

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Applying glue on stiffener and attaching on counter 1	0.00408260	0.00	0.00385406	0.00428284	0.00312496	0.00497105
Applying glue over quarter lining	0.00481105	0.00	0.00460381	0.00506871	0.00394539	0.00571803
Apron Tongue Lining and counter1 and counter2	0.02706398	0.00	0.02509781	0.02913509	0.01536481	0.04234647
Bottom strap attaching	0.00740109	0.00	0.00695433	0.00773740	0.00585038	0.00906005
Collar and quarter1 attaching	0.01272435	0.00	0.01243489	0.01315307	0.01061795	0.01463080
Collar quarter1 and counter1 with2 stitching	0.01964997	0.00	0.01752632	0.02232187	0.01487871	0.03062696
Eyeleting	0.00592309	0.00	0.00565277	0.00636212	0.00529763	0.00691771
inserting collar foam and Hammering	0.01628184	0.00	0.01532002	0.01948630	0.01401350	0.02231920
Lining and collar area stitching	0.01565075	0.00	0.01486603	0.01661049	0.01338203	0.01860067
Moulding	0.00323687	0.00	0.00305824	0.00338613	0.00255757	0.00386396
Quality Check	0.00389683	0.00	0.00361737	0.00410432	0.00307914	0.00468474
Quarter lining and bottom strap stitching	0.02725399	0.00	0.02313741	0.03218869	0.01507771	0.04423071
Quarter lining stitching	0.00841253	0.00	0.00808574	0.00866582	0.00732062	0.00969340
Quarter1 and quarter 23 stitching	0.00453933	0.00	0.00430196	0.00482916	0.00348690	0.00595863
Quarter2 and quarter3 stitching	0.01471213	0.00	0.01407382	0.01678868	0.01254618	0.02003767
Trimming	0.00572168	0.00	0.00519435	0.00624252	0.00425798	0.00703804
Upper strap and quarter1 with quarter2 stitching	0.02565718	0.00	0.02233929	0.03014375	0.01457107	0.04256324

Table 5.17 b) Stitching section modified simulation model *accumulated VA time* result

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Applying glue on stiffener and attaching on counter 1	0.05203673	0.00	0.04863695	0.05567697
Applying glue over quarter lining	0.05877742	0.00	0.05524567	0.06282032
Apron Tongue Lining and counter1 and counter2	0.2440	0.00	0.2407	0.2485
Bottom strap attaching	0.0992	0.00	0.0904	0.1067
Collar and quarter1 attaching	0.2163	0.00	0.2114	0.2236
Collar quarter1 and counter1 with2 stitching	0.2273	0.00	0.2169	0.2314
Eyeleting	0.05811604	0.00	0.05264876	0.06362124
inserting collar foam and Hammering	0.1738	0.00	0.1666	0.1921
Lining and collar area stitching	0.1571	0.00	0.1500	0.1724
Moulding	0.03053799	0.00	0.02752412	0.03292647
Quality Check	0.03532300	0.00	0.03255629	0.04083494
Quarter lining and bottom strap stitching	0.2437	0.00	0.2356	0.2488
Quarter lining stitching	0.1094	0.00	0.1051	0.1127
Quarter1 and quarter 23 stitching	0.06056926	0.00	0.05594610	0.06595114
Quarter2 and quarter3 stitching	0.2351	0.00	0.2249	0.2484
Trimming	0.05721681	0.00	0.05194350	0.06242523
Upper strap and quarter1 with quarter2 stitching	0.2270	0.00	0.2212	0.2341

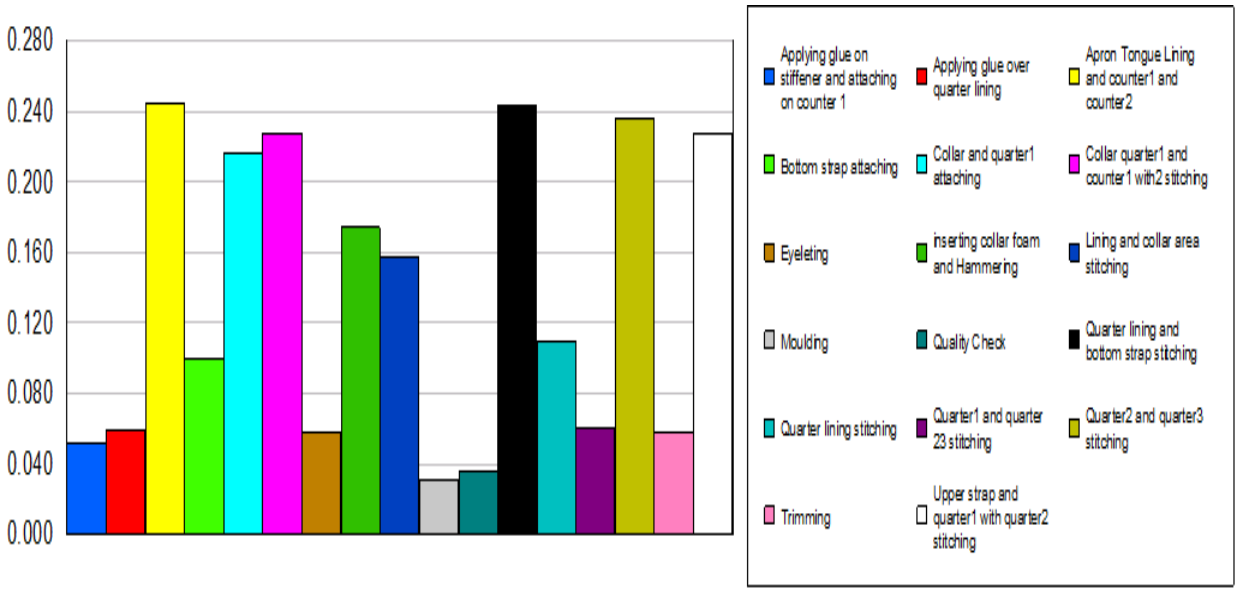


Figure 5.15. Stitching section modified simulation model *accumulated VA time* result interms of graph

Table 5.17 c) Stitching section modified simulation model *accumulated wait time* result

Accum Wait Time	Average	Half Width	Minimum Average	Maximum Average
Apron Tongue Lining and counter1 and counter2	0.1619	0.01	0.1352	0.1898
Bottom strap attaching	0.00	0.00	0.00	0.00
Collar and quarter1 attaching	0.00	0.00	0.00	0.00
Collar quarter1 and counter1 with2 stitching	0.04639646	0.00	0.02342497	0.07206152
Eyeleting	0.00	0.00	0.00	0.00
inserting collar foam and Hammering	0.00794084	0.00	0.00	0.04169454
Lining and collar area stitching	0.00286809	0.00	0.00004226	0.00990865
Moulding	0.00	0.00	0.00	0.00
Quarter lining and bottom strap stitching	0.1641	0.01	0.1092	0.2150
Quarter lining stitching	0.00	0.00	0.00	0.00
Quarter2 and quarter3 stitching	0.00670093	0.00	0.00036775	0.03501689
Trimming	0.00	0.00	0.00	0.00
Upper strap and quarter1 with quarter2 stitching	0.1322	0.01	0.08990618	0.1909

Table 5.17 d) Stitching section modified simulation model *number in per process* result

Number In	Average	Half Width	Minimum Average	Maximum Average
Applying glue on stiffener and attaching on counter 1	13.0000	0.00	13.0000	13.0000
Applying glue over quarter lining	12.7500	0.16	12.0000	13.0000
Apron Tongue Lining and counter1 and counter2	17.0000	0.00	17.0000	17.0000
Bottom strap attaching	14.0000	0.00	14.0000	14.0000
Collar and quarter1 attaching	17.0000	0.00	17.0000	17.0000
Collar quarter1 and counter1 with2 stitching	16.0000	0.00	16.0000	16.0000
Eyeleting	10.0000	0.00	10.0000	10.0000
inserting collar foam and Hammering	12.2188	0.15	12.0000	13.0000
Lining and collar area stitching	11.1563	0.13	11.0000	12.0000
Moulding	9.8125	0.14	9.0000	10.0000
Quality Check	9.4375	0.18	9.0000	10.0000
Quarter lining and bottom strap stitching	17.0000	0.00	17.0000	17.0000
Quarter lining stitching	13.4063	0.18	13.0000	14.0000
Quarter1 and quarter 23 stitching	13.9375	0.09	13.0000	14.0000
Quarter2 and quarter3 stitching	17.0000	0.00	17.0000	17.0000
Trimming	10.2188	0.15	10.0000	11.0000
Upper strap and quarter1 with quarter2 stitching	16.4375	0.18	16.0000	17.0000

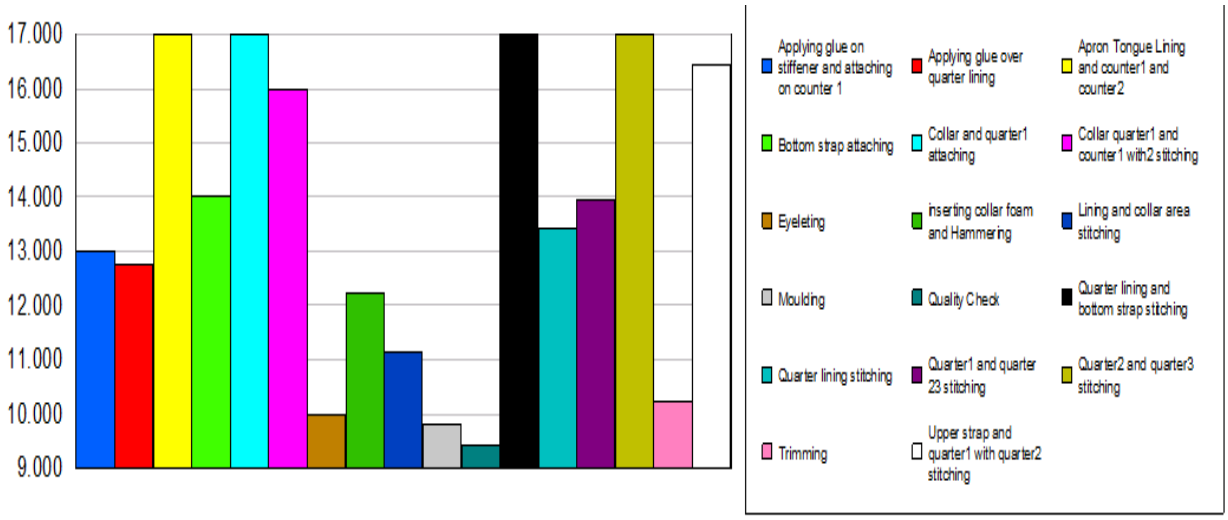


Figure 5.16 Stitching section modified simulation model *number in per process* result graph

Table 5.17 e) Stitching section modified simulation model *number out per process* result

Number Out	Average	Half Width	Minimum Average	Maximum Average
Applying glue on stiffener and attaching on counter 1	12.7500	0.16	12.0000	13.0000
Applying glue over quarter lining	12.2188	0.15	12.0000	13.0000
Apron Tongue Lining and counter1 and counter2	15.0000	0.00	15.0000	15.0000
Bottom strap attaching	13.4063	0.18	13.0000	14.0000
Collar and quarter1 attaching	17.0000	0.00	17.0000	17.0000
Collar quarter1 and counter1 with2 stitching	13.9375	0.09	13.0000	14.0000
Eyeleting	9.8125	0.14	9.0000	10.0000
inserting collar foam and Hammering	11.1563	0.13	11.0000	12.0000
Lining and collar area stitching	10.2188	0.15	10.0000	11.0000
Moulding	9.4375	0.18	9.0000	10.0000
Quality Check	9.0625	0.09	9.0000	10.0000
Quarter lining and bottom strap stitching	14.9688	0.06	14.0000	15.0000
Quarter lining stitching	13.0000	0.00	13.0000	13.0000
Quarter1 and quarter 23 stitching	13.3438	0.17	13.0000	14.0000
Quarter2 and quarter3 stitching	16.4375	0.18	16.0000	17.0000
Trimming	10.0000	0.00	10.0000	10.0000
Upper strap and quarter1 with quarter2 stitching	14.0000	0.00	14.0000	14.0000

Table 5.17 f) Stitching section modified simulation model *waiting time in queue* result

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Apron Tongue Lining and counter1 and counter2.Queue	0.01157039	0.00	0.00972711	0.01351206	0.00	0.02762425
Bottom strap attaching.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Collar and quarter1 attaching.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Collar quarter1 and counter1 with2 stitching.Queue	0.00393589	0.00	0.00207135	0.00619556	0.00	0.01594800
Eyeleting.Queue	0.00	0.00	0.00	0.00	0.00	0.00
inserting collar foam and Hammering.Queue	0.00071242	0.00	0.00	0.00327782	0.00	0.00674494
Joining 1.Queue	0.00459957	0.00	0.00374684	0.00514791	0.00	0.01615707
Joining 2.Queue	0.00188887	0.00	0.00043792	0.00369595	0.00	0.01216820
Joining 3.Queue	0.00544169	0.00	0.00350655	0.00691427	0.00	0.01802184
Lining and collar area stitching.Queue	0.00029170	0.00	0.00000384	0.00086226	0.00	0.00305638
Moulding.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Quarter lining and bottom strap stitching.Queue	0.01174626	0.00	0.00788923	0.01630203	0.00	0.02950849
Quarter lining stitching.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Quarter2 and quarter3 stitching.Queue	0.00041391	0.00	0.00003651	0.00205982	0.00	0.00531545
Trimming.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Upper strap and quarter1 with quarter2 stitching.Queue	0.01019252	0.00	0.00717410	0.01443617	0.00	0.02808694

Table 5.17 g) Stitching section modified simulation model *number waiting in queue* result

