ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
MECHANICAL ENGINEERING DEPARTMENT
POSTGRADUATE PROGRAM IN INDUSTRIAL ENGINEERING

ASSEMBLY LINE MODELING AND SIMULATION OF FOOTWEAR MANUFACTURING
(A Case Study on Ramsey Shoe Factory)

By: Nahom Mulugeta

Advisor: Dr. - Ing Daniel Kitaw

Co-Advisor: Ato Temesgen Garoma (Phd candidate)

A thesis submitted to School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirement for the Degree of Masters of Science in Industrial Engineering (Mechanical Engineering Department)

September, 2011

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Declaration

I, the undersigned, declare that this thesis entitled “Assembly Line Modeling and Simulation of Footwear Manufacturing: A Case Study of Ramsey Shoe Factory” is the result of my own research carried out under the supervision of Dr. - Ing Daniel Kitaw and Ato Temesgen Garoma. It has not been presented as a thesis in any other university and all source of material used for this thesis are accordingly sited and acknowledged.

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Nahom Mulugeta Date

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

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Nahom Mulugeta

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Abstract

In today's competitive global market, companies are mostly striving to strengthen themselves as much as possible in all competiveness dimensions of business. This demands for optimal production system which increases the overall productivity of the company. Survival of any business in today's competitive market place depends mainly on response time, production cost, market price and flexibility of manufacturing. These things motivated continuous research in modeling and performance evaluation of manufacturing systems. In parallel to this, different simulation software play a great role in designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and evaluating various strategies and scenarios for the operating or manufacturing system. Since the majority of consumable and non consumable goods are manufactured on assembly line system; assembly line balancing problem is getting importance now a day. Footwear is one of the goods which are manufactured on assembly line system. Hence, this thesis is concerned with the modeling and simulation of assembly line balancing of footwear manufacturing in Ramsey Shoe Factory. Within the production department this thesis is mainly concerned with the modeling and simulation of the two assembly lines: Stitching and Lasting assembly line. To do so, Arena simulation software is employed to model and measure performance of existing manufacturing systems of both assembly lines. Based on the simulation model result of the existing system, different scenarios are proposed to solve observed problems of the existing manufacturing system. Problems that are identified in simulation model analysis were: Line balance efficiency for both assembly lines is low, Relatively high level of WIP is observed in some work station of stitching assembly line, low production output with respect to the installed capacity, and the output of stitching assembly line is significantly higher than that of the lasting assembly line which causes WIP of different model shoes to be piled up in between the two assembly lines. To solve these problems, five possible scenarios are developed. These are: Avoiding unnecessary

duplication resource from station with low capacity utilization, merging similar operations with low resource utilization together and assign to one worker, increasing level of resource at stations with high WIP, changing working method, and combination of all the above alternatives.

Among the five developed scenarios, the last one, ‘Combination of all the above alternatives’ gives better performance of footwear manufacturing for the selected model shoe.

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List of Acronyms

AGV	Automated Guided Vehicle
ALB	Assembly Line Balancing
APICS	American Production and Inventory Control Society
CPI	Continuous Process Improvement
d	Balance delay
E	Line efficiency
E_b	Balance efficiency
FMS	Flexible manufacturing systems
GPSS	General Purpose Systems Simulator
GT	Group technology manufacturing system
JIT	Just in time production system
KS	Kolmogorov–Smirnov graph
LLPTI	Leather and Leather Products Technology Institute
MALB	Mixed-Model Assembly Line Balancing
M/C	Machine
MLT	Manufacturing lead time
MOTI	Ministry of Trade and Industry
n_e	Number of work elements
PDC	Product development center
R_p	Production rate
RSF	Ramsey Shoe Factory
SALBP	Simple Assembly Line Balancing Problem
Std Dev	standard deviation
T_c	Cycle time
T_{ek}	Time to perform work element k
TLT	Total lead lime
TQC	Total quality control

Ts	The maximum available service time
T_{si}	Service time
T_{wc}	Work content time
w	Number of workers
WIP	Work in Process

Chapter one

Problem and its approach

1.1. Introduction

The increasing demands for productivity, cost reduction, and optimal allocation of resources, have motivated continuous research in modeling and performance evaluation of manufacturing systems. In this domain, one of the most important manufacturing sections is assembly line system. An assembly line is a flow-oriented production system where the productive units performing the operations, referred to as stations, are aligned in a serial manner. The assembly line concept was not invented at one time by one person. It has been independently redeveloped throughout history based on logic. Its exponentially larger development at the end of the 19th century and beginning of the 20th occurred among various people over decades, as other aspects of technology allowed. Henry Ford was the first to master the assembly line and was able to improve other aspects of industry by doing so, such as reducing labor hours required to produce a single vehicle, and increased production numbers and parts. However, the various preconditions for the development at Ford stretched far back into the 19th century, from the gradual realization of the dream of interchangeability, to the concept of reinventing workflow and job descriptions using analytical methods. Ford was the first company to build large factories around the assembly line concept. Mass production via assembly lines is widely considered to be the catalyst which initiated the modern consumer culture by making possible low unit cost for manufactured goods. [10]

Multi-purpose machines with automated tool exchanges allow for a different production sequence of varying models at negligible set-up times and costs. This makes efficient flow-line systems available for low volume assembly-to-order production and enables modern production strategies like mass customization. This in turn ensures that the thorough planning and implementation of assembly systems will remain of high practical relevance in the foreseeable future. [14]

Any assembly line comprises a finite set of work elements sometimes called tasks. Each task is characterized by an operation processing time and a set of precedence relationships, which specify the allowable orderings of the tasks. Assembly line balancing (ALB) is the process of allocating a group of tasks to be performed on an ordered sequence of workstations in such a manner that all workstations have approximately an equal amount of assigned workload to optimize some measures of performance e.g. minimize the number of workstations, minimize cycle time minimize the balance delay, or optimize the combination of the aforementioned objectives, without violating precedence relationships. [2][15]

Therefore, to develop the assembly system, good observation is needed. However, to observe real manufacturing systems is very expensive and sometimes cumbersome. The rapid rate at which the whole process takes place, the interaction between workers, and the different transition times between workers make it increasingly more difficult for a human being to make correct decisions regarding how fast each operator should work in order to continue the process, while at the same time keeping productivity high and throughput at an acceptable level. But with a simulation models, we can explore how an existing system might perform if altered, or how a new system might behave before the prototype is even completed, thus saving on costs and lead times. [11] Therefore, a simulation model is an easier way to build up models to represent real life scenarios, to identify bottlenecks, to enhance system performance in terms of productivity, queues, resource utilization, cycle times, lead times, etc. Hence, this thesis is proposed to model and simulate footwear manufacturing system by taking Ramsey shoe factory as a case study.

1.2. Problem of the statement

Leather and Leather products is one of unexploited business in Ethiopia. Ethiopia is one of the leading countries in the world in terms of its livestock resources. It has been repeatedly told that it ranks first in Africa and tenth in the world in the number of its domestic animals. Ethiopia's livestock population is currently estimated at 35 million cattle, 21 million sheep and 16.8 million goats. Annually it produces 2.7 million hides, 8.1 million sheepskins and 7.5 million goatskins

[24]. Therefore, Ethiopia has a major comparative advantage in the raw materials needed for the leather sector which makes it in principle very appropriate for leather product exporting. This comparative advantage is further underlined by the fact that the cost of raw hides and skins constitute, on average, between 55 to 60 per cent of the production of semi-processed leather. However, for the past years leather sector of the country remain incompetent in the market. As a result of this, the country fails to be economically benefited from this sector. The Ethiopian leather sector has two broad categories. The 1st one is Tanning/ Dressing of leather which focus on producing of semi-processed and finished leather and the second one is the manufacture of footwear, leather garment, bags, belts, stitched upholstery and etc. Currently there are 11 footwear factories under operation which have great potentials to produce shoes for both local and export market. The total current production volume of these footwear factories is estimated around 4,500,000 pairs per annum. But it is argued that Ethiopia has much to gain from the growing global market for leather currently estimated at 40 billion USD a year. [24] Therefore a lot of jobs should be done on this sector so that the country will be benefited more. And for this, the Ethiopian government took action and working extensively to boost up the sector. As a result of this, good hopes are seen recently that most of the footwear manufacturing industries are becoming strong competitor in local market and as well as in export market.

Recently, the Government of Ethiopia has targeted to increase the export from this sector to 500 million USD within next five years which was only 101 million USD in 2007-08. However, the current limitation of technical and technological competence especially in the Footwear and Leather Product sector is being realized as the major challenge towards meeting the export target set by the Government of Ethiopia [24]. So this thesis is proposed to identify bottlenecks which can hinder the performance and effectiveness of footwear manufacturing process. Then by modeling and simulation techniques different scenarios and alternatives are developed that can boost the effectiveness and efficiency of footwear manufacturing process. By doing so, the thesis can provide a significant contribution to meet the government export target point from the sector in the next five years.

This time, in order to respond to a diversified customer needs, companies have to introduce for an individualization of their products through their manufacturing system. Survival of any industry in today's competitive market place depends on response time, production cost and flexibility in manufacturing. The manufacturing Industries in Ethiopia are no exception to this fact. Hence strategies to increase throughput while reducing production costs are being explored. One efficient strategy to reduce production costs is by better control of the manufacturing process. But control of the process is possible only if the intricate details of the system are known. Computer simulation of the manufacturing process offers a cost effective solution not only to visualize the processes but also enables to identify bottlenecks in the system [14].

In general, many researches show that the Ethiopian footwear manufacturing industries are facing the following problems.

- High production cost in contrary to cheap labor
- Relatively higher market price
- High machine setup cost and times
- Low flexibility in manufacturing of different models
- High production time and response time
- Low capacity utilization
- Less variety of products
- Less frequency of new product development
- High work in progress
- Low line balancing efficiency
- More idle resource

When we come to the case study company, Ramsey shoe factory, one of the most footwear manufacturers faces most of the above mentioned problems. Among these, the major ones are; high work in process piled up in between adjacent assembly line (stitching and lasting assembly lines), low line balancing efficiency, high production lead time; as a result of this, low production output, low utilization of production lines and bottlenecks at some stations, and work assignment problems which result in more idle time at some station which leads in turn to low utilization compared to other station. In general, all these specific problems leads to higher production cost which in turn increase the product market price. As we know, product price is one of the three competitiveness dimensions in which the company can be stronger competitor and take more market share in today's global market. Obviously, a company providing a quality product with cheap (affordable) price, fast response and high flexibility win today's market and shares more.

Therefore to enhance and improve the whole sector sustainably a lot of jobs have to be done. Assembly line modeling and simulation of the manufacturing processes is one of the research areas that should be investigated intensively to help the enhancement of the sector.

1.3. Objectives

1.3.1. General objectives

The general objective of this thesis is to identify ways by which the Performance of footwear manufacturing process could be enhanced leading to a cost effective and efficient system by:

- Modeling and simulating the manufacturing process and evaluating the effectiveness of the process in terms of machine, human and system performance to identify bottlenecks and provide means to smooth out which assists the management in arriving at a better decision after evaluation of various alternative results obtained from the simulation.
- Balancing the assembly line for multiple product models based on the simulation result.

1.3.2. Specific objectives

- Mapping out the layout of the manufacturing system and come up with improved layout by taking the effective workplaces design into consideration in which both the study and analysis of working methods (by means of work measurement)
- Develop a computer based simulation model for the footwear production line.

- Verify the model according to the modeling assumptions.
- Validate the model with the real performance measurement from the factory.
- Improve the process by developing different alternatives.

1.4. Methodology

To achieve the objective of this thesis work, the following methodologies will be carried out.

1.4.1. Literature survey

A complete literature survey on footwear manufacturing systems, assembly line balancing, and different modeling and simulation techniques is discussed. Under the term assembly line balancing (ALB) various optimization models is introduced and discussed which aims at supporting the decision maker in configuring efficient assembly systems. In addition, different simulation software that are available which can suit the system is studied.

1.4.2. Data collection

A company which has mostly manufacturing related problems especially assembly line balancing problems, is selected to carry out the case study. In addition to this, the willingness of the company to undertake the study plays a significant role in selecting a company for the case study.

The data collection includes the following parameters which can be used in the measuring of the efficiency and effectiveness of the manufacturing process.

- Total number of tasks
- Processing times of each task
- Transfer time of WIP between stations
- Priorities between processes
- Arrival frequencies of entities or time between arrival
- Manning level for each task
- Layout of machines distance b/n machines (station)
- Conveyor length and speed

- Working hours
- Production output
- Defect rate (rework)

1.4.3. Data analysis

The collected data is analyzed by Arena input analyzer to be used in simulation model development.

1.4.4. Model development and simulation

Based on the data analysis different models are developed and measured for their performance by using Arena simulation software. Then different scenarios and alternative solutions are proposed.

Finally conclusions and recommendations are made on the findings.

1.5. Organization of the Study

The whole thesis work may encompass up to six main chapters which will be presented as follows.

The first chapter briefly discussed the problems and its approach. The second chapter is concerned with related literatures review of assembly line balancing, modeling and simulation techniques, overview of Ethiopian manufacturing and footwear manufacturing process. General overview of the Case Study Company and statistical analysis is discussed in chapter three. Simulation model development which is the core of the thesis is discussed in chapter four. In chapter five different scenarios and alternatives are developed and discussed. The last chapter, chapter six, will present the findings of the study as a conclusion and recommendation, a list of activities which should be performed and should be encompassed in future works in order to enhance the development of leather and leather product sector

Chapter Two

Literature review

2.1. Introduction

Assembly lines are flow-line production systems which are of great importance in the industrial production of high quantity standardized commodities and more recently even gained importance in low volume production of customized products. Due to high capital requirements when installing or redesigning a line, configuration planning is of great relevance for practitioners. Accordingly, this attracted the attention of research, who tried to support practical configuration planning by suited optimization models. In spite of the great amount of extensions of basic assembly line balancing there remains a gap between requirements of real configuration problems and the status of research. This gap might result from research papers focusing on just a single or only a few practical extensions at a time. However Real-world assembly systems require a lot of these extensions to be considered simultaneously [9][16].

Before the 20th century, the craft production was the dominant type of production, characterized by skilled workers that used general purpose tools to produce exactly what the customers asked for. Then the industrial revolution introduced machinery in production, helping in the first phase the craft production to be more productive, by using machinery to support some craftsman work. In the beginning of 20th century, Henry Ford decided to build a car that everybody could own and drive. However, at that time most cars were customized for the client or built one at a time in limited quantities, following the craft production type. Based in the Taylor's theories, he introduced in 1913 at Highland Park plant in Michigan, the revolutionary concept of mass production, characterized by the production of the same product in large scale using a rigid assembly line to produce a car composed by identical interchangeable parts. With the introduction of the production assembly line, the task cycle for the average Ford assembler (i.e. the amount of time that the operator works before repeating the same operations), was reduced from 514 minutes to 2, 3 minutes. Lately, he had further cut the time from 2, 3 minutes to 1, and 2 minutes with the moving line which brought the car to the stationary worker [1].

Assembly line-balancing (ALB) problem has been widely studied since the first analytical statement of the ALB problem was formulated by Bryton in 1954 and published in mathematical form by Salveson in1955. An assembly line is a flow-oriented production system where the productive units performing the operations, referred to as stations, are aligned in a serial manner. The work-pieces visit stations successively as they are moved along the line usually by some kind of transportation system [16]. Given a set of tasks of various durations, a set of precedence constraints among the tasks, and a set of workstations, assigning each task to exactly one workstation in such a way that no precedence constraint is violated and the assignment is optimal is called assembly line balancing problem.

The primary aim of the assembly line was to facilitate mass production, standardization, simplification and specialization. Besides this, assembly line was also useful in dividing complex work structures into a number of elemental tasks, which would simplify the complexity of assembly work. From the manufacturers point of view foremost advantage of ALB is the ability to keep direct labors busy doing productive work. Historically assembly line was designed for high volume production of single item or similar family of items [18].

In order to respond to diversified customer needs, companies have to allow for an individualization of their products. For example, German car manufacturer BMW offers a catalogue of optional features which, theoretically, results in 10^{32} different models. Multi-purpose machines with automated tool exchange allow for facultative production sequences of varying models at negligible setup costs. This makes efficient flow line systems available for low volume assembly to-order production and enables modern production strategies like mass-customization, which in turn ensures that the thorough planning and implementation of assembly systems will remain of high practical relevance in the foreseeable future [16].

Due to the high level of automation, assembly systems are associated with considerable investment costs. Therefore, the re-configuration of an assembly line is of critical importance for implementing a cost efficient production system. Configuration planning generally comprises all tasks and decisions which are related to equipping and aligning the productive units for a given production process, before the actual assembly can start. This includes setting the production system capacity (cycle time, number of stations, station equipment) as well as assigning the work content to productive units (task assignment, sequence of operations).

Production function is the part of an organization, which is concerned with the transformation of a range of inputs into the required outputs (products) having the required quality level. Production is the step-by-step conversion of one form of material into another form to create or enhance the utility of the product to the user.

2.2. Manufacturing systems

Manufacturing is a transformation process in which the inputs (raw materials, equipment, tooling, fixture, electrical energy, and labor) are converted into completed work-piece which carries some definite value in the marketplace. This transformation process usually involves a number of steps, in which the materials are brought closer to the desired final state in each step. These individual steps are generally called production operations, and include such processes as planning, design, procurement, production, inventory, marketing, distribution, sales and management. The key to successful manufacturing is therefore to produce constituent parts in accordance with the desired specification at the lowest cost in the shortest possible time that satisfies the customer requirement [17].

2.3. Classification of manufacturing systems

The classification scheme of manufacturing system is based on the factors that define and distinguish the different types. These factors are the following [17]:

1. Types of operations performed

2. Number of workstations and system layout
3. Level of automation
4. Volume product variety and rate of production

1. **Types of operation performed**

   Based on types of operation performed, manufacturing process can be processing operation on individual work units and assembly operations to combine individual parts into assembled entities.

2. **Number of workstations and system layout.**

   The number of workstation is a key factor in the classification of manufacturing system. It exerts a strong influence on the performance of the manufacturing system in terms of production capacity, productivity, cost per unit, and maintainability. The number of work station in the manufacturing system is a convenient measure of its size. As the number of workstation increased, the amount of work that can be accomplished by the system increases this means higher production rate. More station also means that the system is more complex and therefore more difficult to manage and maintain.