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Apron Tongue Lining and counter1 and counter2.Queue	0.7983	0.03	0.6803	0.9225	0.00	2.0000
Bottom strap attaching.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Collar and quarter1 attaching.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Collar quarter1 and counter1 with2 stitching.Queue	0.2458	0.03	0.1354	0.4223	0.00	2.0000
Eyeleting.Queue	0.00	0.00	0.00	0.00	0.00	0.00
inserting collar foam and Hammering.Queue	0.03521342	0.01	0.00	0.1704	0.00	1.0000
Joining 1.Queue	0.5887	0.01	0.4796	0.6589	0.00	2.0000
Joining 2.Queue	0.2126	0.04	0.04904715	0.4294	0.00	2.0000
Joining 3.Queue	0.6114	0.04	0.3979	0.7744	0.00	2.0000
Lining and collar area stitching.Queue	0.01313340	0.00	0.00016906	0.04138860	0.00	1.0000
Moulding.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Quarter lining and bottom strap stitching.Queue	0.8111	0.04	0.5627	1.1526	0.00	3.0000
Quarter lining stitching.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Quarter2 and quarter3 stitching.Queue	0.02814589	0.01	0.00248250	0.1401	0.00	1.0000
Trimming.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Upper strap and quarter1 with quarter2 stitching.Queue	0.6709	0.04	0.4947	0.9242	0.00	2.0000

b) Arena simulation model for modified lasting and finishing section:

The highlighted part indicates the improved area of processes because of improvement in immediate section of lasting and finishing section that is stitching section. See table 5.18

Table 5.18 Highlighted improved area of processes shows changes made in lasting and finishing section

Number of Operations	Operation name	Number of workers	Number of Processing time Observed per operation (in seconds)														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Last selection	1	7	6	6	6	7	7	5	6	5	5	7	5	6	6	6
2	Last insertion and lasting	1	7	6	6	7	6	8	8	6	7	7	6	6	7	6	8
3	Temporary shoe lace insertion	1	5	7	5	6	6	8	6	7	4	6	7	6	6	7	8
4	Heating	1	7	9	6	8	7	7	9	5	5	9	7	7	6	7	6
5	Hammering	1	10	9	8	8	8	7	10	9	9	7	8	7	8	10	8
6	Wrinckel chassing	1	7	7	6	7	7	6	8	8	7	8	7	6	8	8	6
7	Thread burning	1	5	5	6	4	6	5	4	4	5	6	5	5	4	6	6
8	Cooling	1	6	8	7	7	8	10	8	8	9	10	8	7	5	8	9
9	Creaming	1	6	7	9	7	7	6	8	7	9	6	6	7	7	9	8
10	Burning	1	10	10	11	11	9	10	9	9	10	11	10	11	9	10	10
11	Delasting	1	6	6	8	8	7	9	8	10	8	8	7	10	7	10	6
12	Shoe lacing Final	1	9	9	6	7	8	8	9	10	10	11	7	9	9	11	6
13	Sockes insertion	1	7	9	8	10	8	9	8	11	9	8	8	6	8	10	8
14	Inserting tissue paper	1	8	7	5	6	5	4	3	4	7	5	8	5	7	3	4
15	Quality inspection	1	8	10	10	9	8	8	7	9	8	9	7	8	10	8	8

Figure 5.17 illustrates the modified model of lasting and stitching section based on table 5.17

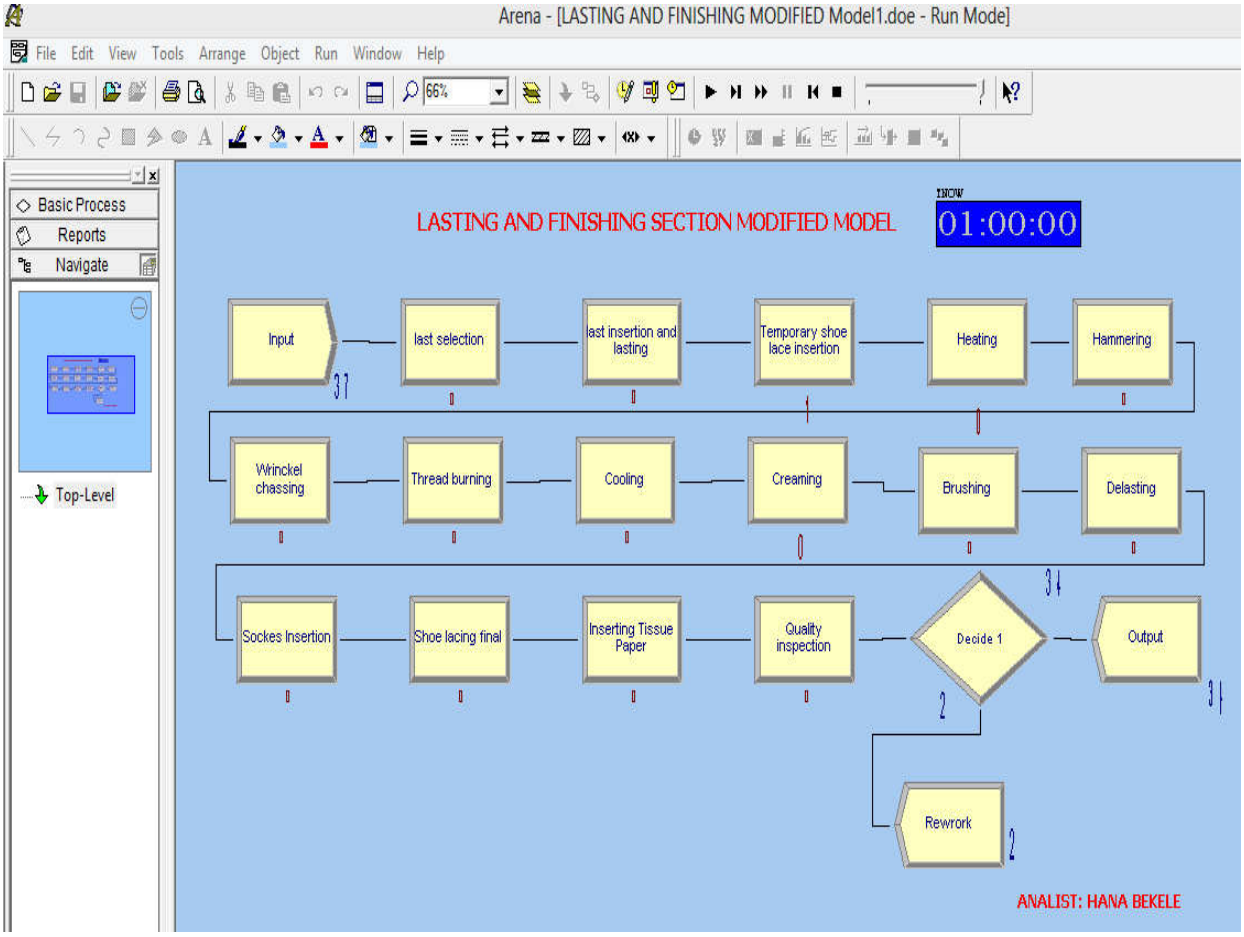


Figure 5.17 Lasting and finishing section modified model

The modified simulation result viewed by the software is displayed below. See figure 5.18.(a) and (b) and table 5.19 (a) to (h).

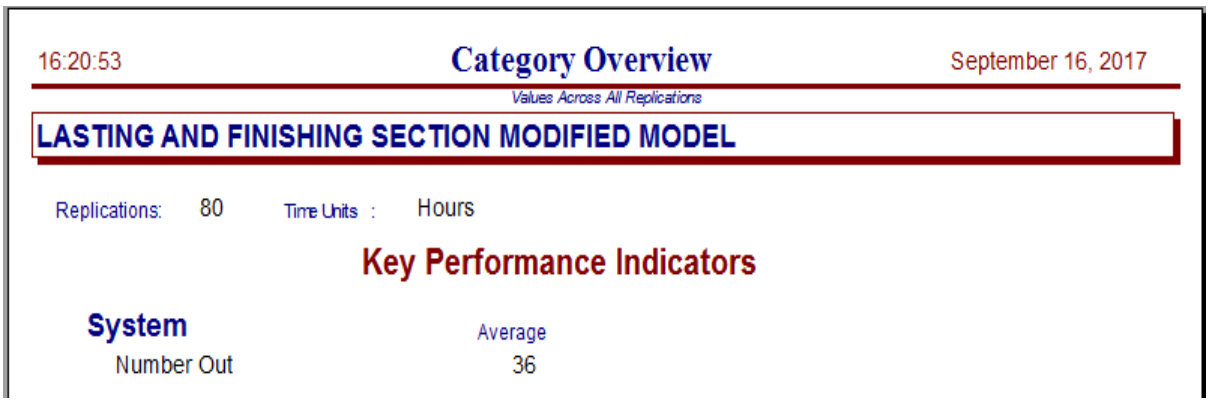


Figure 5.18 a) Lasting and stitching section *modified simulation model number out page*

Table 5.19 a) Lasting and stitching section current simulation model *time per entity* result

Process

Time per Entity

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Brushing	0.00277820	0.00	0.00273962	0.00283298	0.00250304	0.00305276
Cooling	0.00222537	0.00	0.00214389	0.00230515	0.00167951	0.00277253
Creaming	0.00203104	0.00	0.00196862	0.00211438	0.00167527	0.00249036
Delasting	0.00223025	0.00	0.00214314	0.00236583	0.00168011	0.00276305
Hammering	0.00238235	0.00	0.00226764	0.00249332	0.00195368	0.00381079
Heating	0.00193809	0.00	0.00184432	0.00202895	0.00139585	0.00248704
Inserting Tissue Paper	0.00147669	0.00	0.00136308	0.00159646	0.00085300	0.00220462
last insertion and lasting	0.00236017	0.00	0.00211588	0.00264194	0.00167410	0.00489307
last selection	0.00170202	0.00	0.00162500	0.00183449	0.00139091	0.00452858
Quality inspection	0.00321743	0.00	0.00297163	0.00346902	0.00198567	0.00470689
Shoe lacing final	0.00240880	0.00	0.00232801	0.00256343	0.00169867	0.00302762
Sockes Insertion	0.00230927	0.00	0.00217389	0.00245965	0.00168602	0.00304033
Temporary shoe lace insertion	0.00301217	0.00	0.00244988	0.00344934	0.00113488	0.00485250
Thread burning	0.00138974	0.00	0.00133061	0.00143207	0.00111917	0.00165936
Wrinckel chassing	0.00194228	0.00	0.00189445	0.00198550	0.00167322	0.00221917

Table 5.19 b) Lasting and stitching modified simulation model *accumulated VA time* result

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Brushing	0.1000	0.00	0.0986	0.1020
Cooling	0.08011332	0.00	0.07718021	0.08298537
Creaming	0.07311754	0.00	0.07087050	0.07611771
Hammering	0.08322725	0.00	0.08042624	0.08612688
Heating	0.06981938	0.00	0.06639565	0.07304232
last insertion and lasting	0.07195610	0.00	0.07058969	0.07342662
Shoe lacing final	0.08671692	0.00	0.08380852	0.0923
Sockes Insertion	0.08313365	0.00	0.07826005	0.08854752
Temporary shoe lace insertion	0.06061817	0.00	0.05793913	0.06472934
Thread burning	0.05003064	0.00	0.04790198	0.05155463
Wrinckel chassing	0.06992212	0.00	0.06820017	0.07147786

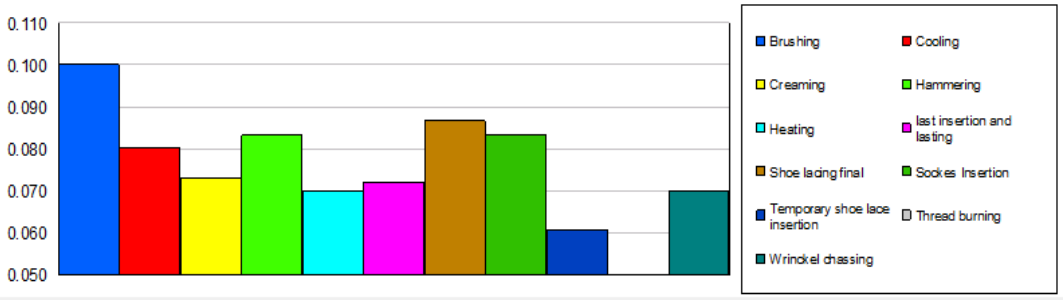


Table 5.19 c) Lasting and stitching section modified simulation model *accumulated wait time* result

Accumulated Time

Accum Wait Time	Average	Half Width	Minimum Average	Maximum Average
Brushing	0.00	0.00	0.00	0.00
Creaming	0.00	0.00	0.00	0.00
Delasting	0.00	0.00	0.00	0.00
Hammering	0.00253750	0.00	0.00065264	0.00505908
last insertion and lasting	0.01537034	0.00	0.00665785	0.02664962
last selection	0.00127792	0.00	0.00	0.00627606
Quality inspection	0.03226293	0.00	0.02226723	0.04149896
Temporary shoe lace insertion	0.04865267	0.00	0.02622970	0.06371479
Thread burning	0.00	0.00	0.00	0.00
Wrinckel chassing	0.00	0.00	0.00	0.00

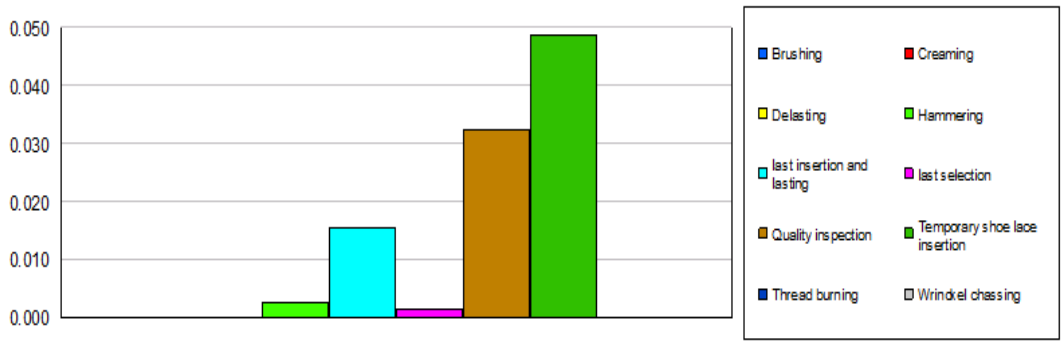


Table 5.19 d) Lasting and stitching section modified simulation model *accumulated NNVA/ other time* result

Accum Other Time	Average	Half Width	Minimum Average	Maximum Average
Delasting	0.08028888	0.00	0.07715293	0.08516997
Inserting Tissue Paper	0.05316076	0.00	0.04907080	0.05747269
last selection	0.06169677	0.00	0.06012499	0.06329393
Quality inspection	0.08267731	0.00	0.07925921	0.08518436