   Based on the arrangement of the work stations, the way how the stations are laid out can be variable routing or fixed routing. Workstation lay outs organized for variable routing can have a variety of possible configurations while lay outs organized for fixed routing are usually arranged linearly as in the production line and cannot have possible alternatives configurations. The layout of stations is an important factor in determining the most appropriate material handling system.

   According to the number of stations and layout of stations a manufacturing system has three levels. These are:

   1. Single station: - this is the simplest case, consisting of one workstation

2. Multiple stations with variable routing:- this manufacturing system consists of two or more stations that are designed and arranged to accommodate the processing or assembly of different part
3. Multiple stations with fixed routing: - this system has two or more workstations which are laid out as a production line.

3. Level of automation

The workstation in a manufacturing system can be manually operated, semi-automated, or automated. For single station we have two possible levels of automations: manned stations and fully automated. For multi station systems there are three possible levels of automations; these are: multi stations manual system with variable routing, multi stations automated system with variable routing and multi station hybrid system with variable routing. For multi stations system with fixed routing, there are three automation levels: multi station manned system with fixed routing, multi stations automated system with fixed routing and multi stations hybrid system with fixed routing.

4. Volume, product variety and rate of production

Based on volume, rate of production and variety of production, manufacturing systems can be classified as project, Job-shop, Batch, Mass and Continuous production systems [17].

1. Project

This deals with the provision of a unique product requiring large-scale inputs to be coordinated, so as to achieve a customer's requirement. The resource inputs will be normally be taken to the point where the product is to be built, since it is not feasible to move it till completed. Typical examples of this kind may include civil engineering projects, the construction of large scale manufacturing or military facilities and aerospace programs.

2. Job-Shop Production

Job-shop production is characterized by manufacturing one or few quantity of products designed and produced as per the specification of customers within prefixed time and cost. The distinguishing feature of this is low volume and high variety of products. A job-shop comprises of general-purpose machines arranged into different departments. Each job demands unique technological requirements, and processing on machines in a certain sequence [8].

3. **Batch Production**

American Production and Inventory Control Society (APICS) define Batch Production as a form of manufacturing in which the job pass through the functional departments in lots or batches and each lot may have a different routing. It is characterized by the manufacture of limited number of Products produced at regular intervals and stocked awaiting sales [8].

4. **Mass Production**

Manufacture of discrete parts or assemblies using a continuous process is called Mass Production. This production system is justified by very large volume of production. The machines are arranged in a line or product layout. Product and process standardization exists and all outputs follow the same path [8].

5. **Continuous Production**

Production facilities are arranged as per the sequence of production operations from the first operations to the finished product. The items are made to flow through the sequence of operations through material handling devices such as conveyors, transfer devices, etc [8].

Among the above five types of production, Assembly line system is becoming great importance in the industrial production of high quantity standardized commodities (batch production system and mass production system) and more recently even gained importance in low volume production of customized products which is a job shop production system. In order to grasp the advantages of mass production system and batch production system, the production lines should be perfectly balanced. Therefore assembly line balancing problem play a great role in both production systems.

2.4. New manufacturing methodologies

During the early stage of industrialization, the manufacturing world was characterized by success because there was very little competition. However, in today's world, where alternatives are abound, one must truly understand customer needs and then articulate products and services to meet their changing needs if one wishes to stay in doing business. Thus the business trend has become customer-oriented which takes more product customization, better product quality, faster order processing and better customer service [17].

These new emphases on customer satisfaction require a complete change in manufacturing attitudes and philosophy. The new methodologies and approaches exercised in today's manufacturing practices include JIT production system, Flexible manufacturing systems, and Group technology manufacturing system.

2.4.1. Just-in-time (JIT)

As the name implies, is to produce goods just-in-time for use or sale. It is a management philosophy that strives to eliminate sources of manufacturing waste by producing the right part in the right place at the right time. It is a Japanese manufacturing Management method developed in the 1970s.

The most significant benefit of JIT is to improve the responsiveness of the firm to the changes in the market place thus providing an advantage in competition.

- Product cost is greatly reduced due to reduction of manufacturing cycle time, reduction of waste and inventories and elimination of non-value added operation.
- Quality is improved because of continuous quality improvement programmes.
- Due to fast response to engineering change, alternative designs can be quickly brought on the shop floor.
- Productivity improvement.
- Higher production system flexibility.

2.4.2. Flexible manufacturing system (FMS)

FMS is a manufacturing system in which there is some amount of flexibility that allows the system to react in the case of changes, whether predicted or unpredicted. This flexibility is generally considered to fall into two categories, which both contain numerous subcategories machine flexibility and routing flexibility. If we properly apply the flexible manufacturing system, there are several advantages that can be obtained. These are: -

- Greater flexibility in production scheduling
- Reduced manufacturing lead times
- Higher labor productivity
- Reduced lead time, setting time, and batch quantities
- Increased machine utilization [17].

2.4.3. Group technology (GT)

GT is manufacturing philosophy in which the parts having similarities (Geometry, manufacturing process and/or function) are grouped together to achieve higher level of integration between the design and manufacturing functions of a firm. The aim is to reduce work-in-progress and improve delivery performance by reducing lead times. GT manufacturing environments are suitable for low to medium volume of production with the following advantages:

- Setup time reduction
- Work-in-process inventory reduction
- Material handling cost reduction
- Equipment cost and direct and indirect labor cost reduction
- Improvement in quality
- Improvement in material flow
- Improvement in machine utilization
- Improvement in space utilization

In all these three new manufacturing methods Assembly line balancing play a great role in harnessing the above advantages of the manufacturing systems [17].

2.5. Manufacturing processes

In a typical manufacturing system, there are four fundamental operations these are processing, assembly, material handling system, and inspection and testing [5].

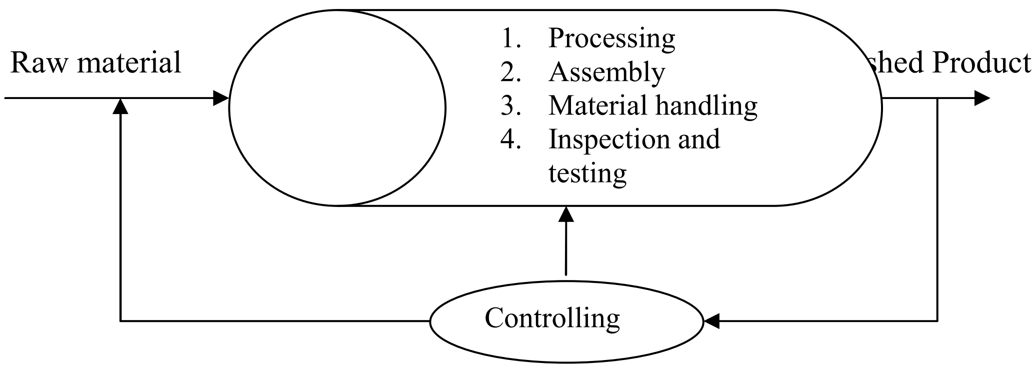

Figure.2.1.A model showing operations of manufacturing processes [5]

i. Processing

Processing operations include those activities which transform work part from one state of completion into a more advanced state of completion. In this operation no material is added to accomplish the transformation. Instead, energy is added to change the shape of the work part, remove material from it, change its physical properties and etc. processing operations can be basic processes which give the work part material its initial form, secondary processes which give the work part its final desired geometry, operations to enhance physical properties and finally, finishing operations which improve the appearance and to provide a protective coating on the part [5].

ii. Assembly

Assembly is the processes of fitting together of individual parts to makeup fabricated products. In assembly operations, two or more separate components are joined together by mechanical fastening operations, joining processes and adhesives [5].

iii. Materials handling and storage

Material handling can be defined as transporting, loading, positioning, unloading, and storing of unfinished goods, work-parts and supplies to and from during manufacturing processes.

iv. Inspection and testing

Inspection is the examination of a work piece, both visually and with instruments, to determine defects, errors, and flaws of material or manufacturing processes. Inspection can be based on measurements or attributes. Testing is the trial of the product by actual functioning or operation, or by subjecting the item to external effects [5].

v. Control

The control function in manufacturing includes both the regulation of the individual processes as well as supervision over the aggregate operations at the plant level. Control at the process level involves the achievement of certain performance objectives by properly manipulating the process inputs. It also includes quality control of the process output. Control at the plant level includes effective use of labor, proper utilization of machines, shipping products of good quality on schedule, and keeping plant operating costs at a minimum possible level [5].

The processing and assembling operations add value to the material being processed, whereas the other functions do not. However, these operations other than processing and assembling take much of the resources in manufacturing of a product. In many production facilities, materials spend as much as 85% to 95% of the time either waiting to be worked on or being moved. Also materials handling often take up more than half of the floor space of a factory. As a result, storage and handling account for as much as 75% of a products total manufacturing and distribution cost [5].

2.6. Manufacturing wastes

Companies always aim for optimizing the resources consumed during production. One way of optimum utilization is to eliminate or minimize waste. Waste elimination or minimization, thereby increasing percentage of time devoted to value adding activities, is one of the most effective ways to increase profitability and competitiveness. As Toyota and other world-class organizations have come to realize, customers will pay for value added work, but never for waste. While products significantly differ between factories, the typical wastes found in manufacturing environments are quite similar [17].

To eliminate waste, it is important to understand exactly what waste is and where it exists. For each waste, there is a strategy to reduce or eliminate its effect on a company, thereby improving overall performance and quality. The seven manufacturing wastes identified by Taichi Ohno are [17]:

1. **Overproduction**

Overproduction is manufacturing of an item before it is actually required. The Toyota Production System is also referred to as “Just in Time” (JIT) in which every item is made just as it is needed. Overproduction manufacturing is referred to as “Just in Case.” This creates excessive lead times, results in high storage costs, and makes it difficult to detect defects. The simple solution to overproduction is turning off the tap. The concept is to schedule and produce only what can be immediately sold / shipped and improve machine changeover / set-up capability.

2. **Inappropriate Processing**

Often termed as “using a sledgehammer to crack a nut,” many organizations use expensive high precision equipment where simpler tools would be sufficient. This often results in poor plant layout because preceding or subsequent operations are located far apart. In addition they encourage high asset utilization (overproduction with minimal changeovers) in order to recover the high cost of this equipment. Toyota is famous for their use of low-cost automation, combined with flawlessly maintained, often older machines. Investing in smaller, more flexible equipment where possible; creating manufacturing cells; and combining steps will greatly reduce the waste of inappropriate processing.

3. **Unnecessary Inventory**

Work in Progress (WIP) is a direct result of overproduction and waiting. Excess inventory tends to hide problems on the plant floor. Excess inventory increases lead times, consumes productive floor space, delays the identification of problems, and inhibits communication. By achieving a seamless flow between work centers, many manufacturers have been able to improve customer service and cut inventories and their associated costs.

4. **Defects**

Having a direct impact to the bottom line, quality defects resulting in rework or scrap are a tremendous cost to organizations. In many organizations the total cost of defects is often a significant percentage of total manufacturing cost. Through employee involvement and Continuous Process Improvement (CPI), there is a huge opportunity to reduce defects at many facilities.

5. **Waiting**

Whenever goods are not moving or being processed, the waste of waiting occurs. Typically more than 90% of a product's life in traditional batch-and-queue manufacture is spent waiting to be processed. Much of a product's lead time is tied up in waiting for the next operation; this is usually because material flow is poor, production runs are too long, distances between work centers are too great and bottleneck due to unbalanced assembly line. One hour lost in a bottleneck process is one hour lost to the entire factory' s output, which can never be recovered. Linking processes together, so that one feeds directly into the next can dramatically reduce waiting

6. **Transportation**

Transporting products between processes is a cost incursion which adds no value to the product. Excessive movement and handling cause damage and are an opportunity for quality to deteriorate. Material handlers must be used to transport the materials, resulting in another organizational cost. Transportation can be difficult to reduce due to the perceived costs of moving equipment and processes closer together. Furthermore, it is often hard to determine which processes should be next to each other. Mapping product flows can make this easier to visualize.

7. **Unnecessary / Excess Motion**

This waste is related to work study and ergonomics and is seen in all instances of bending, stretching, walking, lifting, and reaching. These are also health and safety issues. Jobs with excessive motion should be analyzed and redesigned for improvement with the involvement of plant personnel.

8. **Underutilization of Employees**

Underutilization of Employees has been added as an eighth waste. It is only by capitalizing on employees' creativity that organizations can eliminate the other seven wastes and continuously improve their performance. [Company culture, hiring practices, low pay, and less training are the reasons behind underutilizing the work force available. Proper utilization of human resources is one of the major tasks faced by the manufacturing industries [6][14].

In this paper we are dealing with all these issues, but our primary focus is on minimizing waste related to the last four of the above-mentioned categories. Assembly Line Balancing (ALB) is one way to achieve that.

2.7. Types of assembly line model

Manual Assembly lines can be designed to deal with differences in assembled products. Based on product variety three types of assembly line can be distinguished: single model, batch model and mixed model. When product variety is hard, batch or multi model is the appropriate model. For soft product variety mixed model line is used and when there is no product variety single model line is the most appropriate model.

2.7.1. Single assembly model

In its traditional form, assembly lines were used for high volume production of a single commodity. Nowadays, products without any variation can seldom attract sufficient customers to allow for a profitable utilization of the assembly system. Advanced production technologies enable automated setup operations at negligible setup times and costs. If more than one product (almost identical so that they need not be distinguished) is assembled on the same line, but neither setups nor significant variations in operating times occur, the assembly system can be treated as a single model line. Minimizing the cycle time for a fixed number of workstations and minimizing the number of work stations required in order to achieve that given output rate are the two main goals in Simple Assembly Line Balancing Problem (SALBP) [7][12].

2.7.2. Mixed-model line

In practical, many items do not have sufficient demand to justify separate assembly line, but family of separate product might. We can use multiple product line to match the variable demand; however advantage of inventory reduction is lost. Just-in-time manufacturing brings considerable focus on production of variety of models on the same assembly line, so is the need for Mixed-Model Assembly Line Balancing (MALB). Mixed Model Assembly Line is capable of producing a variety of different product models simultaneously and continuously. Each worker of work-stations is skilled in a certain set of assembly work elements, but the stations are sufficiently flexible that they can perform their respective tasks on different models. Mixed model lines are usually used to complete the final assembly line of automobiles, small and large trucks, major and small appliances. The production processes of varying models are similar enough, so that setup times are not present or negligible. Thus, the units of the different models are produced in an arbitrarily intermixed sequence. The balancing problem is often based on an average model-mix. In order to anticipate the later sequencing problem adequately, a horizontal balancing objective is usually utilized which attempts to equalize the work content of stations over all models [7] [12][17].

2.7.3. Multi-model line

In multi-model production, the homogeneity of assembled products and their production processes is not sufficient to allow for facultative production sequences. In order to avoid setup times and costs the assembly is organized in batches. This leads to a short term lot-sizing problem which groups models to batches and decides on their assembly sequence. Especially if lot sizes are large, the line balance can in principle be determined separately for each model, as the significance of setup times between batches is comparatively small. However, also in multi-model production a certain degree of similarity in production processes should be inherent. Typically, the different models are manufactured by use of the same resources, e.g. machines or operators. If line balances are determined separately, those resources which are shared by models might need to be moved to other stations whenever the production system is setup for a new batch or have to be installed multiple times. This increases setup times and/or costs. If this interdependency is regarded in the line balance, the setup times might be reduced considerably, which in turn allows for a formation of smaller lots with all associated advantages [17][2][7].

The selected case company, Ramsey shoe factory has two assembly lines in the production department; stitching and lasting assembly line. In the stitching assembly line the different upper parts of the shoe are stitched and assembled together where as in the lasting assembly line the upper part of the shoe and external sole are assembled together. Stitching assembly line is not capable of producing different product models simultaneously. As a result of this, different models which are produced on this line follow batch production system. So this assembly line can be considered as multi model assembly line. Whereas lasting assembly line is capable of producing a variety of different product models simultaneously and continuously. Each worker in this assembly line is skilled in a certain set of assembly work elements within the station. Therefore, lasting assembly line can be considered as mixed model assembly line as long as different models can be loaded simultaneously. However since the whole production section of the firm follow batch production system, lasting assembly line is treated as multi model assembly line in this thesis.

2.8. Assembly Line Balancing with regard to its frequency

i. First time installation

Whenever an assembly production system is installed for the first time and resources have not been purchased yet, stations can in fact be treated as abstract entities, to which a certain number of tasks can be assigned. Typically, only the desired product with all its attributes and variants is already determined. The exact production process is often not yet fixed or not even fully substantiated. This can be taken into account in two different ways: The classical approach is to select and fix all tasks and their respective processing modes prior to the balancing decision to form a single precedence graph before the ALB problem is solved. Alternatively, this successive planning can be replaced by selecting the processing alternatives simultaneously with the balancing decision [7].

ii. Reconfiguration

The majority of real-life line balancing problems stem from a reconfiguration rather than from a first time installation (Falkenauer, 2005). A reconfiguration becomes necessary whenever there is a substantial change in the structure of the production program, e.g., a permanent shift in the demand for models. In a reconfiguration, stations have identities in the form of allotted resources and a physical location in the workshop. As stations are already existent, the minimization of the number of stations as an objective is less important. As a consequence, the retrieval of a feasible solution which observes the given number of stations and the cycle time is sufficient.

2.9. ALB and the level of automation

a) Manual lines

In spite of the major advances in the automation of assembly processes, there are still many assembly systems which mainly or completely rely on manual labor. Manual lines are especially common, where work pieces are fragile or if work pieces need to be gripped frequently, as industrial robots often lack the necessary of accuracy (Abdel-Malek and Boucher, 1985). In countries where wage costs are low, manual labor can also be a cost efficient alternative to expensive automated machinery. Task times under manual labor are often subject to stochastic deviations, as the performance of human workers depends on a variety of factors, like motivation, work environment or the mental and physical stress [7]

b) Automated lines

Fully automated lines are mainly implemented wherever the work environment is in some form hostile to human beings, as for instance in the body and paint shops of the automobile industry, or where industrial robots are able to perform tasks more economically and with a higher precision.

c) Combined Manual and Automated lines

As the name indicates, these lines comprise both manual and automated systems which aid in the production process.