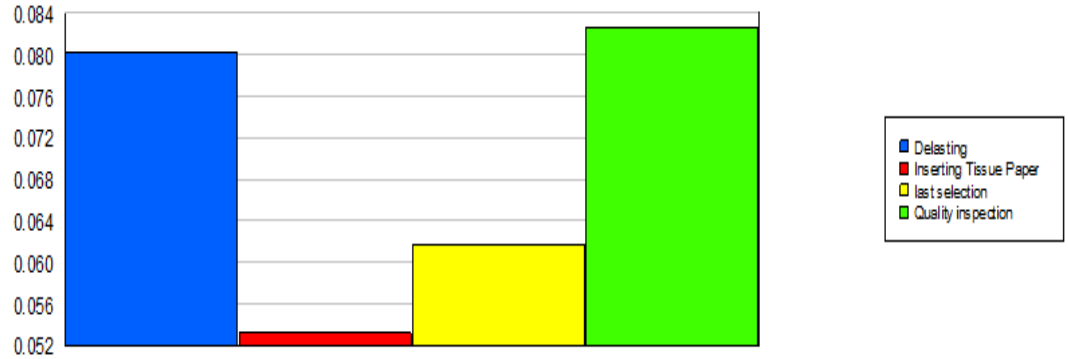


Table 5.19 e) Lasting and stitching section modified simulation model *number in per process* result

Process

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Brushing	36.0000	0.00	36.0000	36.0000
Cooling	36.0000	0.00	36.0000	36.0000
Creaming	36.0000	0.00	36.0000	36.0000
Delasting	36.0000	0.00	36.0000	36.0000
Hammering	36.0250	0.04	36.0000	37.0000
Heating	36.2750	0.10	36.0000	37.0000
Inserting Tissue Paper	36.0000	0.00	36.0000	36.0000
last insertion and lasting	37.0000	0.00	37.0000	37.0000
last selection	37.0000	0.00	37.0000	37.0000
Quality inspection	36.0000	0.00	36.0000	36.0000
Shoe lacing final	36.0000	0.00	36.0000	36.0000
Sockes Insertion	36.0000	0.00	36.0000	36.0000
Temporary shoe lace insertion	37.0000	0.00	37.0000	37.0000
Thread burning	36.0000	0.00	36.0000	36.0000
Wrinckel chassing	36.0000	0.00	36.0000	36.0000

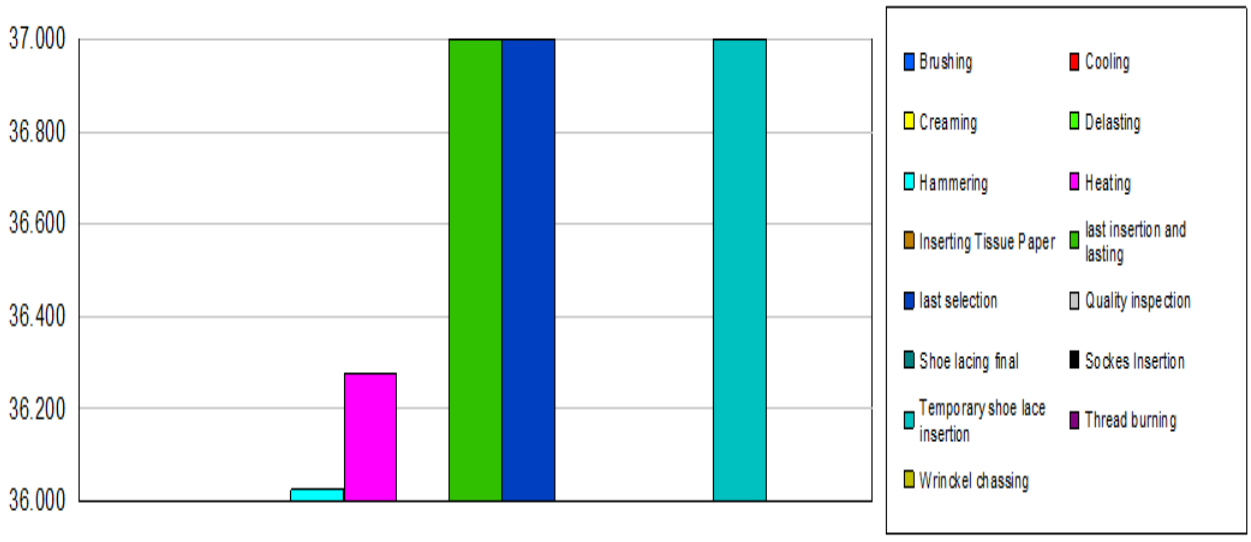


Figure 5.18.b) Lasting and stitching section modified simulation model *number in per process* result graph

Table 5.19 f) Lasting and stitching section modified simulation model *number out per process* result

Number Out	Average	Half Width	Minimum Average	Maximum Average
Brushing	36.0000	0.00	36.0000	36.0000
Cooling	36.0000	0.00	36.0000	36.0000
Creaming	36.0000	0.00	36.0000	36.0000
Delasting	36.0000	0.00	36.0000	36.0000
Hammering	36.0000	0.00	36.0000	36.0000
Heating	36.0250	0.04	36.0000	37.0000
Inserting Tissue Paper	36.0000	0.00	36.0000	36.0000
last insertion and lasting	37.0000	0.00	37.0000	37.0000
last selection	37.0000	0.00	37.0000	37.0000
Quality inspection	35.7250	0.10	35.0000	36.0000
Shoe lacing final	36.0000	0.00	36.0000	36.0000
Sockes Insertion	36.0000	0.00	36.0000	36.0000
Temporary shoe lace insertion	36.2750	0.10	36.0000	37.0000
Thread burning	36.0000	0.00	36.0000	36.0000

Table 5.19 g) Lasting and stitching section modified simulation model *waiting time in queue* result

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Brushing.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Creaming.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Delasting.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Hammering.Queue	0.00007049	0.00	0.00001813	0.00014053	0.00	0.00137024
last insertion and lasting.Queue	0.00041541	0.00	0.00017994	0.00072026	0.00	0.00273179
last selection.Queue	0.00003454	0.00	0.00	0.00016962	0.00	0.00273871
Quality inspection.Queue	0.00090627	0.00	0.00066516	0.00115275	0.00	0.00217234
Temporary shoe lace insertion.Queue	0.00135346	0.00	0.00070891	0.00178286	0.00	0.00276671
Thread burning.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Wrinckel chassing.Queue	0.00	0.00	0.00	0.00	0.00	0.00

Table 5.19 h) Lasting and stitching section modified simulation model *number waiting in queue* result

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Brushing.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Creaming.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Delasting.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Hammering.Queue	0.00254173	0.00	0.00065264	0.00505908	0.00	1.0000
last insertion and lasting.Queue	0.01537034	0.00	0.00665785	0.02664962	0.00	1.0000
last selection.Queue	0.00127792	0.00	0.00	0.00627606	0.00	1.0000
Quality inspection.Queue	0.03262558	0.00	0.02394577	0.04149896	0.00	1.0000
Temporary shoe lace insertion.Queue	0.05007791	0.00	0.02622970	0.06596581	0.00	1.0000
Thread burning.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Wrinckel chassing.Queue	0.00	0.00	0.00	0.00	0.00	0.00

c) Arena simulation model for modified Preparation section:

The highlighted part indicates the improvement area of processes in order to minimize time as well as unnecessary cost related to workers. See table 5.20

Table 5.20 Modified Input data with highlighted improvement area of processes in preparation section

Figure 5.19 illustrates the modified model of preparation section based on table 5.20

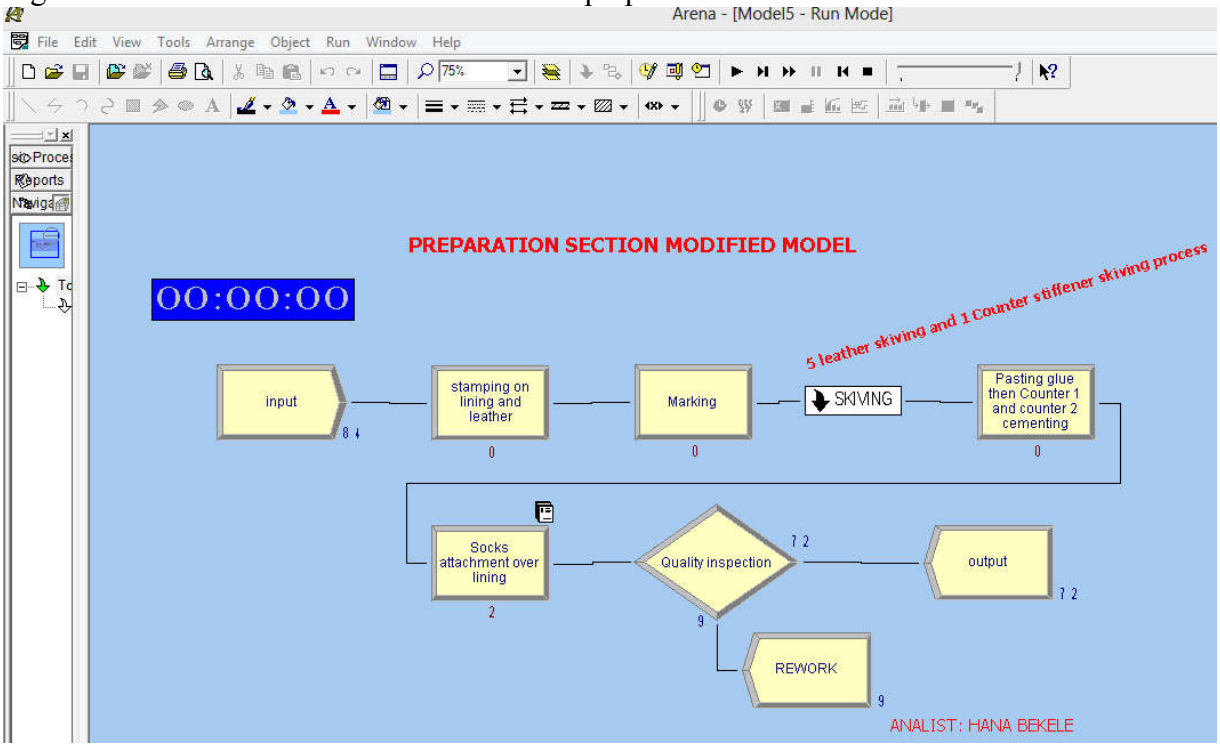


Figure 5.19 Preparation section modified model

Table 5.20 Highlighted improved area of processes shows changes made in lasting and finishing section

Number of Operations	Operation name	Number of workers	Number of Processesing time Observed per operation (in seconds)														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Stamping on lining and leather	1	21.74	13.71	16	19.91	15.7	17.28	16.34	16.78	13.68	13.4	17.21	15.93	16.4	13.87	15.8
2	Marking	1	7.74	10.08	11.77	10.37	10.09	9.47	10.9	7.73	7.32	10.85	5.87	11.29	11.87	7.33	8.67
3	Skiving 1	1	3	3.9	4	4.2	3	3	4	2	3.5	4	3.2	4.1	2.9	3	3.6
4	Skiving 2	1	4	2.5	2.7	3.4	3.1	3	2.2	3.1	2.8	3	2.6	4	4	3.9	3
5	Skiving 3	1	2.5	3.2	3.25	3.4	2.13	2.25	2.55	1.78	2.23	2.5	2.25	3.05	2.45	2.73	2.55
6	Skiving 4	1	3	3.84	3.9	4.08	2.55	2.7	3.06	2.13	2.67	3	2.7	3.66	2.94	3.27	3.06
7	Skiving 5	1	3.26	4.12	4.15	4.33	2.38	2.67	2.51	2.43	2.18	2.39	2.5	3.6	3.23	3.79	2.86
8	Skiving 6	1	3.33	2.4	3.2	3.4	2.75	2.85	4.27	2.3	3.3	4.17	3.17	4.3	3.17	3.47	3.66
9	Pasting glue and Counter 1 and counter 2 cementing	1	24.6	21.4	21.47	22.18	19.82	25.11	22.62	17.08	20.06	23.49	23.9	21	18.75	21.7	23.58
10	Socks attachment over lining	1	19.97	21.7	26.67	22.8	26.03	17.65	27.46	19.88	26.58	20.07	23	24.24	25.69	24.82	19.74

The modified simulation result viewed by the software is displayed below. See figure 5.20 and table 5.21 (a) to (g).

Table 5.21 a) Preparation section current simulation model *time per entity* result

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Counter stifffener skiving	0.00091658	0.00	0.00088700	0.00096377	0.00059035	0.00151280
Marking	0.00262917	0.00	0.00248710	0.00272524	0.00154938	0.00333064
Pasting glue then Counter 1 and counter 2 cementing	0.00605384	0.00	0.00594274	0.00621565	0.00436543	0.00803766
SKIVING 1	0.00370955	0.00	0.00298463	0.00402002	0.00058288	0.01981181
SKIVING 2	0.00281611	0.00	0.00221175	0.00315623	0.00056485	0.01735597
SKIVING 3	0.00136921	0.00	0.00109509	0.00160219	0.00048266	0.01288899
SKIVING 4	0.00175633	0.00	0.00142747	0.00207260	0.00057701	0.01496599
SKIVING 5	0.00210522	0.00	0.00157752	0.00279235	0.00058932	0.01721926
Socks attachment over lining	0.00897678	0.00	0.00763465	0.00950875	0.00474458	0.01921600
stamping on lining and leather	0.00451437	0.00	0.00441245	0.00460999	0.00361947	0.00774323

Table 5.21 b) Preparation modified simulation model *accumulated VA time* result

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Counter stifffener skiving	0.07579617	0.00	0.07362085	0.07902902
Marking	0.2209	0.00	0.2089	0.2289
Pasting glue then Counter 1 and counter 2 cementing	0.4976	0.00	0.4873	0.5097
SKIVING 1	0.07907238	0.00	0.07638994	0.08225389
SKIVING 2	0.07641905	0.00	0.07512707	0.07861988
SKIVING 3	0.05917262	0.00	0.05715950	0.06119286
SKIVING 4	0.06848167	0.00	0.06703203	0.07066751
SKIVING 5	0.07156676	0.00	0.06725747	0.07842875
Socks attachment over lining	0.5189	0.01	0.5094	0.5348
stamping on lining and leather	0.3792	0.00	0.3706	0.3872

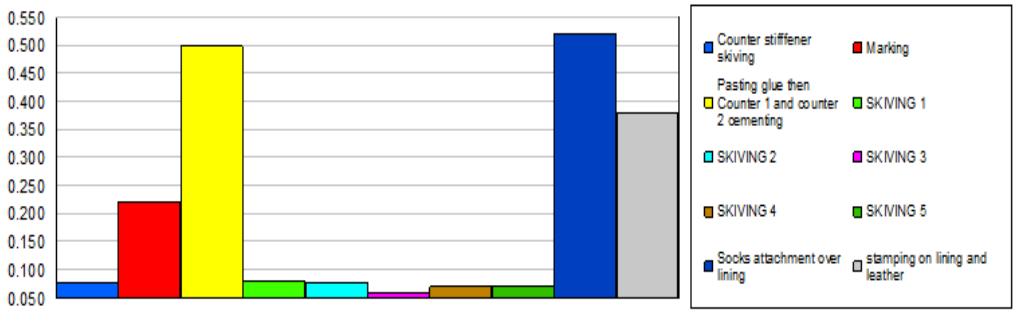


Table 5.21 c) Preparation section modified simulation model *accumulated wait time* result

Accum Wait Time	Average	Half Width	Minimum Average	Maximum Average
SKIVING 1	0.2299	0.02	0.1715	0.2574
SKIVING 2	0.1570	0.02	0.1067	0.1837
SKIVING 3	0.05418744	0.01	0.03373283	0.07418005
SKIVING 4	0.07675236	0.01	0.04861660	0.1031
SKIVING 5	0.1026	0.02	0.05732885	0.1645
Socks attachment over lining	0.2099	0.03	0.1166	0.2403
stamping on lining and leather	0.00	0.00	0.00	0.00

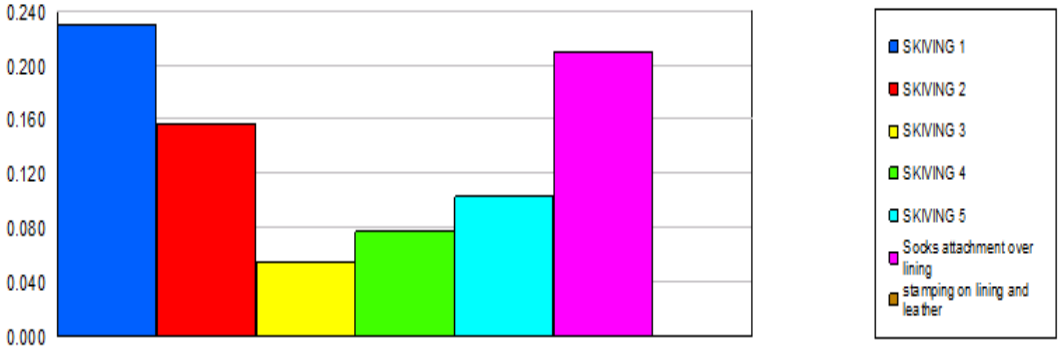


Table 5.21 d) Preparation section modified simulation model *number in per process* result

Number In	Average	Half Width	Minimum Average	Maximum Average
Counter stifffener skiving	82.7000	0.35	82.0000	83.0000
Marking	84.0000	0.00	84.0000	84.0000
Pasting glue then Counter 1 and counter 2 cementing	82.7000	0.35	82.0000	83.0000
SKIVING 1	84.0000	0.00	84.0000	84.0000
SKIVING 2	83.3000	0.35	83.0000	84.0000
SKIVING 3	82.9000	0.41	82.0000	84.0000
SKIVING 4	82.8000	0.30	82.0000	83.0000
SKIVING 5	82.7000	0.35	82.0000	83.0000
Socks attachment over lining	82.2000	0.45	81.0000	83.0000
stamping on lining and leather	84.0000	0.00	84.0000	84.0000

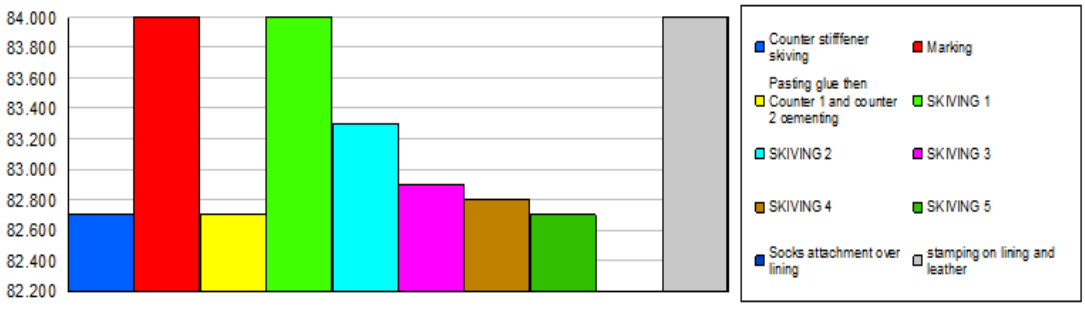


Table 5.21 e) Preparation section modified simulation model *number out per process* result

Number Out	Average	Half Width	Minimum Average	Maximum Average
Counter stifffener skiving	82.7000	0.35	82.0000	83.0000
Marking	84.0000	0.00	84.0000	84.0000
Pasting glue then Counter 1 and counter 2 cementing	82.2000	0.45	81.0000	83.0000
SKIVING 1	83.3000	0.35	83.0000	84.0000
SKIVING 2	82.9000	0.41	82.0000	84.0000
SKIVING 3	82.8000	0.30	82.0000	83.0000
SKIVING 4	82.7000	0.35	82.0000	83.0000
SKIVING 5	82.7000	0.35	82.0000	83.0000
Socks attachment over lining	81.2000	0.45	80.0000	82.0000
stamping on lining and leather	84.0000	0.00	84.0000	84.0000

Table 5.21 f) Preparation section modified simulation model *waiting time in queue* result

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
SKIVING 1.Queue	0.00275838	0.00	0.00204190	0.00306454	0.00	0.01907426
SKIVING 2.Queue	0.00189263	0.00	0.00128544	0.00224004	0.00	0.01646421
SKIVING 3.Queue	0.00065359	0.00	0.00040642	0.00089374	0.00	0.01212593
SKIVING 4.Queue	0.00092749	0.00	0.00058574	0.00124210	0.00	0.01435680
SKIVING 5.Queue	0.00123983	0.00	0.00069913	0.00198202	0.00	0.01591997
Socks attachment over lining.Queue	0.00257802	0.00	0.00142247	0.00298748	0.00	0.01177332
stamping on lining and leather.Queue	0.00	0.00	0.00	0.00	0.00	0.00

Table 5.21 g) Lasting and stitching section modified simulation model *number waiting in queue* result

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
SKIVING 1.Queue	0.2306	0.02	0.1715	0.2574	0.00	2.0000
SKIVING 2.Queue	0.1583	0.02	0.1070	0.1896	0.00	1.0000
SKIVING 3.Queue	0.05418744	0.01	0.03373283	0.07418005	0.00	1.0000
SKIVING 4.Queue	0.07675236	0.01	0.04861660	0.1031	0.00	1.0000
SKIVING 5.Queue	0.1026	0.02	0.05732885	0.1645	0.00	2.0000
Socks attachment over lining.Queue	0.2118	0.03	0.1166	0.2450	0.00	2.0000
stamping on lining and leather.Queue	0.00	0.00	0.00	0.00	0.00	0.00

5.2.4. Comparison and analysis of current and proposed simulation section wise result

According to controlling parameter simulation result of all section (stitching, lasting/finishing and preparation) is summarized on appendix –D and total sum of processes result is re-summarized in table 5.22 and will be explained section wise below.

Table 5.22 Comparison of current and modified simulation result

Key performance indicator	sections					
	stitching		lasting and finishing		preparation	
	current	modified	current	modified	current	modified
total time per entity	0.2187	0.207	0.06491	0.0334	0.1015	0.0348
accumulated time						
2.1. VAT	2.308	2.2853	0.8549	0.8287	2.3563	2.047
2.2. NVAT	0	0	0	0	0	0
2.3 waiting time	0.5622	0.5222	0.7284	0.1001	1.99	0.8302
2.4. others	0.0216	0	0.3796	0.2778	0	0
Average number in per each process(in pair/hour)	13	13.5	31	36.1	95.03	83.13
Average number out per each process(in pair/hour)	12.18	12.69	31	36.1	93.5	82.8
waiting time in queue	0.0546	0.0507	0.0228	0.0027	0.0761	0.01
number waiting in queue	4.19	4.0154	0.737	0.1018	1.7299	0.8342

a) **Stitching section:**

As it is mentioned in chapter 4 of this paper, currently 1600 pairs/day production capacity is maintained with 4 lines and the average capacity utilization of the section is around 73% which is most likely capacity to produce specific model per line ranges from 250 to 300 pairs of shoe. However, the average current production based on the **current simulation result of stitching section is 256 pairs of shoe per day** which is in the range mentioned in the existing scenario of the factory above.

Up on completion of observation and identification of value adding and non-value adding activities using lean waste minimizing approach (see section 2.2) followed by simulation of the modified process using Arena software, the section production capacity is raised to 288 pairs of shoe per day(5.88% WIP reduction). The identified wastes through the implementation of VSM in this section were mainly of two. The first one is single hammering machine usage for two independent lines and excess man power usage for an activity demanding less skill and processing time is the second. The most likely processing time to hammer one pair of shoe using

hammering machine is 60 seconds and the most likely processing time to hammer manually is 31 seconds which is observed from another line. See table 5.23 hammering process observed time in second.

Table 5.23 Manual hammering process observed time in second.

Stations	Operation name	Expression
Other line	Manual hammering	TRI(30,31,36) (max, most likely, min)

Changing the hammering operation from machine to manual and merging two independent but easy operations that demand less skilled operator i.e. Inserting collar foam and manual hammering have brought change of time reduction from 84 second to 55 Second including transportation time loss from line to line according to the modified simulation result.. In other words total processing time for both hammering and inserting collar foam will be reduced by 32.5%. Secondly, merging trimming and tread burning processes will bring reduction in an average processing time as well as number of worker assigned for that station by one. This process can be made by single worker as it is easy with low skill level even. Merging the process in to one have minimized the number of workers from 2 to 1. The average salary that a worker paid is about 850 ETB, which implies that the factory will save 850 ETB per day (10200 ETB per year).

b) **Lasting and finishing section:**

According to lasting literature of chapter four, using 85% of machineries available in this section an average of 512 pairs of shoe are being produced on each two identical lines that leads to the total section capacity to be around 1024 pairs per day. The current production output is 248 pair per day which demands a step by step improvement without stopping searching for alternative improvement methods keeping the past improvements. Relative to the existing production output, the modified one results 256 pair par day which has an increment of 8 pairs per day or 3.125% positive change relative to the existing production. The improvement in this section is mainly because of production quantity level increment in stitching section.

c) Preparation section

In preparation section the improvement area focuses on Pasting glue operation and Counter 1 and counter 2 cementing operation. Both operation demands less skill and the process by itself performed one after the other. i.e pasting glue is performed first and till it dries one can have a time to look other task. This is an opportunity to the section improvement regarding time minimization as well as direct cost related to labour. This minimizes the current total time per

pair by 41.1 %. The average salary that a worker paid is 850 ETB, which will be saved per each month because of reduction of one of the two workers during improvement.

Keeping reducing the processing time of the entity/part in this section, the improvement also focus on minimizing the production size to balance with the production output of stitching increment. This will easily be limited by knowing the intake capacity of stitching section i.e. 544 pair per day. In the current manufacturing process simulation of preparation section 688 pair per day was the output production where 144 pairs are WIP for the next turn of production. In the modified manufacturing process, 100 pairs are kept as buffer and 40 pairs are not produced. There for the total pair produced in current system is reduced to 648 per day in the modified.

The above section wise comparison and analysis will be summarized with table and graph as follows. Table 5.24 and figure 5.20 Illustrates that waiting numbers as well as waiting time in queue of stitching section is higher than others which indirectly shows that it is a bottleneck area of the factory.

Table 5.24 Waiting time and number waiting in queue summary.

Key performance indicator	preparation		Stitching		lasting and finishing	
	current	modified	current	modified	current	Modified
Total waiting time in queue(in minute)	36.528	4.8	104.832	97.344	10.944	1.296
Total number waiting in queue(in minute)	13.8392	6.6736	134.08	128.4928	5.896	0.8144

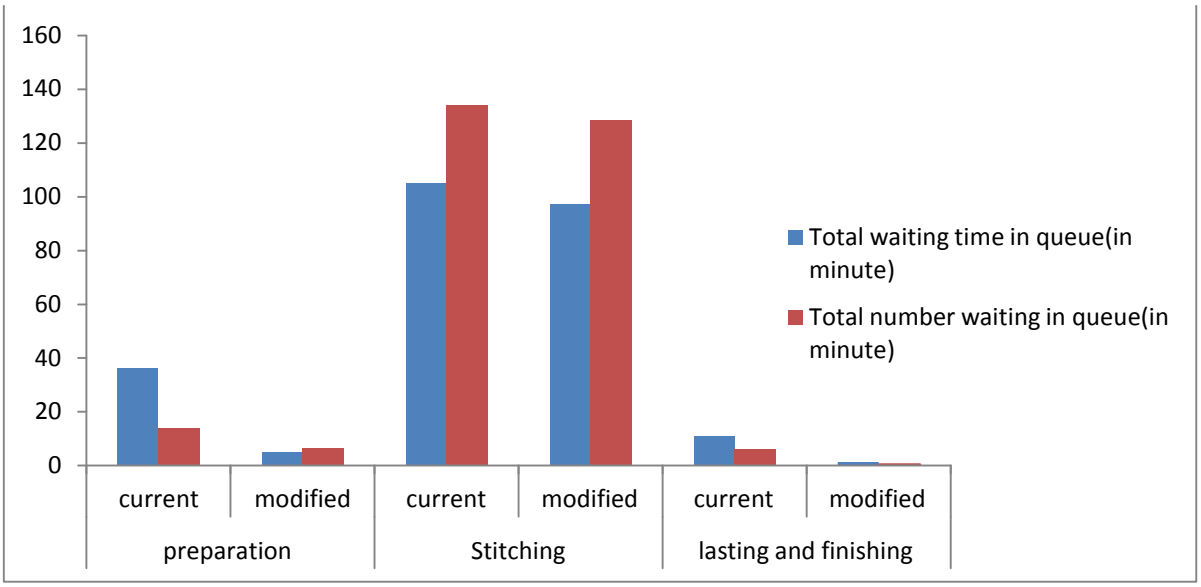


Figure 5.20 Total waiting time and number waiting in queue summary graph.