Most manufactured consumer products are usually made on a manual assembly line. Factors favoring the use of manual assembly lines include the following [17]:

- When demand for the product is high or medium
- When the product made on the line are identical or similar
- When the total work required to assemble the product can be divided into small work elements
- When it is technologically impossible or economically infeasible to automate the assembly operations.

➢ The assembly line of the case company, Ramsey shoe factory is considered to be a manual assembly production system. Manual assembly lines are so productive compared with alternative methods in which multiple workers each perform all the tasks to assemble the products [12]:

- Specialization of labor or division of labor in which: when a large job is divided into small tasks and each task is assigned to one worker, the worker becomes highly proficient at performing the single task. As a result of this each worker becomes specialist.
- Interchangeable parts, in which each component is manufacture to sufficiently close tolerances that any part of a certain type can be selected for assembly with its mating component.
- Work principle in material handling, which provides that each work unit flows smoothly through the production line, travelling minimum distances between stations.
- Line pacing: workers on assembly line are usually required to complete their assigned tasks on each product unit within a certain cycle time, which paces the line to maintain a specified production rate.

2.10. Work transport system in assembly line

In a manual assembly system, there are two basic ways to accomplish the movement of work units: manually or mechanized system.

Manual methods of work transport: in manual work transport, the units of product are passed from station to station by hand. There are two problems resulted from this mode of operation: starving and blocking. Starving is the situation in which the assembly operator has completed the assigned task on the current work unit, but the next work unit has not yet arrived at the station. When the station is blocked, it means that the operator has completed the assigned task on the current work unit but cannot pass the unit to the downstream station because that worker is not yet ready to receive it. To mitigate the effects of these problems, storage buffers are sometimes used between stations [17].

In case of mechanized work transport system powered conveyors and other types of mechanized material handling equipment are widely used to move units along a manual assembly line. The three major categories of work transport systems in mechanized work transport system are: continuous transport, synchronous transport and asynchronous transport.

In continuous transport system a continuously moving conveyor that operates at constant velocity is usually used on manual assembly lines.

In synchronous transport systems, all work units are moved simultaneously between stations with quick, discontinuous motion, and then positioned at their respective stations.

In asynchronous transport system, a work unit leaves a given station when the assigned task has been completed and the worker releases the unit. Work units move independently rather than synchronously [17].

- The work transport system of the case company, Ramsey shoe factory is a mechanized work transport system in which work elements are transported on a continuously moving conveyor that operates at constant velocity.

2.11. Line pacing

To achieve the required production rate of the line, manual assembly line usually operates at a certain cycle time. Each worker must complete the assigned task at his or her station within this cycle time, or else the required production rate will not be achieved. Manual assembly lines can be designed with three alternative levels of pacing: rigid pacing, pacing with margin and no pacing [17].

In rigid pacing, each worker is allowed only a certain fixed time each cycle to complete the assigned task. The allowed time in rigid pacing is usually set equal to the cycle time of the line.

In pacing with margin, the worker is allowed to complete the task at the station within a specified time range

In no pacing, no time limit exists within which the task at station must be finished. This allows workers to take as much time as desired to complete a given unit.

2.12. Line balancing problem

The assembly line must be designed to achieve a production rate R_p sufficient to satisfy demand for the product. This production rate must be converted to a cycle time T_c , which is the time interval at which the line will be operated. The cycle time must take into account the reality that some production time will be lost due to occasional equipment failures, power outages, lack of a certain component needed in assembly, quality problems, labor problems and other reasons. As a result of these losses, the line will be up and operating only a certain proportion of time out of the total shift time available; this uptime proportion is referred to as the line efficiency [17].

Hence; $T_c = 60E/R_p$……………………………….. (Eq. 2.1)

Where T_c = cycle time of the line (min/cycle); R_p = required production rate (units/hr) and E = line efficiency. Typical values of E for a manual assembly line are in the range 0.98 – 0.98.

An assembled product requires a certain total amount of time to build, called the work content time T_{wc}. This is the total time of all work elements that must be performed on the line to make one unit of the product. The work content performed on an assembly line consists of many separate and distinct work elements. Invariably, the sequence in which these elements can be performed is restricted, at least to some extent. And the line must operate at a specified production rate, which reduces to a required cycle time. Given these conditions, the line balancing problem is concerned with assigning the individual work elements to work stations so that all workers have an equal amount of work. A minimum rational work element is a small amount of work having a specific limited objective. The sum of the work element times is equal to the work content time.

$T_{wc} = \sum T_{ek}$…………………………………………………………………… (Eq.2.2)

Where T_{ek} = time to perform work element k and n_e = number of work elements into which the work content is divided; that is k= 1, 2, 3….n_e. The time to perform the assigned task at each station is called service time $T_{si.}$ The Service time at each station is composed of the work element times that have been assigned to that station; that is

$$T_{si} = \sum T_{ek} \qquad \text{(Eq. 2.3)}$$

Service times will vary among stations because the total work content cannot be allocated evenly among stations. Some stations will have more work than others will. There will be at least one station at which T_{si} is maximum. A station, at which the service time is maximum, is referred to as bottleneck station. This station establishes the cycle time for the entire line.

Different work elements require different times and when the elements are grouped into logical tasks and assigned to workers, the station service times T_{si} are not likely to be equal. Thus, simply because of the variation among work element times, some workers will be assigned more work, while others will be assigned less. Although service times vary from station to station, they must add up to the work content time [17].

$$T_{wc} = \sum T_{si} \qquad \text{(Eq. 2.4)}$$

2.13. Measures of line balance efficiency

Because of the difference in minimum rational work element times and the precedence constraints among the elements, it is virtually impossible to obtain a perfect line balance. Measures must be defined to indicate how good a given line balancing solution is. One possible measure is balance efficiency, which is the work content time divided by the total available service time on the line.

$$E_b = T_{wc}/wT_s \qquad \text{(Eq. 2.5)}$$

Where E_b = balance efficiency, often expressed as a percentage; Ts = the maximum available service time on the line and w = number of workers. The complement of balance efficiency is balance delay, which indicates the amount of time lost due to imperfect balancing as a ratio to the total time available.

$$d = (wT_s - T_{wc})/wT_s \ldots\ldots \text{(Eq. 2.6)}$$

Where d = balance delay; and the other terms have the same meaning as before. A balance delay of zero indicates a perfect balance. Note that $E_b + d = 1$

2.14. Performance measurement and productivity

Current economic realities (liberalized and dynamic markets, constantly changing customer preferences, new structure of production and work, etc.) are leading to a rethinking of the notion/concept of productivity. Whereas traditionally, productivity is viewed mainly as an efficiency concept (amount of outputs in relation to efforts or resources used), productivity is now viewed increasingly as an efficiency and effectiveness concept, effectiveness being how the enterprise meets the dynamic needs and expectations of customers (buyers/users of products and services) i.e. how the enterprise creates and offers customer value. Productivity is now seen to depend on the value of the products and services (utility, uniqueness, quality, convenience, availability, etc) and the efficiency with which they are produced and delivered to the customers.

The globalization of the economy and other associated trends require a much broader conception of productivity and a fuller appreciation of the changing dynamics of the determinants involved in the process of its improvement. The increased competitiveness, internationalization and sophistication of markets, the globalization of manufacturing and the increased concern about social and ecological issues make productivity improvement more important.

At this moment, researches on the subject matter of performance measurement are hot issues for the companies to be competitive in the global markets. To exist in a competitive market, organizations need reliable and sustainable improvement on their business performance. Measurement is the first step for business performance improvement. Hence, there are a number of opportunities to conduct researches in companies. Neely (1995) described performance measurement as the process of quantifying action, where measurement is the process of quantification and action correlates with performance [15][13].

Throughout history, performance measures have been used to assess the success of organizations. To achieve sustainable business success in the demanding world marketplace, a company must use relevant performance measures. Performance measures of manufacturing systems are [1]: Manufacturing lead time (MLT), Work in process (WIP), Machine utilization, Throughput, Capacity, Flexibility, Quality and Cost

i. Manufacturing Lead Time

Manufacturing is a transformation process that converts raw materials into quality products and that the process of manufacturing consists of a sequence of machining and assembly operations. In between these operations, non value adding operations are performed. Ideally, we would want to eliminate these wasteful operations or at least minimize the time that a part spends in a manufacturing system. There are two variants of lead time: Manufacturing lead time (MLT) and Total lead lime (TLT) [1]

The manufacturing lead time (MLT) of a product is the total time required to process the product through the manufacturing plant. The total lead time (TLT) of a product is the total time elapsed from the instant at which raw materials are ordered until the instant the finished product is delivered. Ideally, MLT should be equal to the actual machining and assembly time. This is possible with zero inventories, zero material handling, zero setup time, zero defects, zero breakdowns and a batch size of one. The TLT is a complex quantity since it involves procurement, vendor, manufacturing; engineering, tooling and customer lead times. Here we focus on manufacturing lead time (MLT) [1]

Components of MLT: While focusing on MLT, we assume that raw materials are currently in stock (i.e., procurement lead time is zero and that we have made these items before, we have on hand the design, the process plan and the necessary tooling). Four components that constitute MLT: Processing time, Setup time, Move time, and Queue time.

Processing time: Processing time is the actual time spent on processing the manufacturing operation like machining, etc. In conventional batch processing, actual processing time and setup time together represent less than 5 % of MLT. Queuing and transport times account for the rest of the MLT.

Setup time: Setup time or changeover time is the time required by a machine or a system manufacturing one product type to switch to another product type. The setup time generally includes time required for fixing, tool changing and preparing the work piece. To minimize the setup time and costs, a batch of products is manufactured after a single setup. However, large batch size results in high inventory levels.

Move time: The moving of work pieces could be within the machine shop, within a factory, across factories or between various subcontracted processes performed by the vendors. Small batch sizes imply more number of moves between machine processes for the same production target. The need then would be for a smart material handling system that can make a large number of deliveries of small loads in a short time. The best material handling is no material handling and optimal move time is zero move time. Three ways to reduce transport times: creating versatile computer-controlled machine centers with automatic tool changers capable of performing a variety of processing operations, adapting product layouts or cellular layouts based on group technology principles, and using more efficient transfer mechanism such as belt conveyors, fork lifts, chutes and smart AGVs that can make faster delivery of unit loads [1].

Queuing time: Queuing times or waiting time before the resources such as machine centers, AGVs, etc., are the longest elements that make up the MLT. Queues occur before machine centers and AGVs because there are almost always jobs waiting to be processed by these resources. The queue length is proportional to the amount of work in process (WIP). The three contributory factors for long queues include inadequate capacity, erratic flow and poor part release policies.

ii. Work in Process (WIP)

Work in process (WIP) is the amount of semi-finished product currently resident on the factory floor. A semi-finished product is either being processed or is waiting for the next processing operation. Inventories are also seen as the insurance buffer against various uncertainties induced by delayed supplies, machine breakdowns, absenteeism and uncertain customer orders. Inventory is the evidence of poor design, poor forecasting, poor coordination and poor operation of the manufacturing system. WIP should be low [1].

iii. Machine Utilization

High machine utilization is assumed to be good because it amortizes the cost of the machinery faster. Idle time is supposed to be bad since high-priced equipment does not produce anything. Trade off, which one would benefit business more? Idle machine asset or idle inventory asset. Effective resource utilization is to run the machine to manufacture exactly the right quantity of exactly the right things at exactly the right time.

iv. Throughput

For a manufacturing system, the throughput is generally expressed as an hourly or daily production rate (i.e., the number of parts produced per hour or day). The reciprocal of the throughput or production rate is the production time per unit of the product. For transfer lines the throughput approximates the reciprocal of the cycle time (transfer time + longest operation time).

v. Capacity

The term capacity, or plant capacity, is used to define the maximum possible output of the transformation process the plant is able to produce over some specified duration. For a continuous plant, the duration is 24 hours a day, 7 days a week, whereas for an automobile plant the capacity is defined over a shift period.

vi. Flexibility

A flexible system is one that is able to respond to change, and flexibility is the ability of the system to respond effectively to change. Flexibility is fundamental to achieve competitiveness. In general, high degree of flexibility requires higher levels of automation and more investments. However, such a system will be an adapting organism capable of surviving in uncertain and changing markets. Changing circumstances include both internal and external changes. Internal changes or disturbances include breakdown of equipment, variability in processing time, work absenteeism and quality problems. External changes are typically changes in design, demand and product mix. The ability to cope with internal changes requires a degree of redundancy in the system, whereas the ability to cope with external changes requires that the system should be versatile and capable of producing a wide variety of part types with minimum changeover times and costs to switch from one product to another [1].

vii. **Quality**

Maintenance of high quality requires conscious efforts in various stages in design and manufacture. The effects of total quality control (TQC) are "fewer rework labor hours" and "less material waste" in addition to higher quality of finished goods. Thus good quality is not expensive but actually increases productivity, because so many costs such as rework, scrap, inspection, customer returns and warranty costs are all avoided with quality improvement. Continual improvement is a must since what was good last year will not make the grade this year.

viii. **Cost**

This includes decreasing the total cost of production by reducing value adding cost, non value adding cost, holding cost, waiting cost, material handling cost, and other costs [1].

2.15. An overview of Ethiopian footwear manufacturing industries

Manufacturing industries in Sub-Saharan Africa countries have generally been stagnant or shrinking for the last three decades. From the viewpoint of poverty reduction, this is worrying because industrial development is expected to offer plenty of employment opportunities to the poor. As many researchers argue, industrial development in Africa has been hindered by many problems ranging from high transportation costs, high transaction costs to highly risky business and political environments [22]. Moreover, both the provision of public services and the development of grass-roots institutions and social capital are considered to be insufficient in Africa to cope with such problems [15][13].

It is believed that leather and leather products plays a significant role in the development process of both developed and the developing countries. As a result of this, it can be said that there is an explicit attention of the present Ethiopian government for the leather sector; this includes the further strengthening of such a pivotal institution as the Leather and Leather Products Technology Institute (LLPTI) and footwear manufacturing industries. This policy attention is likely to create favorable conditions necessary for a substantial expansion of activities in the leather footwear sector.

Leather and Leather products is one of the most unexploited business in Ethiopia. It is repeatedly said that Ethiopia is one of the leading countries in the world in terms of its livestock resources. Ethiopia ranks first in Africa and tenth in the world in the number of its domestic animals. Ethiopia's livestock population is currently estimated at 35 million cattle, 21 million sheep and 16.8 million goats. Annually it produces 2.7 million hides, 8.1 million sheepskins and 7.5 million goatskins [23]. Therefore, Ethiopia has a major comparative advantage in the raw materials sector needed for the leather sector which makes it in principle very appropriate for leather product exporting. This comparative advantage is further underlined by the fact that the cost of raw hides and skins constitute, on average, between 55 to 60 per cent of the production of semi-processed leather. However, for the past years leather sector of the country remain incompetent in the market. As result of this the country fails to be economically benefited from this sector. The Ethiopian leather sector has two broad categories. The 1st one is Tanning/ Dressing of leather which focus on producing of semi-processed and finished leather and the second one is the manufacture of footwear, shoe uppers, leather garment, bags, belts, stitched upholstery and etc. Currently there are 11 footwear factories under operation which have great potentials to produce shoes for both local and export market. The total current production volume of these footwear factories is estimated around 4,500,000 pairs per annum. But it is argued that Ethiopia has much to gain from the growing global market for leather currently estimated at 40 billion USD a year [24]. Therefore a lot of jobs should be done on this sector so that the country will be benefited more. And for this, the Ethiopian government took action and working extensively to boost up the sector. As a result of this, good hopes are seen recently that most of the footwear manufacturing industries are becoming strong competitor in local market and as well as in export market.

Recently, the Government of Ethiopia has targeted to increase the export from this sector to 500 million USD within next five years which was only 101 million USD in 2007-08. However, the current limitation of technical and technological competence especially in the Footwear and Leather Product sector is being realized as the major challenge towards meeting the export target set by the Government of Ethiopia [24]. So this thesis is proposed to identify bottlenecks which can hinder the performance and effectiveness of footwear manufacturing process. Then by modeling and simulation techniques different scenarios and alternatives will be developed that can boost the effectiveness and efficiency of footwear manufacturing process. By doing so, the thesis can provide a significant contribution to meet the government export target point from the sector in the next five years.

This time, in order to respond to a diversified customer needs, companies have to introduce for an individualization of their products through their manufacturing system. Survival of any industry in today's competitive market place depends on response time, production cost and flexibility in manufacturing. The manufacturing Industries in Ethiopia are no exception to this fact. Hence strategies to increase throughput while reducing production costs are being explored. One efficient strategy to reduce production costs is by better control of the manufacturing process. But control of the process is possible only if the intricate details of the system are known. Computer simulation of the manufacturing process offers a cost effective solution not only to visualize the processes but also enables to identify bottlenecks in the system [14]

2.16. Modelling and simulation of manufacturing systems

Even though we have moved beyond the Industrial Age and into the Information Age, manufacturing remains an important part of the global economy. Modeling and simulation are emerging as key technologies to support manufacturing in the 21st century. There have been numerous efforts to use modeling and simulation tools and techniques to improve manufacturing efficiency over the last four decades. Process modeling and simulation are modeling techniques available to support companies in gaining a better understanding of their manufacturing system behaviors and processes and therefore helping them in decision making. Process modeling provides management with a static structural approach to business improvement, providing a holistic perspective on how the business operates, and provides a means of documenting the business processes. It also allows management to study the dynamics of the business and to consider the effects of changes without risk. According to the Oxford English dictionary, simulation means: The technique of imitating the behavior of some situations or systems (economic, military, mechanical etc.) by means of analogous situation, model or apparatus, either to gain information more conveniently or to train personnel. [9] Or in other word simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and evaluating various strategies for the operating system. A model is defined as an abstract and simplified representation of a system which includes the most important system components and the behavior or interaction between these components. Therefore the model can be used to [20][4]:

- Analyze current operations and identify problem area
- Test various scenarios for improvement and
- Design new manufacturing systems.