The average in and out pairs in station shows stations capacity level to take and out rather than giving exact production output result. This is because, it is an average number of in and out from each process in each section. See table 5.25 and related graph on figure 5.21 . The figure implicates that increasing the production capacity of stitching i.e. bottleneck area through lean implementation(waste minimization) make the production process smooth from section to section. Till the continuous improvement reachs the stitching production level up to the preparation production capacity (also cutting production capacity level), the WIP currently shown in preparation section will be decreased while the production output of lasting and finishing section increases.

Table 5.25 Average number in and number out per stations (in pair)

Key performance indicator	preparation		stitching		lasting and finishing	
	current	modified	Current	modified	current	modified
Average number in per station(in pair)	760.24	665.04	416	432	248	288.8
Average number out per stations (in pair)	748	662.4	389.76	406.08	248	288.8

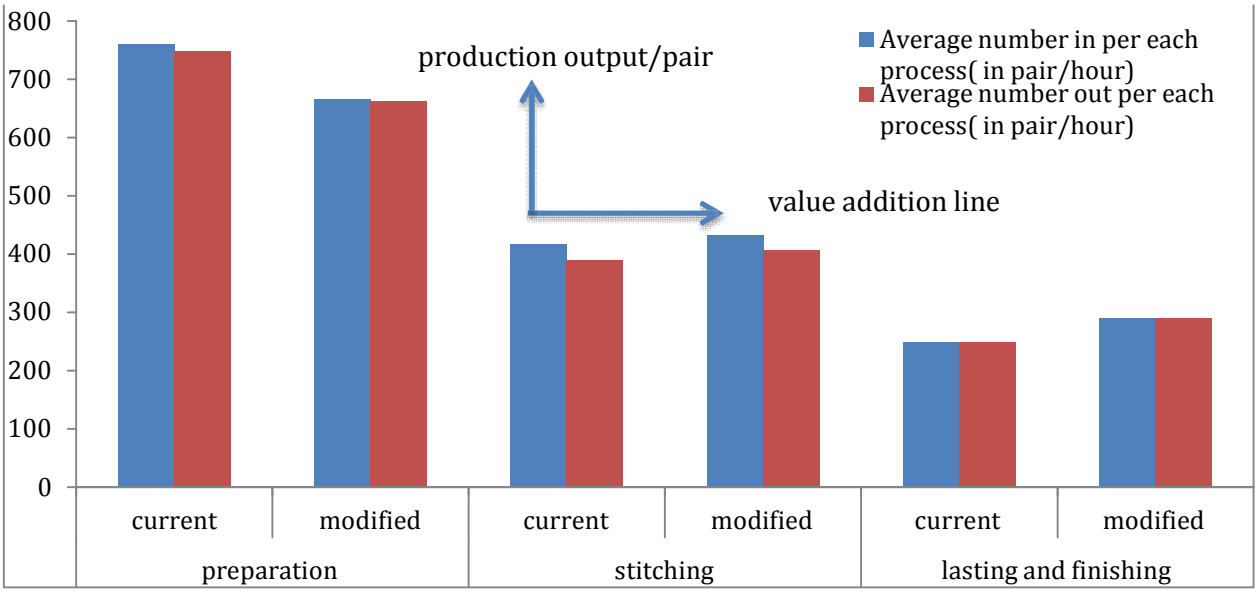


Figure 5.21 Average number in and number out per stations (in pair) graph

The total throughput time that an entity spends on each section line is shown in table 5.26 Figure 5.22 shows that an entity spends more time in stitching section than other.

Table 5.26 Total time (summation of VA, NNVA and waiting time) per entity

Key performance indicator	**preparation**		**stitching**		**lasting and finishing**	
	current	**modified**	**current**	**modified**	**Current**	**modified**
total time per entity(in minute)	48.72	16.704	419.904	397.44	31.1568	16.032

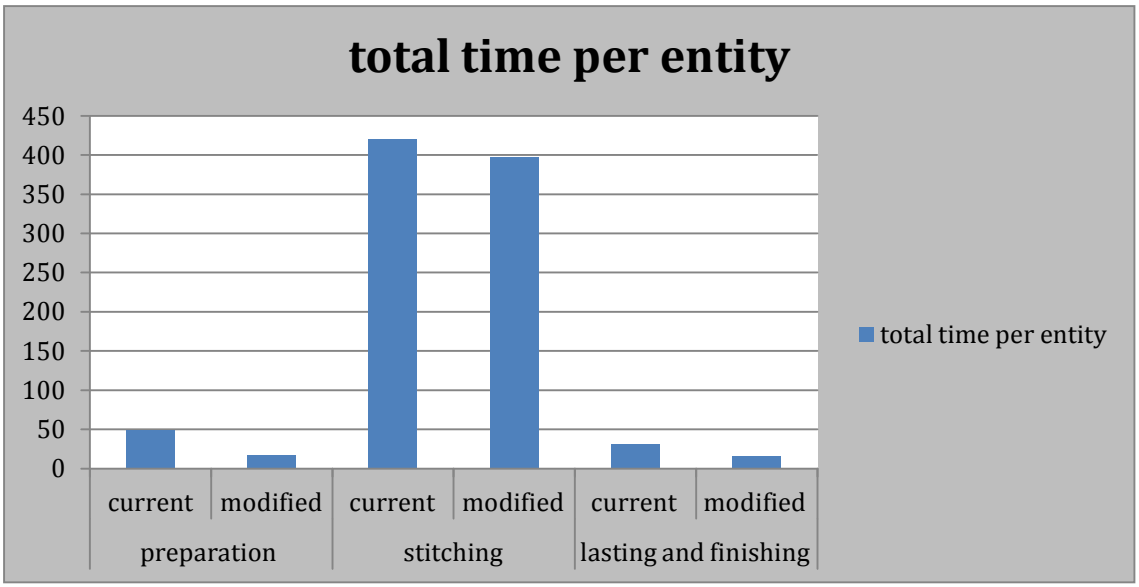


Figure 5.22 Total time (summation of VA, NNVA and waiting time) per entity graph

5.3. Implementation mechanism of proposed production system

Implementation mechanisms for the proposed manufacturing system are:

- use hammering machine only for the Classic 1(C1) model or use manual hammering on stitching line.
- merging easy and less skill demanding tasks together.
- produce products based on the intake level of next section.
- reduce WIP count in preparation section till stitching section reaches its existing production level.

♦ ♦ ♦

Chapter 6: Conclusion, recommendation and future work

6.1. Conclusion

- Generally, the current manufacturing systems in kangaroo shoe company demands an improvement regarding WIP and waste minimization issue. The WIP count in cutting department is 216 per day. Which is too big compared to preparation intake capacity. Similarly, the WIP count in preparation capacity is unbalanced with the next section called clothing/stitching.

  This all have caused unbalanced WIP count (beyond level) between sections which is categorised as waste since it not processed based on order plan.
- The input level of each section also not balanced. The intake capacity of current stitching is less by 144 pair of the preparation output. Through the proposed modified model, it is deduced by 27.78 %.
- Upper transportation from **inserting collar foam** to **hammering machine as well as waiting for other model to be hammered as it is on other line with in stitching section** lower the total processing time of stitching by 32.5% number compared to using manual hammering.
- Merging two easy and less skill demanding processes in preparation section i.e., **pasting glue operation** with **Counter 1 and counter 2 cementing operation,** saves the total operation time by 41.1% per day.
- From the study it is concluded that Stitching section is a bottleneck that uses much time compared to other neighbouring sections. Its intake as well as output capacity is less.
- Both VSM (value stream mapping) and Arena simulation software have simplified the data analysing mechanism through their easy data manipulating capacity and their ability to support and visualize further improvement areas
- The number out result of current vs. modified final output of lasting and finishing section is 248 and 288.8 pair per day which is 40 pair increment per day. This shows that there is an improvement made on stitching section which is the identified bottleneck as the number in and out result of lasting section is almost same.
- About 20400 ETB per year is saved through implementation of the study as the result of reduced man power and 968,000 ETB is the estimated gain as a result of increased production by 8pairs of shoe/day with an average selling price of 550ETB (calculated by taking 220 factory working days /year)

6.2. Recommendation

- The company should implement waste minimization tool (Lean) and measure improvement continuously to enhance availability of better alternative manufacturing process that leads to increased competitiveness and profitability,
- From the study, it is recommended to use process measuring tools like Arena and VSM in order to visualize and search for further improvement easily.
- Primarily, the factory should focus to reach the stitching section installed production capacity rather than continuously producing stitching inputs (from cutting and preparation section) without balancing the intake capacity with production output capacity.
- Till the continuous improvement reaches the stitching production level up to the preparation production capacity (also cutting production capacity level), the WIP currently (increasing its production count) while the production yield of lasting and finishing section increases.
- Stitching section model C1 line must use manual hammering and or hammering machine for itself in order to minimize the processing time.
- The factory should measure each process tasks operating methods and merge to one to save cost related issues (time and salary).

6.3. Future work

As lean follows continuous improvement, the factory needs further improvement step by step. Mainly there are three categories in improving the factory production system.

1. High cutting section production capacity and high WIP> stitching current production(low) lasting and finishing product output.
2. Cutting section WIP decreasing > increasing stitching production increasing lasting and finishing product output
3. Cutting section daily production = stitching section daily production lasting and finishing product output

The first is the current state of production in the company and this paper is positioned on the second level. Even though it needs more improvement steps to reach on the third improvement level, the journey lie on the future work.

♦ ♦ ♦

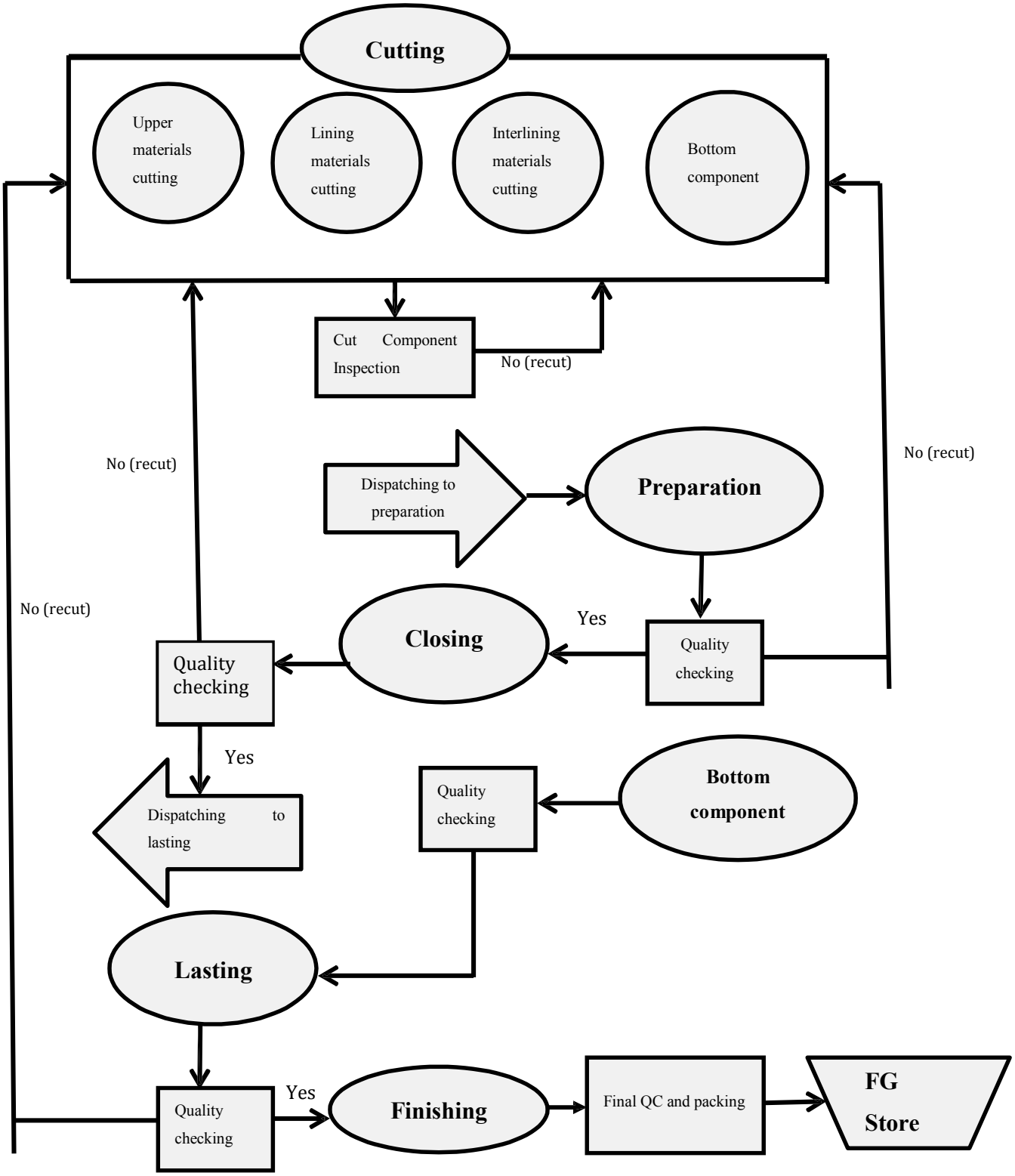
Reference

1. Altiok, T.&Melamed, B., Simulation Modeling and Analysis with Arena. California (USA): Elsevier, 2007.
2. Denish B. Modi, HemantThakkar, ‐Lean thinking: reduction of waste, lead time, cost through lean manufacturing tools and technique‖ Gujarat, India, 2014.
3. Vorne /www.vorne.com/, ITASCA, IL,USA
4. Lonnie wilson, ‐How to implement lean manufacturing, New York, US, 2010.
5. Ohno, T.,Toyota Production System Beyond Large-Scale Production, Productivity Press, Portland, OR. 1973.
6. MarekPiatkowski - F.S.P. Consulting Inc. ‐Basic concepts of Lean Manufacturing‖ e-Mail: Marek.Piatkowski@rogers.com, Toronto, Canada.
7. Detty, R. B.&Yingling, J. C. (2000). Quantifying benefits of conversion to lean manufacturing with discrete event simulation: a case study. International Journal of Production Research,VOL. 38, NO. 2, 429-445, U.S.A
8. Schroer, B. J. (2004). Simulation as a Tool in Understanding the Concepts of Lean
9. Manufacturing. SIMULATION
10. Jon H. Marvel & Charles R. Standridge(2009), A simulation-enhanced lean design process, U.S.A
11. Petri Kärki, ‐The Impact of Customer Order Lead Time-Based Decisions on the Firm‘sAbility to Make Money – Case Study: Build to Order Manufacturing of ElectricalEquipment and Appliances‖, Finland, 2012.
12. Phillip J., Lederer, and Seung-kyu Rhee, (1996), ‐performance measurement in a cost center considering production lead time ,‖simon school working paper, Korea.
13. Khalid A. Aldakhilallah, ‐The Determination of the Average WIP Inventory and Buffer
14. Size for a Two-stage Manufacturing System‖Saudi Arabia,2002
15. T- table, http://www.sjsu.edu/faculty/gerstman/StatPrimer/t-table.pdf

APPENDICIES

APPENDIX- A

Footwear production process



APPENDIX- B

Pair cut per clicker calculation examples.

Example - 1

Each 10 types components contribute 1/10th component of one single shoe. Sumation of each row under each column provide the total cut for each component types cut by the clicker	Component 1	Component 2	Component 3	component 4	component 5	Component 6	Component 7	component 8	component 9	Component 10	
	21	**1**	**26**	**11**	**12**	**6**	**0**	**12**	**11**	**2**	**total number**
	1	1	1	1	1	1	0	1	1	1	0.9
	1	0	1	1	1	1	0	1	1	1	0.8
	1	0	1	1	1	1	0	1	1	0	0.7
	1	0	1	1	1	1	0	1	1	0	0.7
	1	0	1	1	1	1	0	1	1	0	0.7
	1	0	1	1	1	1	0	1	1	0	0.7
	1	0	1	1	1	0	0	1	1	0	0.6
	1	0	1	1	1	0	0	1	1	0	0.6
	1	0	1	1	1	0	0	1	1	0	0.6
	1	0	1	1	1	0	0	1	1	0	0.6
	1	0	1	1	1	0	0	1	1	0	0.6
	1	0	1	0	1	0	0	1	0	0	0.4
	1	0	1	0	0	0	0	0	0	0	0.2
	1	0	1	0	0	0	0	0	0	0	0.2
	1	0	1	0	0	0	0	0	0	0	0.2
	1	0	1	0	0	0	0	0	0	0	0.2
	1	0	1	0	0	0	0	0	0	0	0.2
	1	0	1	0	0	0	0	0	0	0	0.2
	1	0	1	0	0	0	0	0	0	0	0.2
	1	0	1	0	0	0	0	0	0	0	0.2
	1	0	1	0	0	0	0	0	0	0	0.2
	0	0	1	0	0	0	0	0	0	0	0.1
	0	0	1	0	0	0	0	0	0	0	0.1
	0	0	1	0	0	0	0	0	0	0	0.1
	0	0	1	0	0	0	0	0	0	0	0.1
	0	0	1	0	0	0	0	0	0	0	0.1

total half pair of copmonents	10.2
total pair of components	5.1

Note: the highlighted column indicates the un-cut component necessary to make single shoe (half pair).

Example - 2

Total cut/ 10 independent components	10 different types of components that are needed to be cut for single shoe										total number of types of cut components/ 10 components
	component 1	component 2	component 3	component 4	component 5	component 6	component 7	component 8	component 9	component 10	
	18	2	15	9	12	2	0	3	11	1	
Each 10 types components contribute 1/10th component of one single shoe. Sumattion of each row under each column provide the total cut for each component types cut by the clicker	1	1	1	1	1	1	0	1	1	1	0.9
	1	1	1	1	1	1	0	1	1	0	0.8
	1	0	1	1	1	0	0	1	1	0	0.6
	1	0	1	1	1	0	0	0	1	0	0.5
	1	0	1	1	1	0	0	0	1	0	0.5
	1	0	1	1	1	0	0	0	1	0	0.5
	1	0	1	1	1	0	0	0	1	0	0.5
	1	0	1	1	1	0	0	0	1	0	0.5
	1	0	1	0	1	0	0	0	1	0	0.4
	1	0	1	0	1	0	0	0	1	0	0.4
	1	0	1	0	1	0	0	0	0	0	0.3
	1	0	1	0	0	0	0	0	0	0	0.2
	1	0	1	0	0	0	0	0	0	0	0.2
	1	0	1	0	0	0	0	0	0	0	0.2
	1	0	0	0	0	0	0	0	0	0	0.1
	1	0	0	0	0	0	0	0	0	0	0.1
	1	0	0	0	0	0	0	0	0	0	0.1
									total half pair of copmonents		7.3
Note: the highlighted column indicates the un-cut component necessary to make single shoe (half pair).									total pair of components		3.65

Example - 3

	10 different types of components that are need to be cut for single shoe										total number of types of cut component s/ 10 component s
	component 1	component 2	component 3	component 4	component 5	component 6	component 7	component 8	component 9	component 10	
Total cut/ 10 independent components	**12**	**0**	**7**	**5**	**3**	**0**	**5**	**5**	**3**	**7**	
Each 10 types components contribute 1/10th component of one single shoe. Sumattion of each row under each column provide the total cut for each component types cut by the clicker	1	0	1	1	1	0	1	1	1	1	0.8
	1	0	1	1	1	0	1	1	1	1	0.8
	1	0	1	1	1	0	1	1	1	1	0.8
	1	0	1	1	0	0	1	1	0	1	0.6
	1	0	1	1	0	0	1	1	0	1	0.6
	1	0	1	0	0	0	0	0	0	1	0.3
	1	0	1	0	0	0	0	0	0	1	0.3
	1	0	0	0	0	0	0	0	0	0	0.1
	1	0	0	0	0	0	0	0	0	0	0.1
	1	0	0	0	0	0	0	0	0	0	0.1
	1	0	0	0	0	0	0	0	0	0	0.1
	1	0	0	0	0	0	0	0	0	0	0.1
									total half pair of components		4.7
Note: the highlighted column indicates the un-cut component necessary to make single shoe (half pair).									total pair of components		2.35

APPENDIX- C

Section wise **observed** and **improved** processing time data In terms of expression used in constructing current and modified simulation process. (Set using Arena simulation software input analyser)

1) Observed processing time data expression used for **current simulation process**

a) Preparation section

Stations	Operation name	Expression
S1	Stamping on lining and leather	13 + WEIB(3.59, 1.47)
S2	Marking	5.27 + 6.73 * BETA(1.52, 0.939)
S3	Skiving	2 + 2.42 * BETA(1.58, 1.1)
S4		2.02 + 1.98 * BETA(0.782, 0.418)
S5		TRIA(1.64, 2.47, 3.56)
S6		TRIA(2, 2.69, 4.3)
S7		2 + LOGN(1.13, 0.978)
S8		2.09 + WEIB(1.39, 2.16)
S9	Pasting glue	TRIA(4.52, 4.79, 5.67)
S10	Counter 1 and counter 2 cementing	14 + 8.96 * BETA(2.13, 1.57)
S11	Socks attachment over lining	17 + 11 * BETA(1.15, 0.931)

b) Stitching section

Stations	Operation name	Expression
S1	Quarter lining and bottom strap stitching	TRI(53,57,66)
S2	Apron Tongue Lining and counter1 and counter2	TRI(55,58,63)
S3	Collar and quarter1 attaching	TRI(38,46,53)
S4	Quarter2 and quarter3 stitching	TRI(45,50,60)
S5	Upper strap and quarter1 with quarter2 stitching	TRI(52,58,65)
S6	Collar quarter1 and counter1 with2 stitching	TRI(52,59,65)
S7	Quarter1 and quarter 23 stitching	TRI(12,15,22)
S8	Bottom strap attaching	TRI(21,25,33)
S9	Quarter lining stitching	TRI(26,30,35)
S10	Applying glue on stiffener and attaching on counter 1	TRI(11,15,18)
S11	Apply Glue over quarter lining	TRI(14,17,21)
S12	Inserting collar foam	TRI(20,24,27)
S13	Hammering	TRI(59,60,65)
S14	Lining and collar area stitching	TRI(48,55,63)
S15	Trimming	TRI(10,12,14)
S16	Thread burning and cutting	TRI(5,9,12)
S17	Eyeleting	TRI(19,20,21)
S18	Molding	TRI(9,12,14)
S19	Quality inspection	TRI(11,14,17)

c) Lasting and finishing section

Stations	Operation name	Expression
S1	Last selection	TRIA(5, 6, 8)
S2	Last insertion and lasting	TRIA(6, 7, 8)
S3	Temporary shoe lace insertion	TRIA(4, 6, 8)
S4	Heating	TRIA(9, 11, 13)
S5	Hammering	TRIA(9, 10, 12)
S6	Wrinkle chasing	TRIA(6, 7, 9)
S7	Thread burning	TRIA(4, 5 6)
S8	Cooling	TRIA(6, 8,10)
S9	Creaming	TRIA(9, 11, 13)
S10	Burning	TRIA(10, 13, 15)
S11	Delasting	TRIA(9, 10, 11)
S12	Shoe lacing Final	TRIA(6, 9, 11)
S13	Socks insertion	TRIA(9, 10, 11)
S14	Inserting tissue paper	TRIA(7, 9, 12)
S15	Quality inspection	TRIA(16, 18, 21)

2) Improved processing time data expression used for modified simulation process (The highlighted part indicates the area of improvement)

a) Preparation section

Stations	Operation name	Expression
S1	stamping on lining and leather	13 + WEIB(3.59, 1.47)
S2	Marking	5.27 + 6.73 * BETA(1.52, 0.939)
S3	Skiving	2 + 2.42 * BETA(1.58, 1.1)
S4		2.02 + 1.98 * BETA(0.782, 0.418)
S5		TRIA(1.64, 2.47, 3.56)
S6		TRIA(2, 2.69, 4.3)
S7		2 + LOGN(1.13, 0.978)
S8		2.09 + WEIB(1.39, 2.16)
S9	Pasting glue and Counter 1 and counter 2 cementing	NORM(21.8, 2.15)
S10	Socks attachment over lining	17 + 11 * BETA(1.15, 0.931)

b) Stitching section

Stations	Operation name	Expression
S1	Quarter lining and bottom strap stitching	TRI(53,57,66)
S2	Apron Tongue Lining and counter1 and counter2	TRI(55,58,63)
S3	Collar and quarter1 attaching	TRI(38,46,53)
S4	Quarter2 and quarter3 stitching	TRI(45,50,60)
S5	Upper strap and quarter1 with quarter2 stitching	TRI(52,58,65)
S6	Collar quarter1 and counter1 with2 stitching	TRI(52,59,65)
S7	Quarter1 and quarter 23 stitching	TRI(12,15,22)
S8	Bottom strap attaching	TRI(21,25,33)
S9	Quarter lining stitching	TRI(26,30,35)
S10	Applying glue on stiffener and attaching on counter 1	TRI(11,15,18)
S11	Apply Glue over quarter lining	TRI(14,17,21)
S12	Inserting collar foam and hammering	TRI(50,55,63)
S13	Lining and collar area stitching	TRI(48,55,63)
S14	Trimming ,Thread burning and cutting	TRI(15,21,26)
S15	Eyeleting	TRI(19,20,21)
S16	Molding	TRI(9,12,14)
S17	Quality Inspection	TRI(11,14,17)

c) Lasting and finishing section

Stations	Operation name	Expression
S1	Last selection	TRIA(5, 6, 7)
S2	Last insertion and lasting	TRIA(6, 7, 8)
S3	Temporary shoe lace insertion	TRIA(4, 6, 8)
S4	Heating	TRIA(5, 7, 9)
S5	Hammering	TRIA(7, 8, 10)
S6	Wrinckel chassing	TRIA(6, 7, 8)
S7	Thread burning	TRIA(4, 5 6)
S8	Cooling	TRIA(6, 8,10)
S9	Creaming	TRIA(6, 7, 9)
S10	Burning	TRIA(9, 10, 11)
S11	Delasting	TRIA(6, 8, 10)
S12	Shoe lacing Final	TRIA(6, 9, 11)
S13	Sockes insertion	TRIA(6, 8, 11)
S14	Inserting tissue paper	TRIA(3, 5, 8)
S15	Quality inspection	TRIA(7, 8, 10)

APPENDIX- D

Current and modified simulation result comparison based on controlling parameter and Key performance indicators in terms of processes