Simulation models allow to test potential changes in an existing system without disturbing it or to evaluate the design of a new system without building it. Simulation early in the design cycle is important, because the cost to repair mistakes increases dramatically the later in the product life cycle the error is detected. This methodology also allows comparing new concepts, equipments or scenarios before purchasing. [20]

For some purpose, simulations are better than the analysis of real data. With real data, it is never possible to perfectly know the real-world process that caused a particular measured situation, because of the too complex interactions inherent in large systems. In a simulation, the analyst controls all the factors making up the data and can manipulate them systematically to see directly how specific problems and assumptions affect the analysis. Because simulation software keeps track of statistics about model elements, performance can be evaluated by analyzing the model data. One important, but often difficult task for the "simulator" is to define a suitable level of representation with respect to the overall objectives of the simulation study [23].

System modeling can be used to study an existing system under various scenarios without modifying it, or for planning the construction of a new system which does not exist yet. System models are developed in order to evaluate some functional or non-functional properties of the system. Functional properties include throughput, mean execution time, reliability and so on. Non-functional properties include deadlock-freedom, usability, responsiveness and others.

Simulation is one of several alternative methods of analyzing systems. Another technique is the use of mathematical analysis. Analytical modeling involves building a system description using some formal, mathematical notation. Unfortunately mathematical analysis is limited to a relatively small number of simple systems and the opportunity to represent manufacturing systems in this way is felt to be limited [4].

Based on state of the system simulation can be categorized as using either a continuous or discrete time representation. Systems may have discrete or continuous state. In some systems the state changes all the time, not just at the time of some discrete events. For example, the water level in a reservoir with given in and outflows may change all the time. In such cases "continuous simulation" is more appropriate. The status of components is continuously changing with respect to time. It uses differential equations to track properties. Other systems however, only change at discrete points in time. For example, in an industrial plant, the system status changes when a new part arrives at a machine or when a machine breaks down. Between any two events, the status of the modeled system remains constant. To represent the changes in the system, it is only necessary to describe the actions or events which cause the status of the system to change. This is referred to as discrete event system modeling.

Discrete event simulation has applications in a wide range of sectors including automotive, healthcare, defense, electronics, pharmaceuticals, food and beverages, packaging, construction, footwear manufacturing and logistics. Manufacturing, industrial and service sectors have been the most common fields of simulation applications

Simulation in general is to pretend that one deals with a real thing while really working with an imitation. The imitation is a computer model of the simulated reality. It is very costly, dangerous and often impossible to make experiments with real systems. So that models are very important to describe reality, experimenting with them can save money, suffering and even time. This is done by developing a simulation model of the system. The model is based on a set of assumptions on the real system behavior, and on the workload driving the system. A correct and validated simulation model in fact can substitute the real system as long as the underlying assumptions are met [4].

In general, simulation is a practical methodology for understanding the high-level dynamics of a complex manufacturing system. Simulation has several strengths including:

- Time compression – the potential to simulate years of real system operation in a much shorter time,
- Component integration – the ability to integrate complex system components to study their interactions,
- Risk avoidance – hypothetical or potentially dangerous systems can be studied without the financial or physical risks that may be involved in building and studying a real system,
- Physical scaling – the ability to study much larger or smaller versions of a system,
- Repeatability – the ability to study different systems in identical environments or the same system in different environments, and
- Control – everything in a simulated environment can be precisely monitored and exactly controlled.

Modern manufacturing is characterized by high levels of automation and integration, complex interactions among system elements, and high capital costs. While modeling and analysis are important to help ensure good system performance, the integration and complexity of systems often makes purely analytic tools difficult to use. Hence, simulation remains one of the most widely used tools to fill this need. A number of commercially available software packages are in use both in industry and academia, including ARENA., AutoMod., QUEST, Simu8, and WITNESS. Such packages and simulation in general, have experienced great improvements with recent advances in computational technologies. Specific improvements include graphical user interfaces to facilitate model-building, integration with spreadsheets and databases for better data management, and powerful capabilities to visualize and animate model execution. In general, increased computational power has enabled development of detailed "high fidelity" models of systems to aid in design and operation. The ability to create high fidelity models has important potential benefits in prototyping system performance.

Computer simulation modeling has been applied to manufacturing industry since the late 1960's when IBM introduced its General Purpose Systems Simulator (GPSS) package.

Simulation was found to be a very useful means of analyzing the dynamics of materials flow through a manufacturing plant, for example, to:

- Identify current or potential bottlenecks and their impact on profitability.
- Examine effects of changing resource capacity (eg adding or subtracting operators or units of equipment, working additional shifts, purchasing extra machine etc).
- Analyze effects of different batch sizing policies on inventory levels, throughput and lead times.
- Examine effects of random equipment breakdowns and the potential impact of different maintenance strategies.
- Analyze the relative impact on material flow velocity of reducing process variability in alternative targeted areas.
- Check on the overall ability of the plant to respond to different assumed rates of demand increase, and identification of what resources will be the first to come under pressure

2.17. Arena simulation software

The Arena modeling system from Systems Modeling Corporation is a flexible and powerful tool that allows analysts to create animated simulation models that accurately represent virtually any system. First released in 1993, Arena employs an object-oriented design for entirely graphical model development. Simulation analysts place graphical objects—called modules—on a layout in order to define system components such as machines, operators, and material handling devices. Arena is built on the SIMAN simulation language. After creating a simulation model graphically, Arena automatically generates the underlying SIMAN model used to perform simulation runs.

Arena allows the interactions with other computer tools such as Visual Basic, Excel, etc., and it is very well integrated in Windows environment. With Arena, it is possible to choose the level of complexity by using « basic features » or features that are more specific. It is even possible to create customized tools in the program. [7] Consequently, Arena is a very good tool for doing research, since it can be linked with other programs in Windows environment and models as complex and accurate as needed can be created. Because of the above advantages of the software and its availability (student version); Arena simulation software is selected for this thesis work. The commercial version software is available in the market but it is expensive to afford. Therefore, by taking some assumptions it is decided to use the student version Arena software.

Chapter three

Overview of the Case Study Company and General Statistics

3.1. Introduction

Ramsay shoe factory is a private limited company, under ELFNESH-ZELALEM SHOE AND LEATHER PRODUCTS MANUFACTURING S.C. It has been established in 1993/2000 for the main purpose of export market with a maximum production capacity of 2000 pairs of shoes per day. It is located in Addis Ababa, at Saris Industry Zone. At present, the company has around 267 employees, of which 149 are females.

The company has got different awards from Prime Minister; Meles Zenawi, Ministry of Trade and Industry (MOTI), and Brown Shoes USA due to the factory's good performance and supportive management. Now the company exports to Europe, Japan and most African countries and major buyers are Geox Italy, Brown Shoes USA and Hiroki Japan.

Currently, the company is producing different type of fashion and casual Footwear for different market segment. The major products from footwear segment comprises of Men's dress, open and casual, ladies wedge, casual, boots (ankle and calf boot), and children casual footwear. Most of the products are designed and exported to the international markets. Apart from the export the company is also having its presence in the domestic market meeting the local demand of the footwear. The market share of the company is growing gradually.

The company has show room for the purpose of display of footwear within the premises of the company. Apart from this the company is also involved in selling footwear through agents, retail outlets & institutional sales in the domestic segment.

The organization of the company has flat structure with the General Manager as Chief Executive Officer as Managing Director, Production Manager, Quality control manager, marketing head, merchandising head, Finance manager, Planning manager & Human resource development manager.

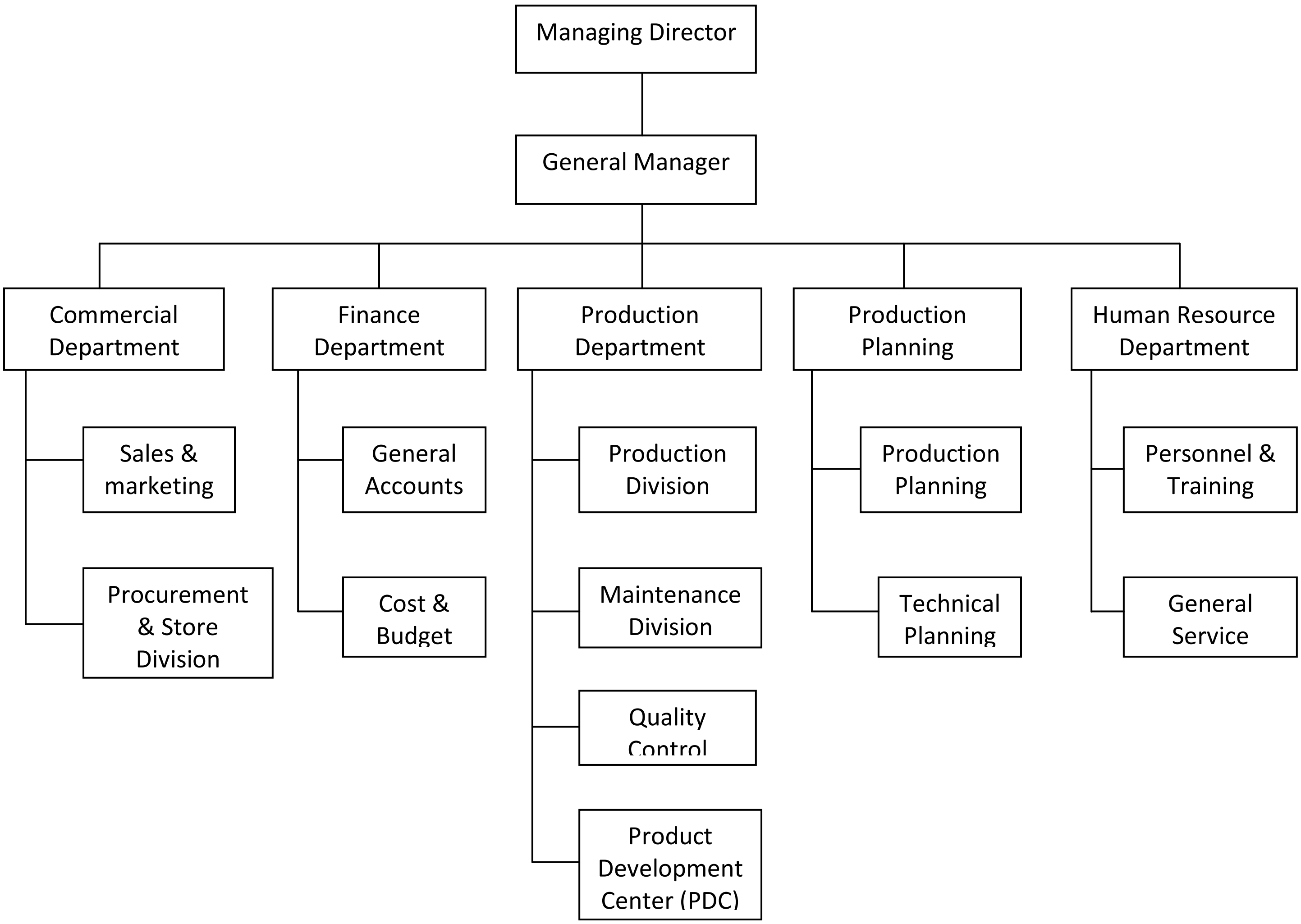

Figure 3.1 organizational structure of Ramsey shoe factory

The production department has four divisions: production division, maintenance division, quality control division and product development center (PDC). This thesis is concerned with the production division. Within the production department there are three sections: cutting section, stitching section and lasting section. In this thesis we focus on modeling and simulation of assembly line balancing of the last two sections of the production department: stitching and lasting section in which each comprises two assembly lines. In the stitching assembly lines the different upper parts of the shoe are stitched together and assembled. This assembly line has two U type conveyors on which the different components or parts of the shoe are transported from one work station to another work station. However, at the time of data collection and investigation only one assembly line was under operation. The length of this line's conveyor is 37.5 meters.

Likewise, in the lasting department the upper part of the shoe which is the output of the stitching assembly line and the internal and external sole of the shoe are assembled together. Similar to stitching assembly line, lasting assembly line has two U type conveyors on which the upper part of the shoe and external sole of the shoe are transported from work station to work station. However, at the time of data collection and investigation only one assembly line was under operation. The length of this line's conveyor is 28meters.

Currently, the company is producing over 40 types of shoe models of men's, ladies and children's. However, for this thesis work a simple model shoe called moccasin with model number 7101 is selected. The main reason for this selection is: the number of assembled parts of this model shoe is lower compared to the other shoe models. On the other hand, the student version Arena software is incapable of modeling complex and vast processes. It is incapable of handling more than 300 modules. For this reason, the simplest model shoe moccasin 7101 is selected for this thesis work.

Even if the company has high installed production capacity, its capacity utilization is too much low. The main reason for this low capacity utilization is the global shoe market. The company production system is totally driven by the market. When there is high demand (order) its capacity utilization will increase relatively. In contrary when there is low market demand its capacity utilization will decrease. The average daily and monthly production volume of the company is shown in the following table 3.1 and 3.2.

As a result of this, usually the company follows a make to order batch production system for its export market. However, for its local market the company usually follows a make to stock batch production system. The company sells its local product through its shops located in Addis Ababa and other part of the country. The company owns 8 shops in Addis Ababa and planning to open new branches in the other part of the country. Therefore whenever there is an order for export market, the production department will fully engaged on the production of export product even if there is local product in the pipe line.

Table 3.1 Daily production volume of the company for September (Historical data)

No.	Sep. 2003 E.C	Production volume (pairs of shoe)
1	1/7/2003	196
2	2/7/2003	374
3	3/7/2003	488
4	4/7/2003	277
5	5/7/2003	-
6	6/7/2003	420
7	7/7/2003	-
8	8/7/2003	-
9	9/7/2003	212
10	10/7/2003	406
11	11/7/2003	-
12	12/7/2003	252
13	13/7/2003	145
14	14/7/2003	184
15	15/7/2003	247
16	16/7/2003	79
17	17/7/2003	137
18	18/7/2003	111
19	19/7/2003	144
20	20/7/2003	326
21	21/7/2003	427
22	22/7/2003	437

23	23/7/2003	412
24	24/7/2003	362
25	25/7/2003	354
26	26/7/2003	400
27	27/7/2003	400
28	28/7/2003	-
29	29/7/2003	-
30	30/7/2003	-
Average		290

Table 3.2 Average daily actual production volume of the company from September – March 2003 (Historical data)

No.	Months (2003 E.C)	Production volume
1	September	290
2	October	298
3	November	359
4	December	268
5	January	412
6	February	272
7	March	290
Average production volume		301

From the above tables; we can see how the production volume of the company changes even within consecutive days and months. As a result of this, the capacity utilization of the company changes from day to day. The average capacity utilization with respect to the installed capacity can be simply calculated as follows.

Average capacity utilization = Average production volume/ Installed production capacity

= 301/2000

= 15.05%

To boost up the capacity utilization there is a need to work more jobs in relation to the market to get more shares. This can be achieved by several ways. Performance improvement at the core business function of the company, which is the production department, will bring a one big step improvement in reducing manufacturing cost. Reducing manufacturing cost will decrease market price of the product. When the market price of the product decreases, buying capacity of customer will increase. Then the company market share will increase. This will in turn increase production output. When the production output increases capacity utilization will also increase.

3.3. Data collection process

In a simulation project, the ultimate use of input data is to drive the simulation model. This process involves the collection of input data, analysis of the input data, and use of the analysis of the input data in the simulation model. For simulation model development of the footwear manufacturing of Ramsey shoe factory the following data were gathered:

- Total number of tasks
- Processing times of each task
- Priorities between processes
- Arrival frequencies of entities or time between arrival of each assembly line
- Manning level for each task
- Conveyor length and speed
- Working hours
- Production output
- Defect rate (rework)

These input data may be either obtained from historical records or collected in real time. The collection of input data is often the most difficult process involved in conducting a simulation modeling and analysis project. Initially, data collection begins from identifying and observing the different operations done on each assembly line. After observing all operations or tasks which are done on the assembly lines; we define individual work elements to each work stations. Individual work element is a minimum rational work element having a specific limited objective.

Based on this, the number of tasks on each assembly lines are determined and the processing time for each task is collected and tabulated in the following tables (Table 3.3 and 3.4)

All processing times and arrival frequencies were found to be probabilistic rather than deterministic. The processing time was defined as the time span from entry to the station to the end of process completion excluding the times of stoppages, rework times, and queue times. Sometimes workers are going upstream ahead of the conveyor and picked up the WIP from the moving conveyor. This makes difficult and complex the data collection process. Processing time for each task was measured in seconds and was taken using digital stop watch in every workstation. The number of data collection in this model is 15 data for each process that involved. The collected raw data for each process of assembly line is tabulated as follows.

Table. 3.3. Collected processing time for each task of stitching assembly line (raw data)

Stitching department						**Model 7101 (Moccasin)**								**July 6-9, 2011**	
No.	**Operation**	**No. of workers**	**Observed time (In seconds)**												**Remark**
1	Marking	4	120	110	130	125	122	124	134	141	145	115	110	111	
			112	120	128										
2	Skiving	5	198	185	189	187	176	169	195	185	184	172	170	162	
			186	164	173										
3	Printing size number (on M/C sicomec)	1	14	12	15	10	14	15	13	12	12	13	14	15	
			13	12	15										
4	Sorting	1	30	35	21	25	24	28	30	35	40	42	38	36	
			30	28	25										
5	Apron gluing (upper)	1	20	21	25	40	19	17	28	19	38	21	25	25	
			32	26	30										
6	Apron gluing (lining)	1	23	18	25	24	38	35	30	26	19	21	25	27	
			20	24	26										
7	Vamp gluing (upper)	1	29	41	31	39	32	37	36	41	32	41	44	39	
			30	36	36										
8	Vamp gluing (lining)	1	31	28	30	32	34	27	30	33	32	39	36	35	
			30	31	30										
9	Sponge attaching to the apron	1	8	9	8	10	9	9	10	15	12	19	13	10	
			12	10	12										
10	Spnge attaching to the vamp	1	13	15	12	9	10	11	13	11	12	10	12	10	
			12	15	13										

11	Apron pasting	1	32	30	28	25	22	21	19	20	21	18	23	24	
			30	25	25										
12	Vamp pasting	1	44	31	32	28	31	20	21	26	33	30	27	25	
			30	28	32										
13	Vamp pressing	1	13	11	14	10	12	9	13	14	12	12	11	10	
			9	8	7										
14	Apron pressing	1	10	9	8	11	10	8	9	10	11	12	14	9	
			10	9	11										
15	Recutting Apron		16	15	18	13	15	14	20	22	16	14	14	19	
			15	15	16										
16	Recutting Vamp	1	14	16	14	15	13	20	17	21	19	22	14	14	
			16	14	15										
17	Vamp marking	1	29	28	30	25	35	26	31	22	26	28	32	29	
			26	22	31										
18	Vamp skiving	1	8	12	8	11	16	19	8	14	12	8	10	11	
			11	9	12										
19	Back sime stitch `	1	30	17	18	17	18	17	15	21	17	19	16	19	
			18	15	17										
20	Back sime taping	1	9	10	10	10	9	11	10	11	10	9	10	11	
			9	10	11										
21	Apron stitch	1	35	34	36	33	41	37	38	35	36	33	37	34	
			33	35	35										
22	Vamp stitch	1	16	19	38	12	16	22	23	21	22	22	20	22	
			23	22	21										
23	Counter gluing	1	26	37	25	23	23	31	20	26	21	24	26	22	

			23	21	22										
24	Stiffener gluing	1	17	15	12	14	12	13	14	13	12	15	14	16	
			14	13	11										
25	Pasting Stiffener on counter	1	19	17	22	31	25	22	23	20	19	18	20	21	
			25	21	22										
26	Vamp gluing	1	11	10	9	12	8	11	9	11	12	8	10	12	
			11	10	12										
27	Pasting Counter on vamp	1	9	10	11	11	10	12	15	13	15	14	16	17	
			11	12	11										
28	Hill grip (counter lining) gluing		5	7	7	6	5	9	5	5	5	6	5	6	
			7	6	8										
29	Hill grip pasting on the vamp	1	7	7	11	8	7	9	7	7	6	8	8	8	
			7	8	8										
30	Counter stitch	4	48	43	35	35	39	67	51	31	35	70	75	80	
			77	83	73										
31	Hill grip trimming	1	14	12	13	11	10	12	10	14	13	10	14	14	
			12	11	10										
32	Binding taping	2	20	21	25	24	22	17	25	20	21	22	18	20	
			25	21	24										
33	Binding stitch	4	75	65	73	120	68	63	65	75	80	94	75	110	
			87	94	113										
34	Binding hammering	1	16	24	24	23	19	21	20	19	18	20	22	23	
			21	22	19										
35	Binding stitch	3	76	65	45	32	44	44	40	65	75	70	80	90	
			50	83	49										
36	Edge coloring of Apron	1	20	22	21	19	24	18	18	25	19	20	18	19	
			19	20	22										
37	Burning	2	15	22	13	10	12	11	15	16	14	15	12	20	

			18	13	15										
38	Back molding	1	23	15	16	17	16	17	18	17	16	18	16	15	
			17	15	16										
39	Hand stitch	12	680	672	470	530	480	495	641	600	720	660	540	480	
Total		65	415	490	540										

Table 3.4. Collected processing time for each task of lasting assembly line (raw data)

Lasting department			Model 7101 (Moccasin)											July 12-15, 2011	
No.	**Operations**	**No. of worker**	**Observed time (In seconds)**												**Remark**
1	Insole attaching	1	46	37	23	24	40	37	44	33	35	27	19	21	
			24	23	33										
2	Sole peraiming	1	11	11	8	9	12	10	11	10	12	9	10	12	
			11	11	12										
3	Inserting upper in the last (salento tecnica m/c)	1	17	19	29	29	35	30	25	19	20	22	22	16	
			18	19	22										
4	Back centering (salento tecnica m/c)	1	21	22	23	24	24	24	22	36	19	30	22	22	
			24	25	22										
5	Lasting margin gluing	1	19	26	19	22	19	20	19	20	18	22	20	21	
			24	18	20										
6	Heating (RSF M/C 04)		24	23	44	21	25	24	28	21	24	25	28	22	
			23	24	25										
7	Side lasting (salento tecnica m/c)	1	22	31	42	35	40	33	29	37	37	32	22	24	
			33	32	25										
8	Heating (RSF M/C 04)		16	18	16	19	33	15	18	20	23	18	17	20	
			18	18	19										
9	Back lasting (RSF M/C 05)	1	30	19	16	24	26	19	22	25	25	17	16	18	
			19	31	27										
10	Tack removing		7	8	8	8	7	7	6	7	10	7	8	7	
			7	8	7										
11	Heating (RSF M/C 06)	1	65	65	65	65	65	65	65	65	65	65	65	65	
			65	65	65										

12	Boiling (RSF M/C 19)	1	46	48	37	33	28	33	40	34	38	28	33	26	
			37	33	35										
13	Hammering	1	37	25	21	24	20	30	33	16	28	24	25	22	
			24	23	27										
14	Crime	1	24	23	23	20	24	19	23	29	30	23	25	24	
			23	22	23										
15	Ironing (RSF M/C 07)	1	27	28	28	26	17	22	20	22	24	30	26	26	
			22	26	28										
16	Brushing (RSF M/C, Diabson)	1	19	21	21	19	17	17	19	15	18	19	17	16	
			21	19	19										
17	Sole marking	1	33	37	24	32	25	40	35	34	35	29	34	35	
			37	35	29										
18	Roughening (RSF M/C 11)	2	52	56	50	53	54	50	53	50	48	53	54	52	
			50	52	53										
19	Upper gluing 1st	1	19	19	25	19	18	19	19	20	23	22	24	21	
			22	19	18										
20	Sole gluing	1	9	11	13	10	12	11	10	8	9	8	7	9	
			10	11	8										
21	Upper gluing 2nd	1	25	26	19	21	18	24	23	19	21	22	23	21	
			22	21	22										
22	Drying	19minu t	113	Con											
23	Heat activation (RSF M/C)		24	cons											
24	Sole attaching	1	7	12	9	9	9	8	10	11	10	11	12	11	
			9	8	7										
25	Sole pressing (RSF M/C)	1	31	27	23	19	21	22	24	23	24	22	21	23	
			21	18	19										

26	Sole edge cleaning (RSF M/C)		19	15	20	18	19	18	20	18	18	19	20	17	
			19	18	17										
27	Frizzing (RSF M/C)	1	240	cons											
28	Delasting (RSF M/C)	1	9	7	7	7	14	9	7	8	8	8	7	7	
			7	8	8										
29	Sock gluing	1	9	7	15	10	9	9	8	7	7	9	8	10	
			9	7	8										
30	Sock attaching	1	19	12	13	10	12	11	13	14	12	16	13	11	
			10	9	12										
31	Cleaning and burning	4	49	55	30	45	56	65	46	59	70	75	82	49	
			95	67	79										
32	Edge coloring	1	23	22	20	27	30	23	19	31	25	23	18	26	
			20	23	21										
33	Spray (RSF M/C 17)	1	7	8	10	8	9	7	6	8	9	11	9	7	
			10	9	8										
34	Brushing (RSF M/C 16)	1	21	22	21	16	15	19	21	18	16	15	18	21	
			27	19	20										
35	Taging and inserting soft paper	2	46	50	44	48	47	50	40	52	51	53	39	45	
			41	42	44										
36	Final quality inspection	2	30	32	46	28	24	30	39	35	40	29	28	30	
			40	38	32										
37	Packing	2	27	24	20	24	22	20	26	19	21	19	18	20	
			22	21	22										
Total		38													

3.2. Production processes

The selected moccasin model shoe has a total number of 19 parts to be assembled on both lines. These are listed below.

1. Apron
2. Vamp
3. Apron lining
4. Vamp lining
5. Apron sponge
6. Vamp sponge
7. Counter
8. Counter lining
9. Stiffner
10. Vamp reinforcement
11. Apron reinforcement
12. Insole
13. Sock lining
14. Sock pad (sponge)
15. Shank board
16. Shank steel
17. Binding
18. External sole
19. Saddle

As mentioned above, the production division of the production department has three sections; Cutting, Stitching, and Lasting assembly line. The production of any shoe model starts from the production planning department where the company resources are directed and coordinated towards the achievement of pre-decided production goal of the firm. From the production planning department production schedule of a specified shoe model is sent to the production department. Within the production department the Product Development Center (PDC) will check the design and develop prototype or sample of the intended shoe model. Ones the developed shoe model is checked it will be sent to the cutting section of the production department. In the cutting section the different assembled parts of the shoe is prepared as per the design specification. After the cutting section the parts will be sent to the stitching section where the different parts of the shoe are assembled. In the stitching assembly line there are 37 defined tasks (processes) to be done. These tasks, their predecessor, manpower level, average processing time, and machine names are listed down in the table below (Table 3.5). From the stitching assembly line the stitched or assembled parts of the shoe will be sent to the Lasting assembly line section in which the upper assembled part and the external sole are assembled. In this assembly line there are 37 defined tasks. These tasks, their predecessor, manpower level, average processing time, and machine name are listed down in the table below (Table 3.6).

Table 3.5. Stitching assembly line processes and their predecessors

No.	Basic Operation in stitching assembly line	Man power	M/C Name	Predecessor	Average processing time
1	Marking	4	-	-	141.6
2	Skiving	5	RSFM/C	1	206.6
3	Printing size number	1	M/C sicomec	2	15
4	Sorting	1	-	3	35.8
5	Apron gluing (upper)	1	-	4	29.6
6	Apron gluing (lining)	1	-	4	29
7	Vamp gluing (upper)	1	-	4	41.7
8	Vamp gluing (lining)	1	-	4	36.6
9	Sponge attaching to the apron	1	-	5,6	12.7
10	Sponge attaching to the vamp	1	-	7,8	13
11	Apron pasting	1	-	6,9	27.8
12	Vamp pasting	1	-	8,10	33.6
13	Vamp and Apron pressing	1	RSF M/C35	11,12	24
14	Recutting Vamp and Apron	1	RSF M/C50	13	37
15	Vamp marking	1	-	14	32
16	Vamp skiving	1	RSF M/C162	15	13
17	Back sime stitch (on M/C 141)	1	RSF M/C141	16	21
18	Back sime taping (on M/C 49)	1	RSF M/C49	17	11.5
19	Apron stitch (on M/C 139)	1	RSF M/C139	14	40.8
20	Vamp stitch (on M/C 143)	1	RSF M/C143	16	24.5
21	Counter roughening and gluing	1	-	-	28.4
22	Stiffener gluing	1	-	21	15.7
23	Pasting Stiffener on counter	1	-	22	24.9
24	Vamp gluing	1	-	20	12
25	Pasting Counter on vamp	1	-	23,24	14
26	Hill grip (counter lining) gluing and pasting	1	-	24	7
27	Hill grip pasting on the vamp	1		26	9
28	Counter stitch	4	RSFM/C116, 113,112 &103	25,26	64.5

29	Hill grip trimming	1	RSF M/C27	27	13.8
30	Binding taping	2	-	3	25
31	Binding stitch	3	RSF M/C150	29	96
32	Binding hammering	1	RSF M/C55	30	23.8
33	Binding stitch (opposite side)	4	RSF M/C 144,138, 137	31	69.6
34	Edge coloring of Apron	1	-	32	23
35	Burning Apron	2	-	33	17
36	Back molding	1	RSF M/C	34	19
37	Hand stitch	12	-	35	574
Total man power		65			

Table 3.6. Lasting assembly line processes and their predecessors

No.	List of all processes in lasting assembly line	Man powe	M/C	Predecessor	Average processing time
1	Insole attaching	1	-	-	41.5
2	Sole praiming	1	-	-	18
3	Inserting upper in the last	1	Salento	2	32
4	Back centering	1	Salento	3	33
5	Gluing lasting margin	1	-	4	29
6	Side lasting heating	-	RSF M/C 04	5	35
7	Side lasting	1	-	6	42
8	Back lasting heating	-	RSF M/C 04	7	27.8
9	Back lasting	1	-	8	31
10	Tack removing	1	-	9	14
11	Heating	-	RSF M/C 06	10	65
12	Boiling	1	RSF M/C 19	11	46
13	Hammering	1	-	12	34.8
14	Creaming	1	-	13	33
15	Ironing	1	RSF M/C 07	14	34
16	Brushing	1	RSF M/C	15	27
17	Sole marking	1	-	16	43.6
18	Roughening	2	RSF M/C 11	17	65.5
19	Upper gluing 1st	1	-	18	29
20	Sole gluing	1		2	17
21	Upper gluing 2nd	1	-	19	31
22	Drying	-	-	19, 20, 21	1138
23	Heat activation		RSF M/C	22	24
24	Sole attaching	1	-	23	16.7
25	Sole pressing	1	RSF M/C	24	31.7
26	Sole edge cleaning	1	RSF M/C	25	27
27	Frizzing	-	RSF M/C	26	240
28	Delasting	1	RSF M/C	27	15
29	Sock gluing	1	-	28	16
30	Sock attaching	1	-	29	20
31	Cleaning and burning	1	-	30	76

32	Edge coloring	1	-	31	32.7
33	Spraying	1	RSF M/C 17	32	15
34	Brushing	1	RSF M/C 16	33	28
35	Final quality inspection	2	-	34	44
36	Taging and inserting soft paper	2	-	35	58.8
37	Packing	3	-	36	30.7
Total man power		36			

3.4. Arena input analyzer

The analysis involves the identification of the theoretical distribution that represents the input data. The use of the input data in the model involves specifying the theoretical distributions in the simulation program code. The input analyzer tools built in Arena was used to convert the collected data into probability distributions to be used in the simulation model.

The process of determining the underlying theoretical distribution for a set of data usually involves what is known as a goodness of fit test. These tests are based on some sort of comparison between the observed data distribution and a corresponding theoretical distribution. If the difference between the observed data distribution and the corresponding theoretical distribution is small, then it may be stated with some level of certainty that the input data could have come from a set of data with the same parameters as the theoretical distribution. There are four different methods for conducting this comparison: Graphic approach, Chi-square test, Kolmogorov–Smirnov test and Square error

The Input Analyzer has the capability to calculate chi-square, Kolmogorov–Smirnov (KS), and square error tests. In addition to these it is capable of determining the quality of fitness of probability distribution functions to input data and generate high-quality data plots.

Therefore, the data was processed in the Input Analyzer tool built in Arena, and the results are used to set the type of function and its value to be used in simulation model

It was critical phase to determine the best distribution because it affects the performance of the assembly line. In deciding which distribution to present, it tried to choose those that are simple to describe, implement and are reasonably efficient as well (Law et al., 1991). The distributions that are occurring in continuous simulation are Uniform, Exponential, Erlang, Gamma, Weibull, Normal, Lognormal, Beta, Pearson Type V, Pearson Type VI, Log-Logistic and Triangular.

For example, sample input analyzer data distribution of a task back lasting in the lasting assembly line is shown in the figure below (Figure.3.2). Whereas; input analyzer data distribution function for all processes of both assembly lines is attached in Appendix I.

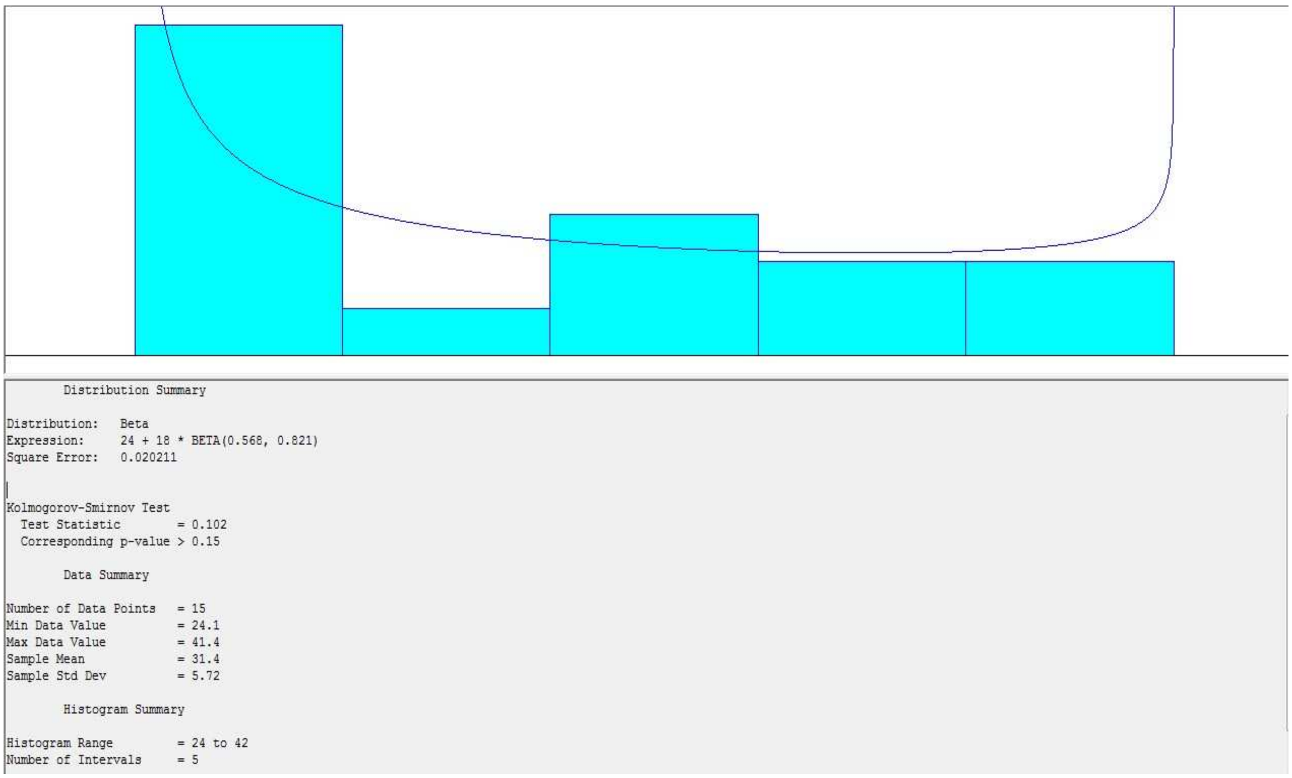

Figure.3.2 Input analyzer data distribution function window for back lasting operation

Distribution Summary

Distribution: Beta

Expression: 24 + 18 * BETA (0.568, 0.821)

Square Error: 0.020211

Kolmogorov-Smirnov Test

Test Statistic = 0.102

Corresponding p-value > 0.15

Data Summary

Number of Data Points = 15

Min Data Value = 24.1

Max Data Value = 41.4

Sample Mean = 31.4

Sample Std Dev = 5.72

Histogram Summary

Histogram Range = 24 to 42

Number of Intervals = 5

From the above data fit test, the function that best fits the distribution is the expression: 18 + 18 * BETA (0, 0) and therefore back lasting operation follows the above distribution in the simulation process.