Controlling parameter	Key performance indicator	stitching section(19 stations)				lasting and finishing section(6 stations)				preparation section(19 stations)			
		Simulated for 15 minutes		Simulated for 15 minutes		Simulated for 3600 sec		Simulated for 3600 sec		Simulated for 3600 sec		Simulated for 3600 sec	
		operations in current system	*Current system average*	*operations in modified system*	*Modified system average*	*operations in current system*	*Current system average*	*operations in modified system*	*Modified system average*	*operations in current system*	*Current system average*	*operations in modified system*	*Modified system average*
Process	Total Time Per Entity	Applying glue on stiffener and attaching on	0.00406517	Applying glue on stiffener and attaching on	0.00408260	Brushing	0.00526113	Brushing	0.0028	Counter stifffener skiving	0.000924101	Counter stifffener skiving	0.00091658
		Applying glue over	0.00480182	Applying glue	0.00481105	Cooling	0.00330181	Cooling	0.0022	Marking	0.002628363	Marking	0.00262917
		Apron Tongue Lining and	0.02741274	Apron Tongue Lining and	0.02706398	Creaming	0.00524897	Creaming	0.0020	Pasting glue	0.00253513	Pasting glue then Counter 1 and counter 2 cementing	0.00605384
		Bottom strap attaching	0.00736408	Bottom strap attaching	0.00740109	Delasting	0.00472779	Delasting	0.0022	Counter 1 and	0.007742831		
		Collar and quarter1	0.01267854	Collar and	0.01272435	Hammering	0.00457971	Hammering	0.0024	SKIVING 1	0.004129025	SKIVING 1	0.00370955
		Collar quarter1 and	0.01969712	Collar quarter1	0.01964997	Heating	0.00523869	Heating	0.0019	SKIVING 2	0.033643335	SKIVING 2	0.00281611
		Eyeleting	0.00592846	Eyeleting	0.00592309	Inserting Tissue Paper	0.00258931	Inserting Tissue Paper	0.0015	SKIVING 3	0.002192609	SKIVING 3	0.00136921
		Hammering	0.02151111	inserting collar foam and Manual Hammering	0.01628184	last insertion and lasting	0.00443236	last insertion and lasting	0.0024	SKIVING 4	0.003633757	SKIVING 4	0.00175633
		inserting collar foam	0.00658121			last selection	0.00385827	last selection	0.0017	SKIVING 5	0.033191477	SKIVING 5	0.00210522
		Lining and collar area stitching	0.01529162	Lining and collar area stitching	0.01565075	Quality inspection	0.00679893	Quality inspection	0.0032	Socks attachment over lining	0.006389814	Socks attachment over lining	0.00897678
		Moulding	0.00323293	Moulding	0.00323687	Shoe lacing final	0.00240882	Shoe lacing final	0.0024	stamping on lining and leather	0.004512238	stamping on lining and leather	0.00451437
		Quality Check	0.00387904	Quality Check	0.00389683	Sockes Insertion	0.00277866	Sockes Insertion	0.0023				
		Quarter lining and bottom strap stitching	0.02708112	Quarter lining and bottom strap stitching	0.02725399	Temporary shoe lace insertion	0.00391686	Temporary shoe lace insertion	0.0030				
		Quarter lining stitching	0.00840010	Quarter lining stitching	0.00841253	Thread burning	0.00298708	Thread burning	0.0014				
		Quarter1 and quarter 23 stitching	0.00452641	Quarter1 and quarter 23	0.00453933	Wrinckel chassing	0.00381175	Wrinckel chassing	0.0019				
		Quarter2 and quarter3 stitching	0.01483195	Quarter2 and quarter3	0.01471213								
		Thread burning and cutting	0.00240365	Trimming and Thread burning and cutting	0.00572168								
		Trimming	0.00334835										
		Upper strap and quarter1 with quarter2 stitching	0.02573944	Upper strap and quarter1 with quarter2 stitching	0.02565718								

Noie:- All time values in this table is in hour and (*) sign indicates that the value to the corresponding process is zero

Controlling parameter		Key performance indicator	stitching section(19 stations)				lasting and finishing section(6 stations)				preparation section(19 stations)			
			Simulated for 15 minutes		Simulated for 15 minutes		Simulated for 3600 sec		Simulated for 3600 sec		Simulated for 3600 sec		Simulated for 3600 sec	
			operations in current system	*current system average values/Hr*	*operations in modified system*	*Modified system average values/Hr*	*operations in current system*	*current system average values/Hr*	*operations in modified system*	*Modified system average values/Hr*	*operations in current system*	*current system average values/Hr*	*operations in modified system*	*Modified system average values/Hr*
Process	Accumulated Time	VA time	Applying glue on stiffener and attaching on counter 1	0.05157333	Applying glue on stiffener and attaching on counter 1	0.05203673	Brushing	0.1093	Brushing	0.1000	Counter stifffener skiving	0.08112195	Counter stifffener skiving	0.07580
			Applying glue over	0.05884484	Applying glue	0.05877742	Cooling	0.07094642	Cooling	0.0801	Marking	0.2707	Marking	0.22085
			Apron Tongue Lining and	0.2447	Apron Tongue Lining and	0.2440	Creaming	0.0956	Creaming	0.0731	Pasting glue	0.1212	Pasting glue then Counter 1 and counter 2 cementing	0.49761
			Bottom strap attaching	0.0987	Bottom strap attaching	0.0992	Hammering	0.0919	Hammering	0.0832	Counter 1 and counter 2 cementing	0.4618		
			Collar and	0.2155	Collar and	0.2163	Heating	0.0980	Heating	0.0698	SKIVING 1	0.0973	SKIVING 6	0.07907
			Collar quarter1 and counter1 with2 stitching	0.2273	Collar quarter1 and counter1 with2 stitching	0.2273	last insertion and lasting	0.06423113	last insertion and lasting	0.0720	SKIVING 2	0.08649149	SKIVING 7	0.07642
			Eyeleting	0.05335613	Eyeleting	0.05811604	Shoe lacing final	0.07467357	Shoe lacing final	0.0867	SKIVING 3	0.06726321	SKIVING 8	0.05917
			Hammering	0.1716	inserting collar foam and Manual Hammering	0.1738	Sockes Insertion	0.08613853	Sockes Insertion	0.0831	SKIVING 4	0.07865141	SKIVING 9	0.06848
			inserting collar foam	0.07897449			Temporary shoe lace insertion	0.05469227	Temporary shoe lace insertion	0.0606	SKIVING 5	0.07647953	SKIVING 10	0.07157
			Lining and collar area stitching	0.1419	Lining and collar area stitching	0.1571	Thread burning	0.04439176	Thread burning	0.0500	Socks attachment over lining	0.5506	Socks attachment over lining	0.51887
			Moulding	0.02849078	Moulding	0.03053799	Wrinckel chassing	0.06502417	Wrinckel chassing	0.0699	stamping on lining and leather	0.4648	stamping on lining and leather	0.37921
			Quality Check	0.03162699	Quality Check	0.03532300								
			Quarter lining and bottom strap	0.2435	Quarter lining and bottom	0.2437								
			Quarter lining stitching	0.1092	Quarter lining stitching	0.1094								
			Quarter1 and quarter 23	0.06081653	Quarter1 and quarter 23	0.06056926								
			Quarter2 and quarter3 stitching	0.2350	Quarter2 and quarter3	0.2351								
			Thread burning and cutting	0	Trimming and Thread burning and cutting	0.05721681								
			Trimming	0.03023740										
			Upper strap and quarter1 with quarter2 stitching	0.2270	Upper strap and quarter1 with quarter2	0.2270								
		NVA time	*	*	*	*	*	*	*	*	*	*	*	*

Note:- All time values in this table is in hour and (*) sign indicates that the value to the corresponding process is zero

Controlling parameter		Key performance indicator	stitching section(19 stations)				lasting and finishing section(6 stations)				preparation section(19 stations)			
			Simulated for 15 minutes		Simulated for 15 minutes		Simulated for 3600 sec		Simulated for 3600 sec		Simulated for 3600 sec		Simulated for 3600 sec	
			operations in current system	*Current system average values/ Hr*	*operations in modified system*	*Modified system average values/Hr*	*operations in current system*	*Current system average values/ Hr*	*operations in modified system*	*Modified system average values/Hr*	*operations in current system*	*Current system average values/ Hr*	*operations in modified system*	*Modified system average values/Hr*
Process	Accumulated Time	Other/NNVA	Thread burning	0.02163286	*	*	Delasting	0.08613845	Delasting	0.0802889	*	*	*	*
			*	*	*	*	Inserting Tissue Paper	0.08000859	Inserting Tissue Paper	0.0531608	*	*	*	*
			*	*	*	*	last selection	0.05802822	last selection	0.0616968	*	*	*	*
			*	*	*	*	Quality inspection	0.1555	Quality	0.0826773	*	*	*	*
		Wait time	Apron Tongue Lining and counter1 and counter2	0.1665	Apron Tongue Lining and counter1 and counter2	0.1619	Brushing	0.05419910	Brushing	0	Counter 1 and	0.2100	*	*
			Collar quarter1	0.04781913	Collar quarter1	0.04639646	Cooling	0.03436700	Cooling	0	Pasting glue	0.1004	*	*
			inserting collar foa	0	inserting collar foam and Manual Hammering	0.00794084	Creaming	0.06889359	Creaming	0	SKIVING 1	0.3244	SKIVING 1	0.2299
			Hammering	0.04483476			Delasting	0.06042301	Delasting	0	SKIVING 2	3.1134	SKIVING 2	0.1570
			Lining and collar	0.00005329	Lining and	0.00286809	Hammering	0.05468360	Hammering	0.0025375	SKIVING 3	0.1407	SKIVING 3	0.05418744
			Quarter lining and	0.1618	Quarter lining	0.1641	Heating	0.06959547	Heating	0	SKIVING 4	0.2647	SKIVING 4	0.07675236
			Quarter2 and quarter3 stitching	0.00781734	Quarter2 and quarter3	0.00670093	last insertion and lasting	0.08203665	last insertion and lasting	0.0153703	SKIVING 5	2.8378	SKIVING 5	0.1026
			Upper strap and quarter1 with quarter2 stitching	0.1333	Upper strap and quarter1 with quarter2 stitching	0.1322	last selection	0.06929467	last selection	0.0012779	*	*	Socks attachment over lining	0.2099
							Quality inspection	0.05220181	Quality inspection	0.0322629	Noie:- All time values in this table is in hour and (*) sign indicates that the value to the corresponding process is zero			
							Temporary shoe lace insertion	0.07456426	Temporary shoe lace insertion	0.0486527				
							Thread burning	0.05119495	Thread burning	0				
							Wrinckel chassing	0.05695171	Wrinckel chassing	0				

Controlling parameter	Key performance indicator	stitching section(19 stations)				lasting and finishing section(6 stations)				preparation section(19 stations)			
		Simulated for 15 minutes		Simulated for 15 minutes		Simulated for 3600 sec		Simulated for 3600 sec		Simulated for 3600 sec		Simulated for 3600 sec	
		operations in current system	*Current system average values/ Hr*	*operations in modified system*	*Modified system average values/Hr*	*operations in current system*	*Current system average values/ Hr*	*operations in modified system*	*Modified system average values/Hr*	*operations in current system*	*Current system average values/ Hr*	*operations in modified system*	*Modified system average values/Hr*
Process	Number in per each process (in pair)	Applying glue on stiffener and attaching on	13.0000	Applying glue on stiffener and attaching on	13.0000	Brushing	31.3750	Brushing	36	Counter stifffener skiving	87.8250	Counter stifffener skiving	82.7000
		Applying glue over quarter lining	12.6875	Applying glue over quarter lining	12.7500	Cooling	32.0000	Cooling	36	Marking	103.00	Marking	84.0000
		Apron Tongue Lining and counter1 and counter2	17.0000	Apron Tongue Lining and counter1 and counter2	17.0000	Creaming	31.9000	Creaming	36	Pasting glue	87.7875	Pasting glue then Counter 1 and counter 2 cementing	82.7000
		Bottom strap attaching	13.9688	Bottom strap attaching	14.0000	Delasting	31.0750	Delasting	36	Counter 1 and counter 2	87.4375		
		Collar and quarter1 attaching	17.0000	Collar and quarter1 attaching	17.0000	Hammering	32.0000	Hammering	36.025	SKIVING 1	102.98	SKIVING 1	84.0000
		Collar quarter1 and counter1 with2 stitching	16.0000	Collar quarter1 and counter1 with2 stitching	16.0000	Heating	33.0000	Heating	36.275	SKIVING 2	102.14	SKIVING 2	83.3000
		Eyeleting	9.0313	Eyeleting	10.0000	Inserting Tissue Paper	31.0000	Inserting Tissue Pa	36	SKIVING 3	95.1250	SKIVING 3	82.9000
		Hammering	12.0000	inserting collar foam and Manual Hammering	12.2188	last insertion and lasting	33.0000	last insertion and l	37	SKIVING 4	94.8750	SKIVING 4	82.8000
		inserting collar foam	12.2500			last selection	33.0000	last selection	37	SKIVING 5	94.5000	SKIVING 5	82.7000
		Lining and collar area stitching	10.0625	Lining and collar area stitching	11.1563	Quality inspection	30.9000	Quality inspection	36	Socks attachment over lining	86.7625	Socks attachment over lining	82.2000
		Moulding	9.0000	Moulding	9.8125	Shoe lacing final	31.0000	Shoe lacing final	36	stamping on lining and leather	103.00	stamping on lining and leather	84.0000
		Quality Check	8.8125	Quality Check	9.4375	Sockes Insertion	31.0000	Sockes Insertion	36				
		Quarter lining and bottom strap stitching	17.0000	Quarter lining and bottom strap stitching	17.0000	Temporary shoe lace insertion	33.0000	Temporary shoe la	37				
		Quarter lining stitching	13.4063	Quarter lining stitching	13.4063	Thread burning	32.0000	Thread burning	36				
		Quarter1 and quarter 23 stitching	13.9688	Quarter1 and quarter 23 stitching	13.9375	Wrinckel chassing	32.0000	Wrinckel chassing	36				
		Quarter2 and quarter3 stitching	17.0000	Quarter2 and quarter3 stitching	17.0000								
		Thread burning and cutting	9.0000	Trimming and Thread burning and cutting	10.2188								
		Trimming	9.2813										
		Upper strap and quarter1 with quarter2 stitching	16.3750	Upper strap and quarter1 with quarter2 stitching	16.4375								

Noie:- All time values in this table is in hour and (*) sign indicates that the value to the corresponding process is zero