3.5. Simulation model formulation

The objective of model formulation or development is to determine which components of the system should be included in the model and how the model should flow to imitate the real system.

The model development was started with the declaration of the entity, the location of the workstations, generating path network and resources, declaration of the arrival and processing programming.

Logic flow describes the way by which the entity acts during its journey in the simulation model. It was easy to observe the route the entity follows during the model building stage. For simplicity and limitation with the student version arena software, we made the following assumption and simplifications in developing the simulation model.

1. Two and more similar individual work elements which are done by a single worker are merged together and considered as one individual work element.

2. In addition to the main task the worker entitled; he/she is responsible for quality inspection on his/her work and previous work done in the upstream station. However, considering this task independently in modeling of the footwear manufacturing makes the simulation so difficult since the student version Arena software is incapable of handling more than 150 entities. Therefore, we add up 5sec of processing time for quality inspection on the basic processing time.

3. The other most important thing is the transportation time between stations: WIP are transported by a constantly moving conveyor from station to station. However, taking each transportation time in between stations as one entity makes the simulation and modeling of footwear manufacturing process so complex and difficult in which the student version Arena software is incapable of running if number of entities is greater than 150. Therefore, we divide the transportation time in between the adjacent stations and add up to the basic processing time of each station.

4. The lasting assembly line is categorized as mixed model assembly line in which different models can be loaded at the same time. However; in model development of the assembly process on this line it is treated as multi model assembly line. The main reason for this is the company follows a batch production system. Therefore; even if the line is capable of handling different models at the same time; usually it is loaded a single model based on batch production system.

5. Considering some unanticipated circumstances for example the machine may stack or fail for a while, the worker may take more time in repositioning the work piece, the worker may strolling around his/her station, the worker may be busy in doing some private task other than the intended one. Therefore considering all this unanticipated circumstances we add up15% of the basic processing time as allowance to each basic processing time. By doing so all

processing tasks, their predecessors, average processing time and manning level for each task are listed in the above tables (Table 3.3 & 3.4) for each assembly line.

3.6. Stitching assembly line Model

This assembly line begins with the marking station were the different components of the upper part of the shoe are marked for stitching. Next to this station, the components are transported to the skiving station in which the marked part is skived. Then the work part is transported on the moving conveyor to the next station were the next task is performed. Thus, based on the precedence of task the work part passes all the way through the line stations were the different intended tasks are performed. Finally this line ends up with the final 'hand stitch' work station were workers are stitching the upper part manually by hand. As a result of this, the model logic for stitching assembly line is developed using Arena simulation software and shown below in Figure.3.3

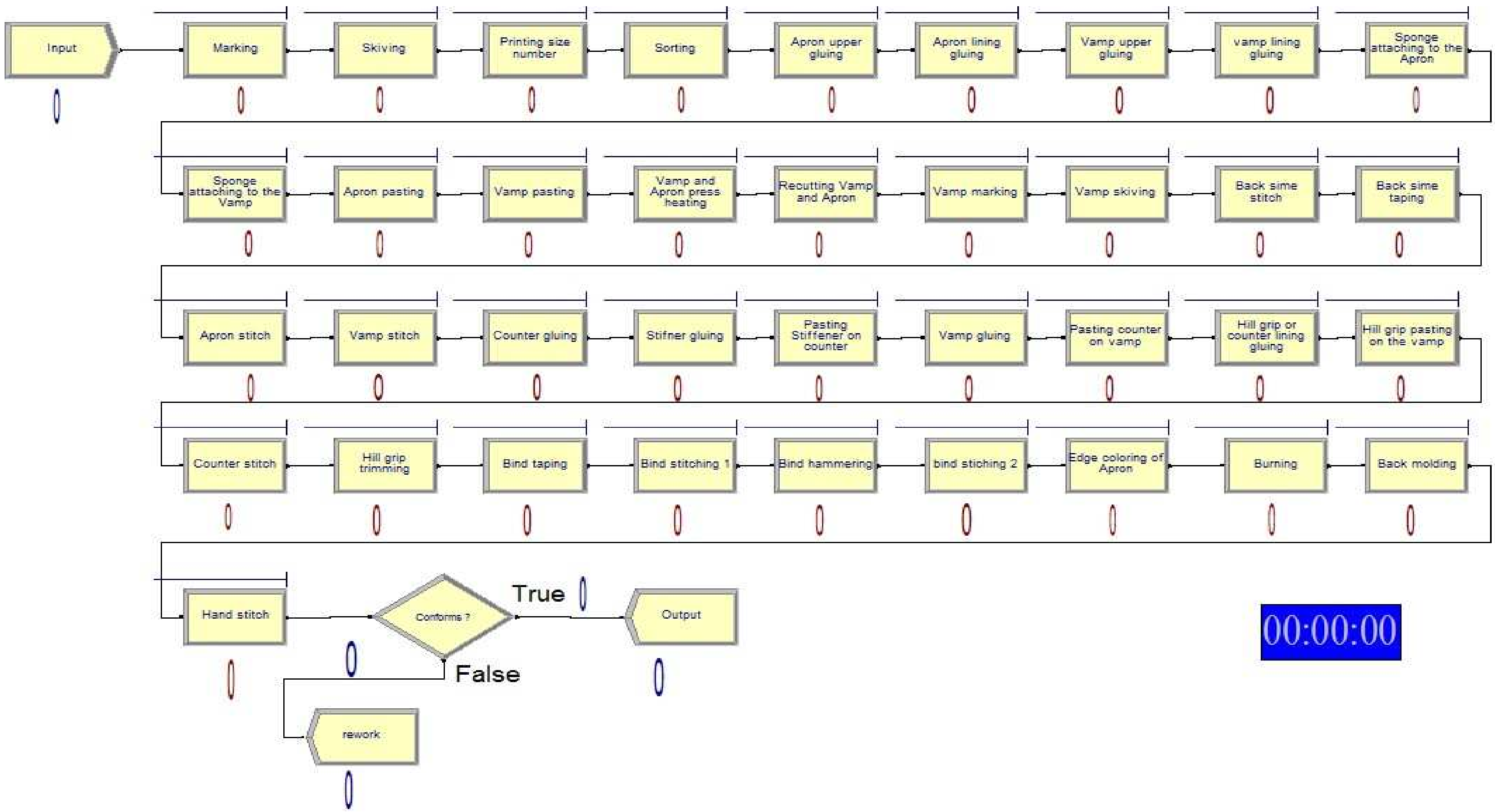

Figure.3.3 stitching assembly line simulation model for existing manufacturing system

3.7. Lasting assembly line Model

This assembly line begins with Insole attaching operation in which the internal sole (Insole) is attaching on the 'last' (plastic mold) by using nails. Similar to the stitching assembly line, the work part is transported on the conveyor to the next station for the next intended operation based on precedence of tasks. Thus, the work part passes all the way through the line stations and finally ends up with the intended shoe. Hence, the model logic for lasting assembly line is also developed using Arena simulation software and shown below in Figure.3.4

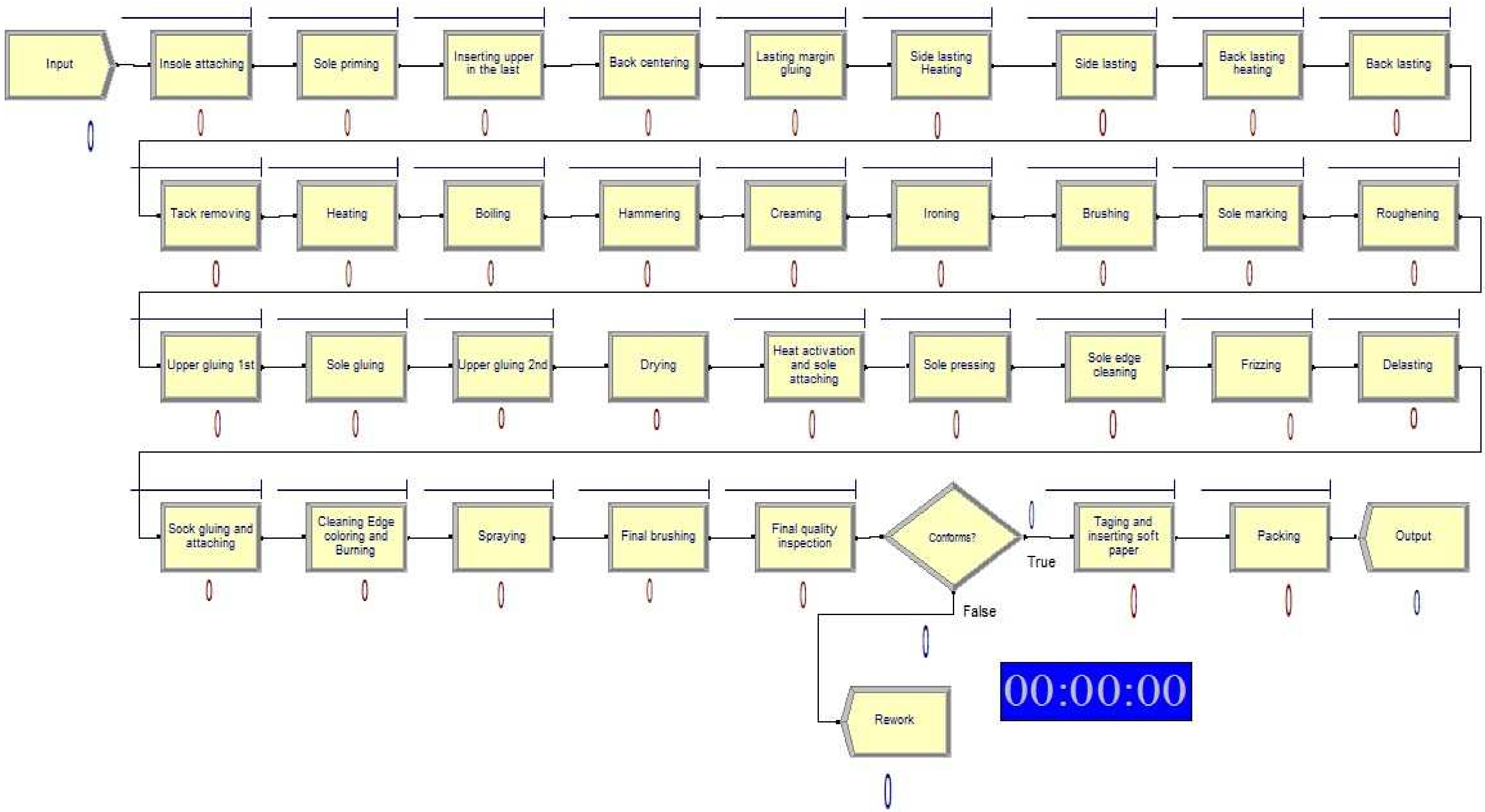

Figure. 3.4. lasting assembliy line model for existing manufacturing system

3.8. Number of replication

Number of replication is number of simulation runs that should be executed to analyze statistically the differences between the simulation model and the real system thereby we can estimate the error we introduce in modeling the real system. It has an integer value greater or equal to 1[21].

The input distributions of simulation models are usually probabilistic in nature. This input variability naturally results in some variation in the output measures of performance. Because the output measures have some variation, it is inappropriate for the simulation practitioner to recommend any given course of action based on the results from a single simulation run or replication. To reduce the chance of making a wrong recommendation, it is necessary to run a number of simulation replications and then make the recommendations based on all of the available data. The question is: If not one replication, then how many? This is the purpose of replication analysis [21]

The replication analysis process begins with selecting an initial number of replications. Summary statistics from this initial set of replications are then used to calculate whether or not additional replications are required at a particular level of confidence. If more replications are required, then there is a need to run additional replications and recalculate the summary statistics and replication formulas for the process.

Therefore; we must begin with some arbitrary number of replications to begin the replication analysis. Relatively, a smaller number of initial replications will increase the probability that the initial number is insufficient and that additional replications will be required. Conversely, a larger number of initial replications will decrease the probability that the initial number of replications is insufficient. However, a larger number of unnecessary initial replications will result in increased time on the part of the practitioner. Although this may not be a problem for relatively small simple models run on fast microcomputers, it could become a serious issue for larger, more complex models. The practitioner must also remember that it is not just one model that will need to undergo replication analysis, but all of the alternative models.

A reasonable practitioner compromise to this situation is to initially run some small number of replications. A common number of initial replication is ten. This provides a sufficient number of replications to have reasonable statistical confidence given that additional replications can always be subsequently added [21].

3.9. Calculations of replication number

In order to perform the replication calculations, we must first calculate the mean and standard deviation of the first ten replication means. The following table 3.5 shows the average output and standard deviation for ten replications of footwear manufacturing for both assembly lines.

These summary statistical values are then used to calculate what is known as the standard error of the data using the following formula [21]:

Standard Error = $t_{1-\alpha/2,\, n-1} * s/\sqrt{n}$ ………………………………………………… (Eq.3.1)

Where:

t = t probability distribution value for 1- α/2 from table

n-1 degrees of freedom

s = standard deviation of the replication means (it is the amount of dispersion around the mean value that data may exhibit)

n = number of observations in the sample

The standard error is essentially the amount of dispersion around the mean value that data may exhibit. The first term *t* comes from the *t* probability distribution table (Appendix II). The *t* value depends on two parameters, the α level and the number of degrees of freedom. The α level has to do with the level of confidence at which we wish to conduct our analysis. If we want to be 95%

confident in the results of our analysis, then the α level is 1 minus the confidence level, or 0.05. We are interested in the dispersion around both sides of the mean, so we divide the α level in half. The mathematical formula for the sample standard deviation of the replication averages is:

$$S = \sqrt{\frac{\sum_1^n xi - x}{n-1}} \quad \text{.........} \quad \text{(Eq.3.2)}$$

Where

s = standard deviation of sample

xi bar = the replication average

x bar bar = average of the replication averages

n = number of replications

Considering the first 10 replications; we have the following:

Table 3.7 Mean, standard deviation and half width for initial 10 replication of foot wear manufacturing

Number of Replications	Stitching line	Lasting line
1	555	523
2	555	518
3	558	524
4	551	522
5	562	526
6	543	520
7	542	522
8	553	524
9	551	520
10	543	525
Mean	551.3	522.4
Standard Deviation	6.78	2.5
Half width	4.85	1.79

The half width statistic is used to help in determining the reliability of the results from the replication. In other word half width is a sampling error we introduce in taking sample. Therefore the value of half width can be simply determined by using the above formula 3.1.

Standard Error = $t_{1-\alpha/2,\, n-1} * s/\sqrt{n}$

Considering a 95% confidence level the value of t can be read from t probability distribution table (Appendix II)

Hence: $t_{(at\ 95\%,9)} = 2.262$

Half width for stitching assembly line:

$= t_{1-\alpha/2,\, n-1} * s/\sqrt{n}$

$= (2.262 * 6.78)/\sqrt{10}$

$= 4.85$

Half width of lasting assembly line:

$= t_{1-\alpha/2,\, n-1} * s/\sqrt{n}$

$= (2.262 * 2.5)/\sqrt{10}$

$= 1.79$

Therefore, the percentage error for stitching assembly line equal to:

$= (551.3 + 4.85)/551.3 = 1.0088 = 0.88\%$

Similarly the percentage error for lasting assembly line equal to:

$= (522.4 + 1.79)/522.4 = 1.0034 = 0.34\%$

To achieve specific half width h, presumably smaller than the one we got in the initial set of 10 replications, we set h equal to the half-width formula above and solved for n.

$n = t^2_{1-\alpha/2,\, n-1} * s^2/h^2$ …………………………………………………………….….. (Eq.3.3)

The difficulty with this is that it wasn't really solved for n since the right hand side still depends on n. However to get at least a rough approximation to the sample size required, we replaced the t probability distribution value in the formula above with the standard normal probability distribution value. This led to the following as an approximate required sample size to achieve a confidence interval with a half width equal to a pre-specified desired value h:

$n \cong z^2_{1-\alpha/2} \frac{s^2}{h^2}$ ……………………………………………………………………...…. (Eq.3.4)

Where s is sample standard deviation from initial set of n replications. The above equation can further be approximated as:

$n \cong n_0 \frac{h_0^2}{h^2}$ …………………………………………………………………………….... (Eq.3.5)

Where, n_0 is the number of initial replications we had and h_o is the half width. If error level from the initial sample of 10 replications is not quite satisfying, the initial half width can be reduced thus greater precision level can be achieved.

Assume we wanted half width for stitching assembly line to be 2.4 and for lasting assembly line to be 0.895, and taking the value of Z at 95% confidence level to be 1.96 form z table (Appendix III) then the number of replication for each line became:

$n \cong 1.96^2 \frac{6.78^2}{2.4^2}$ = 30.65 = 31 replications (stitching assembly line first approximation)

$n \cong 10\frac{4.85^2}{2.4^2}$ = 40.84 = 41 Replications (stitching assembly line second approximation)

$n \cong 1.96^2\,\frac{2.5^2}{0.89^2}$ = 30.3 = 31 replications (Lasting assembly line first approximation)

$n \cong 10\frac{1.79^2}{0.89^2}$ = 40.45 = 41 Replications (Lasting assembly line second approximation)

Therefore 41 replications are taken for both stitching assembly line and lasting assembly line which would give low acceptable error level

3.10. Model verification and validation

A model is an abstract and simplified representation of a real system which includes the most important system components and the behavior or interaction between these components. However, a model cannot represent the real system exactly rather it can approximate the system how it behave and interact. This is mainly due to the assumptions made while developing the model. Therefore; there is some variation between the constructed model and the real system. This variation directly affects the performance measures of the system. The performance measures extracted from a model will only represent the real system if the model is a good representation of the system. Therefore; our criteria for judging the goodness of models will be based on how performance measures extracted from the model correspond to the measures which would be obtained from the real system.