Controlling parameter	Key performance indicator	stitching section(19 stations)				lasting and finishing section(6 stations)				preparation section(19 stations)			
		Simulated for 15 minutes		Simulated for 15 minutes		Simulated for 3600 sec		Simulated for 3600 sec		Simulated for 3600 sec		Simulated for 3600 sec	
		operations in current system	*Current system average values/ Hr*	*operations in modified system*	*Modified system average values/Hr*	*operations in current system*	*Current system average values/ Hr*	*operations in modified system*	*Modified system average values/Hr*	*operations in current system*	*Current system average values/ Hr*	*operations in modified system*	*Modified system average values/Hr*
Process	Number outper each process in pair	Applying glue on stiffener and attaching on counter 1	12.6875	Applying glue on stiffener and attaching on counter 1	12.7500	Brushing	31.0750	Brushing	36.0000	Counter stifffener skiving	87.7875	Counter stifffener skiving	82.7000
		Applying glue over quarter lining	12.2500	Applying glue over quarter lining	12.2188	Cooling	31.9000	Cooling	36.0000	Marking	102.98	Marking	84.0000
		Apron Tongue Lining and counter1 and counter2	15.0000	Apron Tongue Lining and counter1 and counter2	15.0000	Creaming	31.3750	Creaming	36.0000	Pasting glue	87.4375	Pasting glue then Counter 1 and counter 2 cementing	82.2000
		Bottom strap attaching	13.4063	Bottom strap attaching	13.4063	Delasting	31.0000	Delasting	36.0000	Counter 1 and counter 2 cementing	86.7625		
		Collar and quarter1 attaching	17.0000	Collar and quarter1 attaching	17.0000	Hammering	32.0000	Hammering	36.0000	SKIVING 1	102.14	SKIVING 1	83.3000
		Collar quarter1 and counter1 with2 stitching	13.9688	Collar quarter1 and counter1 with2 stitching	13.9375	Heating	32.0000	Heating	36.0250	SKIVING 2	95.1250	SKIVING 2	82.9000
		Eyeleting	9.0000	Eyeleting	9.8125	Inserting Tissue Paper	30.9000	Inserting Tissue Paper	36.0000	SKIVING 3	94.8750	SKIVING 3	82.8000
		Hammering	10.0625	inserting collar foam and Manual Hammering	11.1563	last insertion and lasting	33.0000	last insertion and lasting	37.0000	SKIVING 4	94.5000	SKIVING 4	82.7000
		inserting collar foam	12.0000			last selection	33.0000	last selection	37.0000	SKIVING 5	87.8250	SKIVING 5	82.7000
		Lining and collar area stitching	9.2813	Lining and collar area stitching	10.2188	Quality inspection	30.5625	Quality inspection	35.7250	Socks attachment over lining	86.1625	Socks attachment over lining	81.2000
		Moulding	8.8125	Moulding	9.4375	Shoe lacing final	31.0000	Shoe lacing final	36.0000	stamping on lining and leather	103.00	stamping on lining and leather	84.0000
		Quality Check	8.1563	Quality Check	9.0625	Sockes Insertion	31.0000	Sockes Insertion	36.0000				
		Quarter lining and bottom strap stitching	14.9688	Quarter lining and bottom strap stitching	14.9688	Temporary shoe lace insertion	33.0000	Temporary shoe lace insertion	36.2750				
		Quarter lining stitching	13.0000	Quarter lining stitching	13.0000	Thread burning	32.0000	Thread burning	36.0000				
		Quarter1 and quarter 23 stitching	13.4375	Quarter1 and quarter 23 stitching	13.3438	Wrinckel chassing	32.0000	Wrinckel chassing	36.0000				
		Quarter2 and quarter3 stitching	16.3750	Quarter2 and quarter3 stitching	16.4375								
		Thread burning and cutting	9.0000	Trimming and Thread burning and cutting	10.0000								
		Trimming	9.0313										
		Upper strap and quarter1 with quarter2 stitching	14.0000	Upper strap and quarter1 with quarter2 stitching	14.0000								

Noie:- All time values in this table is in hour and (*) sign indicates that the value to the corresponding process is zero

Controlling parameter	Key performance indicator	stitching section(19 stations)				lasting and finishing section(6 stations)				preparation section(19 stations)			
		Simulated for 15 minutes		Simulated for 15 minutes		Simulated for 3600 sec		Simulated for 3600 sec		Simulated for 3600 sec		Simulated for 3600 sec	
		operations in current system	*Current system average values/ Hr*	*operations in modified system*	*Modified system average values/Hr*	*operations in current system*	*Current system average values/ Hr*	*operations in modified system*	*Modified system average values/Hr*	*operations in current system*	*Current system average values/ Hr*	*operations in modified system*	*Modified system average values/Hr*
Queue	Waiting time in queue	Apron Tongue Lining and counter1 and	0.01189736	Apron Tongue Lining and counter1 and	0.01157039	Brushing.Queue	0.00174572	*	*	Counter 1 and counter 2 cementing.Qu	0.00242396	*	*
		Bottom strap attaching.Queue	0.00	Bottom strap attaching.Queue	0.00	Cooling.Queue	0.00108092	*	*	Pasting glue.Queue	0.00114989	*	*
		Collar and quarter1 attaching.Queue	0.00	Collar and quarter1 attaching.Queue	0.00	Creaming.Queue	0.00223384	*	*	SKIVING 1.Queue	0.00317410	SKIVING 1.Queue	0.00275838
		Collar quarter1 and counter1 with2 stitching.Queue	0.00398429	Collar quarter1 and counter1 with2 stitching.Queue	0.00393589	Delasting.Queue	0.00194931	*	*	SKIVING 2.Queue	0.03274777	SKIVING 2.Queue	0.00189263
		Eyeleting.Queue	0.00	Eyeleting.Queue	0.00	Hammering.Queue	0.00170886	Hammering.Queue	0.00007	SKIVING 3.Queue	0.00148456	SKIVING 3.Queue	0.00065359
		Hammering.Queue	0.00483777	inserting collar foam and Manual Hammering.Queue	0.00071242	Heating.Queue	0.00220385	*	*	SKIVING 4.Queue	0.00279949	SKIVING 4.Queue	0.00092749
		inserting collar foam.Queue	0.00			last insertion and lasting.Queue	0.00248596	last insertion and lasting.Queue	0.00042	SKIVING 5.Queue	0.03234744	SKIVING 5.Queue	0.00123983
		Joining 1.Queue	0.00445584	Joining 1.Queue	0.00459957	last selection.Queue	0.00209984	last selection.Queue	0.00003	*	*	Socks attachment over lining.Queue	0.00257802
		Joining 2.Queue	0.00175070	Joining 2.Queue	0.00188887	Quality inspection.Queue	0.00171720	Quality inspection.Queue	0.00091				
		Joining 3.Queue	0.00541838	Joining 3.Queue	0.00544169	Temporary shoe lace insertion.Queue	0.00225952	Temporary shoe lace insertion.Queue	0.00135				
		Lining and collar area stitching.Queue	0.00000533	Lining and collar area stitching.Queue	0.00029170	Thread burning.Queue	0.00159984	*	*				
		Quarter lining and bottom strap stitching.Queue	0.01158441	Quarter lining and bottom strap stitching.Queue	0.01174626	Wrinckel chassing.Queue	0.00177974	*	*				
		Quarter2 and quarter3 stitching.Queue	0.00049242	Quarter2 and quarter3 stitching.Queue	0.00041391								
		Upper strap and quarter1 with quarter2 stitching.Queue	0.01025766	Upper strap and quarter1 with quarter2 stitching.Queue	0.01019252								

Noie:- All time values in this table is in hour and (*) sign indicates that the value to the corresponding process is zero

Controlling parameter	Key performance indicator	stitching section(19 stations)				lasting and finishing section(6 stations)				preparation section(19 stations)			
		Simulated for 15 minutes		Simulated for 15 minutes		Simulated for 3600 sec		Simulated for 3600 sec		Simulated for 3600 sec		Simulated for 3600 sec	
		operations in current system	*Current system average values/ Hr*	*operations in modified system*	*Modified system average values/Hr*	*operations in current system*	*Current system average values/ Hr*	*operations in modified system*	*Modified system average values/Hr*	*operations in current system*	*Current system average values/ Hr*	*operations in modified system*	*Modified system average values/Hr*
Queue	Number waiting in queue	Apron Tongue Lining and counter1 and counter2.Queue	0.8192	Apron Tongue Lining and counter1 and counter2.Queue	0.7983	Brushing.Queue	0.05458180	*	*	Counter 1 and counter 2 cementing.Queue	0.2116	*	*
		Collar quarter1 and counter1 with2 stitching.Queue	0.2482	Collar quarter1 and counter1 with2 stitching.Queue	0.2458	Cooling.Queue	0.03465153	*	*	Pasting glue.Queue	0.1009	*	*
		Hammering.Queue	0.2397	inserting collar foam and manual Hammering.Queue	0.03521342	Creaming.Queue	0.07135600	*	*	SKIVING 1.Queue	0.3258	SKIVING 1.Queue	0.2306
		inserting collar foam.Queue	0			Delasting.Queue	0.06053105	*	*	SKIVING 2.Queue	3.3587	SKIVING 2.Queue	0.1583
		Joining 1.Queue	0.5703	Joining 1.Queue	0.5887	Hammering.Queue	0.05468360	Hammering.Queue	0.0025417	SKIVING 3.Queue	0.1411	SKIVING 3.Queue	0.05418744
		Joining 2.Queue	0.1966	Joining 2.Queue	0.2126	Heating.Queue	0.07410536	*	*	SKIVING 4.Queue	0.2654	SKIVING 4.Queue	0.07675236
		Joining 3.Queue	0.6103	Joining 3.Queue	0.6114	last insertion and lasting.Queue	0.08203665	last insertion and lasting.Queue	0.0153703	SKIVING 5.Queue	3.0685	SKIVING 5.Queue	0.1026
		Lining and collar area stitching.Queue	0.00021316	Lining and collar area stitching.Queue	0.01313340	last selection.Queue	0.06929467	last selection.Queue	0.0012779	*	*	Socks attachment over lining.Queue	0.2118
		Quarter lining and bottom strap stitching.Queue	0.8010	Quarter lining and bottom strap stitching.Queue	0.8111	Quality inspection.Queue	0.05310210	Quality inspection.Queue	0.0326256				
		Quarter2 and quarter3 stitching.Queue	0.03348442	Quarter2 and quarter3 stitching.Queue	0.02814589	Temporary shoe lace insertion.Queue	0.07456426	Temporary shoe lace insertion.Queue	0.0500779				
		Upper strap and quarter1 with quarter2 stitching.Queue	0.6731	Upper strap and quarter1 with quarter2 stitching.Queue	0.6709	Thread burning.Queue	0.05119495	*	*				
						Wrinckel chassing.Queue	0.05695171	*	*				

APPENDIX- E

Definitions:

- Accumulated NVA Time: The total non-value added time that has accrued for all entities in a process.
- Accumulated Other Time: The total other time (necessary non-value adding time) that has accrued for all entities in a process.
- Accumulated Transfer Time: The total transfer time that has accrued for all entities in a process.
- Accumulated VA Time: The total value added time that has accrued for all entities in a process.
- Accumulated Wait Time: The total wait time that has accrued for all entities in a process.
- Total Accumulated Time: The total time (total of all 5 allocation categories) that has accrued for all entities in a process.
- Wait Time Per Entity: The time each entity spent in any activity of a process, where the allocation is specified as wait. By default, all time spent in a queue is specified as wait.
- Number In: The number of entities that have entered a process.
- Number Out: The number of entities that have left a process.
- Number Waiting: The number of entities residing in a queue.
- Total Number Seized: The total number of units of the resource that were seized during the simulation run.
- T-distribution: symmetric and bell shaped graph like normal distribution but have more than one degree of freedom.

APPENDIX- F

Existing Vs. current simulation result Production capacity of Classic 1 model (C1) in pair

	Existing Vs current simulation result Production capacity of Classic 1 model (C1) in pair				
	Cutting section	Preparation section	Stitching section	Mocassine section	Lasting and finishing section
Existing	843.906367	682.2958801	242.4681648	241.5617978	240.2059925
current simulation result	824	688	256	300	248
percentage error	0.024	0.008	0.056	0.242	0.032

APPENDIX - G

t Table

cum. prob	$t_{.50}$	$t_{.75}$	$t_{.80}$	$t_{.85}$	$t_{.90}$	$t_{.95}$	$t_{.975}$	$t_{.99}$	$t_{.995}$	$t_{.999}$	$t_{.9995}$
one-tail	0.50	0.25	0.20	0.15	0.10	0.05	0.025	0.01	0.005	0.001	0.0005
two-tails	1.00	0.50	0.40	0.30	0.20	0.10	0.05	0.02	0.01	0.002	0.001
df											
1	0.000	1.000	1.376	1.963	3.078	6.314	12.71	31.82	63.66	318.31	636.62
2	0.000	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	22.327	31.599
3	0.000	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841	10.215	12.924
4	0.000	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	0.000	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032	5.893	6.869
6	0.000	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707	5.208	5.959
7	0.000	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	0.000	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355	4.501	5.041
9	0.000	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250	4.297	4.781
10	0.000	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169	4.144	4.587
11	0.000	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	0.000	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055	3.930	4.318
13	0.000	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012	3.852	4.221
14	0.000	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977	3.787	4.140
15	0.000	0.691	0.866	1.074	1.341	1.753	2.131	2.602	2.947	3.733	4.073
16	0.000	0.690	0.865	1.071	1.337	1.746	2.120	2.583	2.921	3.686	4.015
17	0.000	0.689	0.863	1.069	1.333	1.740	2.110	2.567	2.898	3.646	3.965
18	0.000	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878	3.610	3.922
19	0.000	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861	3.579	3.883
20	0.000	0.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845	3.552	3.850
21	0.000	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831	3.527	3.819
22	0.000	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	0.000	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807	3.485	3.768
24	0.000	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797	3.467	3.745
25	0.000	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787	3.450	3.725
26	0.000	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	0.000	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771	3.421	3.690
28	0.000	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763	3.408	3.674
29	0.000	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756	3.396	3.659
30	0.000	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750	3.385	3.646
40	0.000	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704	3.307	3.551
60	0.000	0.679	0.848	1.045	1.296	1.671	2.000	2.390	2.660	3.232	3.460
80	0.000	0.678	0.846	1.043	1.292	1.664	1.990	2.374	2.639	3.195	3.416
100	0.000	0.677	0.845	1.042	1.290	1.660	1.984	2.364	2.626	3.174	3.390
1000	0.000	0.675	0.842	1.037	1.282	1.646	1.962	2.330	2.581	3.098	3.300
z	0.000	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.576	3.090	3.291
	0%	50%	60%	70%	80%	90%	95%	98%	99%	99.8%	99.9%
	Confidence Level										