By its nature a model is more abstract than the system it represents. Viewed in one way, abstraction, and assumptions we make to achieve it, eliminate unnecessary detail and allow us to focus on the elements within the system which are important from a performance point of view; viewed in another way, this abstraction process introduces inaccuracy. Inevitably some assumptions must be made about the system in order to construct the model. However, having made such assumptions we must expect to put some effort into answering questions about the goodness of our model. There are two steps to judging how good a model is with respect to the system. We must ascertain whether the model implements the assumptions correctly which is called model verification and whether the assumptions which have been made are reasonable with respect to the real system which is called model validation.

3.10.1 Model verification

Verification is the process of ensuring that the simulation model operates as intended. This means that the practitioner has included all of the intended components in the model and that the model is actually able to run. In other words, verification is the process of ensuring that the model design (conceptual model) has been transformed into a computer model with sufficient accuracy. Sometimes, model verification confuse with model validation. Verification is the continuous process of insuring that the model operates as intended, whereas validation is the process of insuring that the model represents reality. It is pointless to attempt to see if the model represents reality in case the model does not even operate as intended. In other words, you should not attempt to validate a model that has not successfully undergone the verification process. From a verification perspective, animation provides the information about the internal behavior of the model.

A model which includes all of the components specified under the system definition phase and capable of running without any errors or warnings is considered to be verified successfully.

The model logic was checked whether it manifest the characteristics of the flow process of the real model. In other words, the arrival times, processing time stations take and stations where queues are developed are examined and compared with the real system.

3.10.2. Model validation

Validation is the task of demonstrating that the model is a reasonable representation of the actual system. The inability of the model to represent reality may result from certain actions or omissions on the part of the practitioner with respect to any or all of the following issues assumptions, simplifications, oversight and limitations. These assumptions, simplifications, oversights, and limitations cannot be so gross as to prevent the model from representing reality at a given confidence level. If any of these potential problems do prevent the model from representing reality, the practitioner may have serious problems. The validation process assists the practitioner in knowing whether it is appropriate to proceed with the simulation study or go back to the drawing board.

Model verification techniques are general while the approach taken to model validation is likely to be much more specific to the model, and system, in question.

There are two major types of validation of simulation model. The first is face validity which is to mean that the model at least on the surface represents reality. The second is statistical validity. Statistical validity involves a quantitative comparison between the output performances of the actual system and the model [21].

Model validation for this study is made using statistical validity by comparing the output of the real system and the simulation model output of the existing system. If there is no statistically significant difference between the data sets, then the model is considered valid. Conversely, if there is a statistically significant difference, then the model is not valid and needs additional work before further analysis may be conducted. The output of 7101 moccasin shoe model in the real manufacturing system at an average per eight hours; ranges from 210 to 412 shoes with an average output of 301 shoes. The output level the simulation model offered per eight hour shift is 266 shoes at an average for lasting assembly line. Even the output of the real system highly varied, the output of the simulation model approaches the average output of the real system. Therefore the model can be said to represent the real system, and is said to be valid. In addition to this; work stations with relatively high work in progress and low work in progress in real system are also observed in the simulation model. For instance, in stitching assembly line hand stitching station is observed with high WIP in real system: in case of the running the simulation model for this line, this station is registered with high level of WIP similarly other stations also observed the same phenomena. Therefore, this can also strongly validate the developed model to represent the real system.

Chapter four

Simulation model results and analysis

4.1. Introduction

Output analysis is the examination of data generated by a simulation model. Its purpose is to predict the performance of a system or to compare the performance of two or more alternative system designs. Output analysis also predicts the initial model performance and look after the weaknesses.

Therefore, based on the output of the simulation model the performance measures are analyzed for the existing manufacturing system and for different proposed scenarios to balance assembly lines, increase capacity utilization, increase output, increase production rate, minimize production time, minimize work in process, increase line balance efficiency, and minimize line delay.

4.2. Performance measures by running the model for existing manufacturing system:

4.2.1. Stitching assembly line

- Input = 657
- Manning level 65
- Output (P) per 8 hours = 561 shoes =280.5 pairs
- Production rate (R_p) = P/480 = 1.169 shoes / min
- Make span or work content time (T_{wc}) = 1825.01 sec =30.4min
- Work in process (WIP) = 68.1732 shoes
- Production efficiency (E_p) = Output /Input = 561/657 = 0.854
- Capacity utilization: the instantaneous capacity utilization for each station of Stitching assembly line is shown in the following Table 4.1.

Table: 4.1. Instantaneous capacity utilization of stitching assembly line

No.	Resources	Average	Half	Min	Max	Min	Max
1	Apron paster	0.6155	0.01	0.5731	0.6580	0.00	1.00
2	Apron stitcher	0.2524	0.01	0.2333	0.2706	0.00	1.00
3	Back sime stitch	0.4614	0.01	0.4272	0.4953	0.00	1.00
4	Binder	0,2707	0.00	0.2499	0.2884	0.00	1.00
5	Binder stitcher 2	0.3159	0.00	0.2907	0.3371	0.00	1.00
6	Binding Hammer	0.5163	0.01	0.4745	0.5550	0.00	1.00
7	Binder stitcher 1	0.6976	0.01	0.6464	0.7466	0.00	1.00
8	Burner	0.1850	0.00	0.1684	0.1977	0.00	1.00
9	Counter gluer	0.6214	0.01	0.5691	0.6718	0.00	1.00
10	Counter paster	0.5452	0.01	0.5029	0.5836	0.00	1.00
11	Counter stitcher	0.3530	0.00	0.3206	0.3823	0.00	1.00
12	Counter vamp paster	0.3219	0.00	0.2907	0.3548	0.00	1.00
13	Gluer 1	0.6622	0.01	0.6146	0.7115	0.00	1.00
14	Gluer 2	0.6501	0.01	0.5981	0.6982	0.00	1.00
15	Gluer 3	0.8929	0.01	0.8260	0.9514	0.00	1.00
16	Gluer 4	0.8218	0.01	0.7582	0.8817	0.00	1.00
17	Gluer 5	0.2595	0.00	0.2399	0.2775	0.00	1.00
18	Hand stitcher	0.9405	0.00	0.9159	0.9485	0.00	1.00
19	Hill grip gluer	0.1543	0.00	0.1418	0.1655	0.00	1.00
20	Hill grip paster	0.1946	0.00	0.1780	0.2081	0.00	1.00
21	Marker	0.8112	0.01	0.7498	0.8694	0.00	1.00
22	Molder	0.4162	0.00	0.3820	0.4440	0.00	1.00
23	Press heater	0.5314	0.01	0.4924	0.5699	0.00	1.00
24	Printer	0.3420	0.00	0.3184	0.3656	0.00	1.00
25	Recutter	0.8178	0.01	0.7532	0.8755	0.00	1.00

26	Skiver	0.9223	0.01	0.8548	0.9875	0.00	1.00
27	Sorter	0.7977	0.01	0.7402	0.8511	0.00	1.00
28	Sponge attacher 1	0.2989	0.00	0.2733	0.3311	0.00	1.00
29	Sponge attacher 2	0.2959	0.00	0.2736	0.3135	0.00	1.00
30	Stiffner gluer	0.3445	0.00	0.3178	0.3666	0.00	1.00
31	Tapper	0.2524	0.00	0.2347	0.2699	0.00	1.00
32	Trimmer	0.3000	0.00	0.2762	0.3202	0.00	1.00
33	Vamp marker	0.7091	0.01	0.6551	0.7570	0.00	1.00
34	Vamp paster	0.7430	0.01	0.6940	0.7957	0.00	1.00
35	Vamp skiver	0.2858	0.00	0.2668	0.3073	0.00	1.00
36	Vamp stitcher	0.5387	0.01	0.4949	0.5807	0.00	1.00
37	Edge coloring	0.5035	0.01	0.4625	0.5368	0.00	1.00

From the above table it can be seen that hand stitch station has the highest capacity utilization equal to 94% where as Hill grip gluer has the lowest capacity utilization equal to 15.43%. Therefore, hand stitch station is the bottle neck station for stitching assembly line.

4.2.2. Lasting assembly line

- Input = 554
- Manning level is 36
- Output (P) per 8 hours =531 shoes
- Production rate (R_p) = P/480 = 1.106 shoes / min
- Make span or work content time (T_{wc}) = 1127.72 sec =18.8min
- Work in process (WIP) = 22.73 shoes
- Production efficiency (E_p) = Output /Input = 531/554 = 0.96
- Capacity utilization: the instantaneous capacity utilization for each station of lasting assembly line is shown in the following Table 4.2

Table: 4.2. Instantaneous capacity utilization of lasting assembly line

No.	Resources	Average capacity	Half width	Min Average	Max average	Min value	Max value
1	Attacher	0.7988	0.00	0.7850	0.8180	0.00	1.00
2	Back laster	0.5990	0.00	0.5930	0.6099	0.00	1.00
3	Back lasting heater	0.2659	0.00	0.2627	0.2704	0.00	1.00
4	Boiler	0.8781	0.00	0.8618	0.8884	0.00	1.00
5	Brusher	0.5108	0.00	0.5078	0.5137	0.00	1.00
6	Cleaner and burner	0.3375	0.00	0.3331	0.3462	0.00	1.00
7	Constant heater	0.0892	0.00	0.0892	0.0894	0.00	1.00
8	Cream polisher	0.6262	0.00	0.6194	0.6322	0.00	1.00
9	Delaster	0.2805	0.00	0.2781	0.2832	0.00	1.00
10	Drying section	0.9006	0.00	0.8991	0.9015	0.00	1.00
11	Edge cleaner	0.5009	0.00	0.4986	0.5040	0.00	1.00
12	Edge colour polisher	0.6198	0.00	0.6078	0.6324	0.00	1.00
13	Final brusher	0.5180	0.00	0.5139	0.5245	0.00	1.00
14	Frizzer	0.4295	0.00	0.4289	0.4299	0.00	1.00
15	Gluer 1	0.5640	0.00	0.5577	0.5703	0.00	1.00
16	Hammer	0.6616	0.00	0.6540	0.6699	0.00	1.00
17	Heat activator	0.4498	0.00	0.4492	0.4500	0.00	1.00
18	Inserter	0.6159	0.00	0.6025	0.6263	0.00	1.00
19	Inspector	0.4083	0.00	0.4027	0.4142	0.00	1.00
20	Iron	0.6515	0.00	0.6448	0.6572	0.00	1.00
21	Marker	0.8273	0.00	0.8197	0.8364	0.00	1.00
22	Packer	0.2787	0.00	0.2744	0.2820	0.00	1.00
23	Primer	0.3447	0.00	0.3424	0.3464	0.00	1.00
24	Roughner	0.6246	0.00	0.6215	0.6264	0.00	1.00
25	Salento 2	0.8027	0.00	0.7911	0.8164	0.00	1.00
26	Salento 1	0.6367	0.00	0.6279	0.6504	0.00	1.00
27	Side lasting heater	0.3353	0.00	0.3308	0.3405	0.00	1.00
28	Sock attacher	0.3743	0.00	0.3699	0.3782	0.00	1.00
29	Sock gluer	0.2969	0.00	0.2915	0.3001	0.00	1.00
30	Sole attacher	0.3127	0.00	0.3105	0.3150	0.00	1.00
31	Sole gluer	0.2109	0.00	0.2078	0.2151	0.00	1.00
32	Sole presser	0.5925	0.00	0.5880	0.6033	0.00	1.00
33	Sprayer	0.2857	0.00	0.2830	0.2882	0.00	1.00
34	Tack remover	0.2731	0.00	0.2719	0.2747	0.00	1.00
35	Tagger	0.5327	0.00	0.5239	0.5393	0.00	1.00
36	Upper gluer 1	0.5520	0.00	0.5487	0.5572	0.00	1.00
37	Upper gluer 2	0.5793	0.00	0.5759	0.5830	0.00	1.00

From the above table it can be seen that, drying section has the highest capacity utilization equal to 90% where as constant heater has the lowest capacity utilization equal to 9%.

Table: 4.3. Number of busy resources with respect to scheduled number of resources of stitching assembly line

No.	Resources	Average busy No. of resources	Half width	Min Averag	Max average	Min value	Scheduled resources
1	Apron paster	0.6155	0.01	0.5731	0.6580	0.00	1.00
2	Apron stitcher	0.2524	0.00	0.2333	0.2706	0.00	1.00
3	Back sime stitcher	0.4614	0.01	0.4272	0.4953	0.00	1.00
4	Binder	0.5415	0.01	0.4998	0.5768	0.00	2.00
5	Binder stitcher 2	1.2635	0.01	1.1629	1.3483	0.00	4.00
6	Binding Hammer	0.5163	0.01	0.4745	0.5550	0.00	1.00
7	Binder stitcher 1	2.0927	0.02	1.9393	2.2397	0.00	3.00
8	Burner	0.3701	0.00	0.3368	0.3954	0.00	2.00
9	Counter gluer	0.6214	0.01	0.5691	0.6718	0.00	1.00
10	Counter paster	0.5452	0.01	0.5029	0.5836	0.00	1.00
11	Counter stitcher	1.4119	0.02	1.2824	1.5291	0.00	4.00
12	Counter vamp paster	0.3219	0.00	0.2907	0.3548	0.00	1.00
13	Gluer 1	0.6622	0.01	0.6146	0.7115	0.00	1.00
14	Gluer 2	0.6501	0.01	0.5981	0.6982	0.00	1.00
15	Gluer 3	0.8929	0.01	0.8260	0.9514	0.00	1.00
16	Gluer 4	0.8218	0.01	0.7582	0.8817	0.00	1.00
17	Gluer 5	0.2595	0.00	0.2399	0.2775	0.00	1.00
18	Hand stitcher	11.2861	0.03	10.991	11.3816	0.00	12.00
19	Hill grip gluer	0.1543	0.00	0.1418	0.1655	0.00	1.00
20	Hill grip paster	0.1946	0.00	0.1780	0.2081	0.00	1.00
21	Marker	3.2447	0.04	2.9991	3.4775	0.00	4.00
22	Molder	0.4162	0.00	0.3820	0.4440	0.00	1.00
23	Press heater	0.5314	0.01	0.4924	0.5699	0.00	1.00
24	Printer	0.3420	0.00	0.3184	0.3656	0.00	1.00
25	Recutter	0.8178	0.01	0.7532	0.8755	0.00	1.00
26	Skiver	4.6113	0.05	4.2741	4.9373	0.00	5.00
27	Sorter	0.7977	0.01	0.7402	0.8511	0.00	1.00
28	Sponge attacher 1	0.2989	0.00	0.2733	0.3311	0.00	1.00
29	Sponge attacher 2	0.2959	0.00	0.2736	0.3135	0.00	1.00
30	Stiffner gluer	0.3445	0.00	0.3178	0.3666	0.00	1.00
31	Tapper	0.2524	0.00	0.2347	0.2699	0.00	1.00
32	Trimmer	0.3000	0.00	0.2762	0.3202	0.00	1.00

33	Vamp marker	0.7091	0.01	0.6551	0.7570	0.00	1.00
34	Vamp paster	0.7430	0.01	0.6940	0.7957	0.00	1.00
35	Vamp skiver	0.2858	0.00	0.2668	0.3073	0.00	1.00
36	Vamp stitcher	0.5387	0.01	0.4949	0.5807	0.00	1.00
37	Edge coloring	0.5035	0.01	0.4625	0.5368	0.00	1.00

Table: 4.4. Number of busy resources with respect to scheduled number of resources of lasting assembly line

No.	Resources	Average busy No. of resources	Half width	Min Average	Max average	Min value	Scheduled resource
1	Attacher	0.7988	0.00	0.7850	0.8180	0.00	1.00
2	Back laster	0.5990	0.00	0.5930	0.6099	0.00	1.00
3	Back lasting heater	0.5317	0.00	0.5253	0.5408	0.00	2.00
4	Boiler	0.8781	0.00	0.8618	0.8884	0.00	1.00
5	Brusher	0.5108	0.00	0.5078	0.5137	0.00	1.00
6	Cleaner and burner	1.3501	0.00	1.3323	1.3849	0.00	4.00
7	Constant heater	0.0893	0.00	0.0892	0.0894	0.00	1.00
8	Cream polisher	0.6262	0.00	0.6194	0.6322	0.00	1.00
9	Delaster	0.2805	0.00	0.2781	0.2832	0.00	1.00
10	Drying section	0.9006	0.00	0.8991	0.9015	0.00	
11	Edge cleaner	0.5009	0.00	0.4986	0.5040	0.00	1.00
12	Edge colour polisher	0.6198	0.00	0.6078	0.6324	0.00	1.00
13	Final brusher	0.5180	0.00	0.5139	0.5245	0.00	1.00
14	Frizzer	0.4295	0.00	0.4289	0.4299	0.00	1.00
15	Gluer 1	0.5640	0.00	0.5577	0.5703	0.00	1.00
16	Hammer	0.6616	0.00	0.6540	0.6699	0.00	1.00
17	Heat activator	0.4498	0.00	0.4492	0.4500	0.00	1.00
18	Inserter	0.6159	0.00	0.6025	0.6263	0.00	1.00
19	Inspector	0.8167	0.00	0.8053	0.8285	0.00	2.00
20	Iron	0.6515	0.00	0.6448	0.6572	0.00	1.00
21	Marker	0.8273	0.00	0.8197	0.8364	0.00	2.00
22	Packer	0.5574	0.00	0.5487	0.5641	0.00	2.00
23	Primer	0.3447	0.00	0.3424	0.3464	0.00	1.00
24	Roughner	1.2491	0.00	1.2430	1.2528	0.00	2.00
25	Salento 2	0.8027	0.00	0.7911	0.8164	0.00	1.00
26	Salento 1	0.6367	0.00	0.6279	0.6504	0.00	1.00
27	Side lasting heater	0.6706	0.00	0.6617	0.6810	0.00	2.00
28	Sock attacher	0.3743	0.00	0.3699	0.3782	0.00	1.00
29	Sock gluer	0.2969	0.00	0.2915	0.3001	0.00	1.00
30	Sole attacher	0.3127	0.00	0.3105	0.3150	0.00	1.00

31	Sole gluer	0.2109	0.00	0.2078	0.2151	0.00	1.00
32	Sole presser	0.5925	0.00	0.5880	0.6033	0.00	1.00
33	Sprayer	0.2857	0.00	0.2830	0.2882	0.00	1.00
34	Tack remover	0.2731	0.00	0.2719	0.2747	0.00	1.00
35	Tagger	1.0653	0.00	1.0478	1.0785	0.00	2.00
36	Upper gluer 1	0.5520	0.00	0.5487	0.5572	0.00	1.00
37	Upper gluer 2	0.5793	0.00	0.5759	0.5830	0.00	1.00

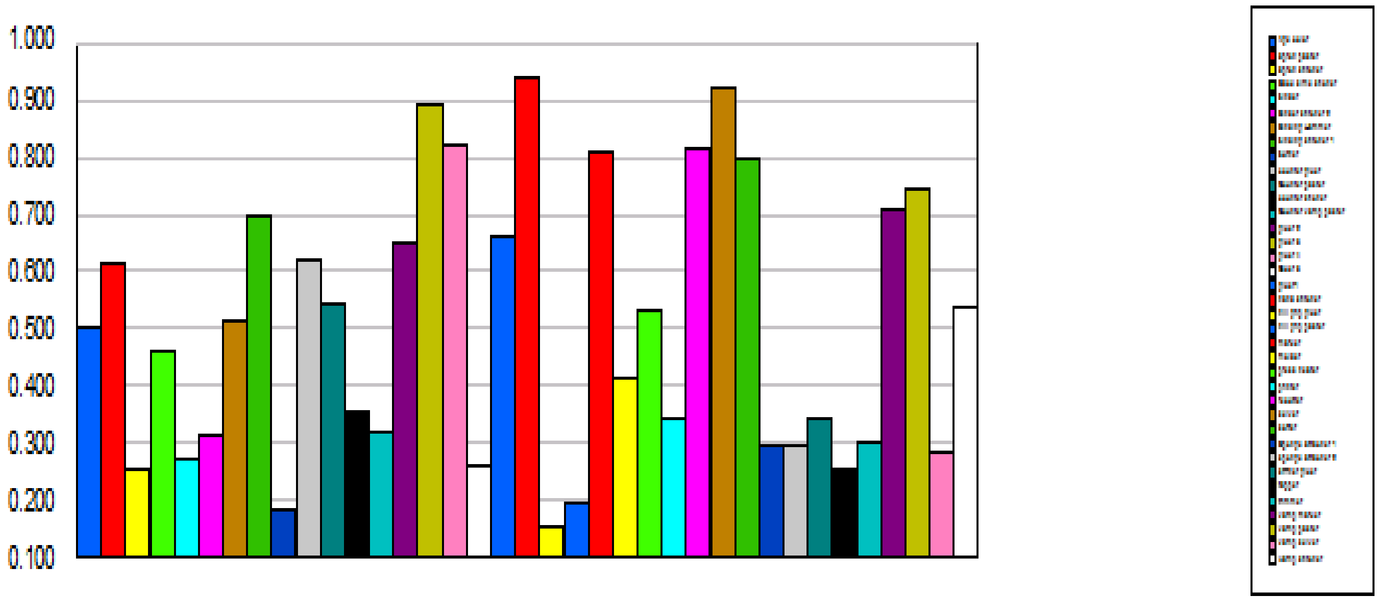

Figure.4.1. Capacity utilization of stitching assembly line resources

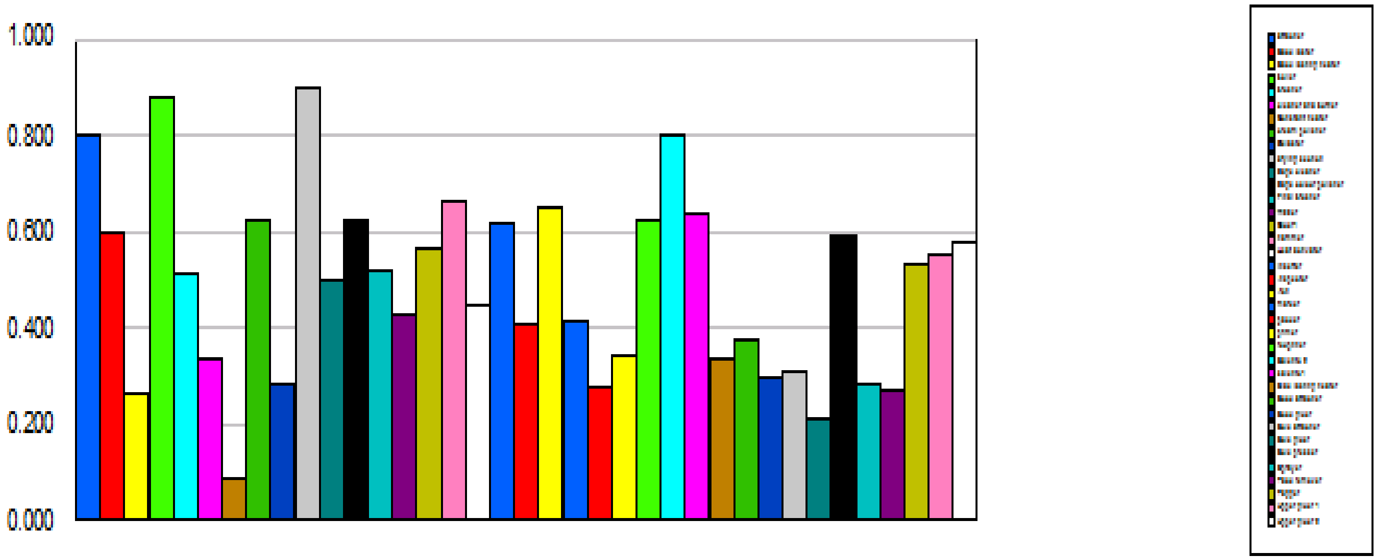

Figure.4.2. Capacity utilization of lasting assembly line resources

From the above figures for both assembly lines we can see clearly how the capacity utilization of different resources of lines is varied. This shows that the work content of both lines is not distributed uniformly among stations. In other word the lines are not balanced.

Using equations 2.5 and 2.6 (chapter 2); line balance efficiency (E_b) and balance delay (d) of each assembly line can be calculated as follows:

$$E_b = T_{wc}/wT_s$$

Where E_b = balance efficiency, T_{wc} = total work content time (make span), Ts = the maximum available service time on the line and w = number of workers on the line. The complement of balance efficiency is balance delay (d), which indicates the amount of time lost due to imperfect balancing as a ratio to the total time available.

$$d = (wT_s - T_{wc})/wT_s$$

Hence, line efficiency and delay for stitching assembly line is:

- Number of workers of stitching assembly line w=65

- Total work content time T_{wc} = 1825.01
- The maximum service time or operation time T_s is measured at hand stitch station = 47.85 sec
- Total service time available on the stitching assembly line to devote on the assembly of one single shoe, wT_s = 65*47.85 = 3110.25

Line balance efficiency E_b = 1825.01/ (65*47.85) *100% = 58.7% and

Delay d = (61*55.02 - 1825.01)/ 61*55.02*100% = 41.3%

In other word this means that; of the total service time available on the stitching assembly line, 45.6% is idle time which is lost for nothing.

Line balance efficiency and delay for lasting assembly line is:

- Number of workers of stitching assembly line w=36
- Total work content time T_{wc} = 1127.72 sec
- The maximum service time or operation time is measured at boiling station equal to T_s = 46.31sec
- Total service time available on lasting assembly line to devote on the assembly of one product unit wT_s = 36*46.31 = 1667.16

Line balance efficiency E_b = 1127.72 / (36*46.31)*100% = 67.6% and

Delay d = (36*46.31 – 1127.72)/ 36*46.31 = 32.4%

Or in other word it can be said that; 32.4% of the total service time available on the lasting assembly line, the workers were idle, doing nothing.

However, typical good line balance efficiencies in manufacturing industry range between 0.90 and 0.95 [17]. Therefore, there is still a room for line efficiency improvement for both lines.

Obviously, the output of the stitching line is the input for the lasting assembly line. However, in the real manufacturing system, it is observed that the output of the stitching assembly line is higher than the lasting assembly line. This phenomenon is also observed in the simulation model analysis in which the output of the stitching assembly line is greater than the output of the lasting assembly line by 30 (561-531) on average. In other word, the output of the two assembly lines is not balanced. As a result of this, WIP of different model shoes of every subsequent day are piled up in between these two lines. This piled up WIP in between the two lines makes difficult to schedule the overall production system. In addition to this, it occupies large space, tide up capital and become sometimes difficult to match different models which create additional non value adding task. To solve this problem there is a need to come up with a solution that at least minimizes the gap between the production outputs of the two assembly lines. Hence for all problems observed, different alternative scenarios are developed in the next section.

Chapter five

Alternative model development

5.1. Introduction

This section is concerned on the development of different alternative models in which all problems that have been identified in the simulation model analysis will be seen and solved for better performance of footwear manufacturing. Problems that are identified in simulation model analysis are listed below.

1. Line balance efficiency for assembly lines, stitching and lasting is low 58.7% and 67.6% respectively. This is significantly below the typical values of good line balance efficiency of industrial manufacturing system.
2. Relatively high level of WIP is observed in some work station of stitching assembly line.
3. Low production output with respect to the installed capacity
4. The output of stitching assembly line is significantly higher than that of the lasting assembly line which causes WIP of different model shoes to be piled up in between the two assembly lines.

For the above identified problems, the following four alternative models are proposed:

1. Avoiding unnecessary duplication resource from station with low capacity utilization
2. Merging similar operations with low resource utilization together and assign to one worker
3. Increasing level of resource at stations with high WIP
4. Changing working method
5. Combination of all the above alternatives

Except the fourth proposed alternative, all the above proposed alternative do not change the layout of the assembly line. The fourth proposed scenario is concerned with changing working method. This changes the layout of the assembly line.

5.1.1. Avoiding unnecessary duplication resource from station with low capacity utilization (Scenario 1)

Some stations have multiple resources but their capacity utilization is below 50%. In these stations unnecessary duplication of resources exists. Therefore, these unnecessary duplication resources should be deducted from the line. From the capacity utilization tables presented above these stations and their respective capacity and average number of busy resources are presented in the following table.

Table: 5.1. Stations with multiple resources of low capacity utilization below 50% of both assembly lines

No.	Station	Resource (man power)	Scheduled capacity	Average Number of busy resources	Deducted Resources (Manpower)
Stitching assembly line					
1	Binding	Binder	2	0.5415	1
2	Bind stitching	Bind stitcher 2	4	1.2635	2
3	Burner	Burner	2	0.3701	1
4	Counter stitching	Counter stitcher	4	1.4119	2
Total			12		6
Lasting assembly line					
1	Cleaning and	Cleaner and burner	4	1.3495	2
Total			4		2

5.1.2. Merging similar operations with low resource utilization together and assign to one worker (Scenario 2)

In other hand, some stations with similar and consecutive operations have low capacity utilization. However, these operations can be merged together and assigned to only one worker. Consecutive similar operations that can be merged together are listed in the following table.

Table. 5.2. Similar and consecutive operations with low capacity utilization that can be merged together for both assembly lines.

No.	Operations	Resource (manpower)	Capacity utilization	Scheduled capacity	Proposed Resource	Deducted Resource (manpower)
Stitching assembly line						
1	Hill grip gluing	Hill grip gluer	0.1543	1	1	2
2	Hill grip pasting	Hill grip paster	0.1946	1		
3	Vamp gluing	Gluer 5	0.2595	1		
4	Stiffner gluing	Stiffner gluer	0.3445	1	1	1
5	Pasting stiffner on counter	Counter paster	0.5452	1		
6	Edge coloring	Edge coloring	0.5035	1	1	1
7	Burning	Burner	0.3701	1		
8	Sponge attaching on apron	Sponge attacher	0.2989	1	1	1
9	Sponge attaching on vamp	Sponge attacher	0.2959	1		
Total				9	4	5
Lasting assembly line						
1	Sock gluing	Sock gluer	0.2965	1	1	1
2	Sock attaching	Sock attacher	0.3740	1		
3	Sole gluing	Sole gluer	0.21 92	1	1	1
4	Upper gluing 1st	Upper gluer 1st	0.5748	1		
Total				4	2	2

The above two scenarios are targeted at decreasing the number of unnecessary idle resources from both assembly lines. By doing so, 11 idle resources can be decreased (6 from the 1st scenario and 5 from the 2nd scenario) from stitching assembly line and 4 idle resources can be decreased (2 from the 1st scenario and 2 from 2nd scenario) from lasting assembly line.

The model developed for the first and second alternative scenarios is shown in figure 5.1 and figure 5.2. for both stitching and lasting assembly lines respectively.

Running the simulation model of 1st and 2nd scenarios for stitching assembly line, we have the following performance measurement:

- Input = 655
- The number of workers of the line is 54 decreased by 11
- Line balance efficiency E_b increased from 58.7% to 70.6%
- Output (P) per 8 hours increased = 563 shoes
- Production rate (R_p) = P/480 = 1.173 shoes / min
- Make span or work content time (T_{wc}) = 1825.5 sec =30.4min
- Work in process (WIP) decreased from 68.1732 to 64.4164 shoes
- Production efficiency (E_p) = Output /Input = 563/655 = 0.86
- Capacity utilization: the instantaneous capacity utilization for each station of the line is increased on average (appendix)

Running the simulation model of 1st and 2nd scenarios for lasting assembly line, we have the following performance measurement:

- Input= 577
- Manning level is 32 decreased by 4
- Output (P) per 8 hours increased = 552 shoes
- Production rate (R_p) = P/480 = 1.15 shoes /min
- Make span or total work content time T_{wc} increases from 1127.72 to 1132.90
- Line balance efficiency E_b increases 67.6 % to E_b = 1132.90 / (32*46.31)*100% = 76.45%
- Work in process (WIP) is increased from 22.73 to 24
- Production efficiency (E_p) = Output /Input = 552/577 = 95.7%
- Capacity utilization: the instantaneous capacity utilization for each station of the line is increased on average (appendix)

The line balance efficiency of both lines is increased. In other word, the distribution of work content among stations is improved. A total of 15 workers are reduced, without decreasing the output of both lines. Taking average direct labor salary equal to 780 ETB we have the following:
Saving money by deducting 15 workers (Annually) = 15*780 *12 = 140,400 ETB

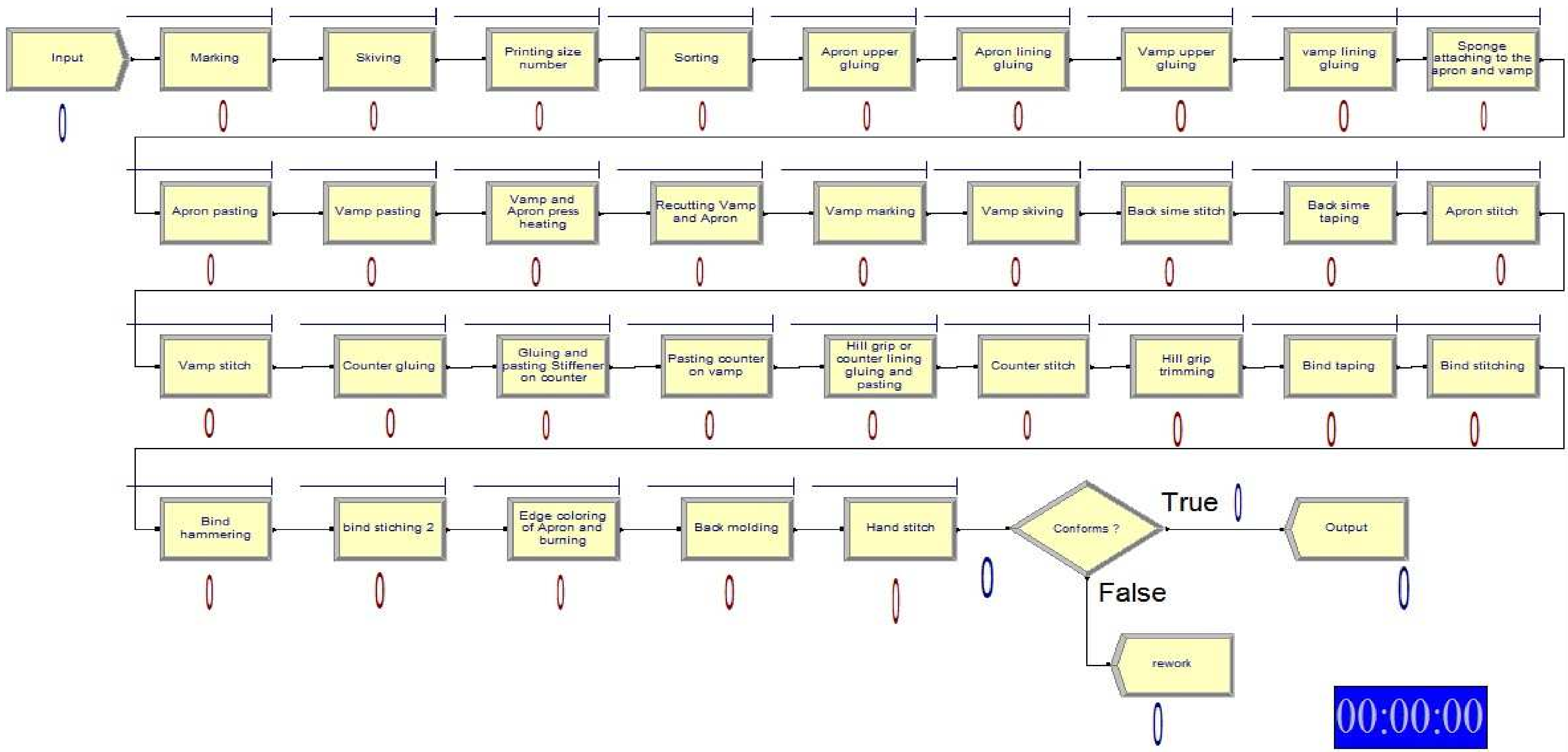

Figure.5.1 Proposed stitching assembly line simulation model for scenario 1 and 2

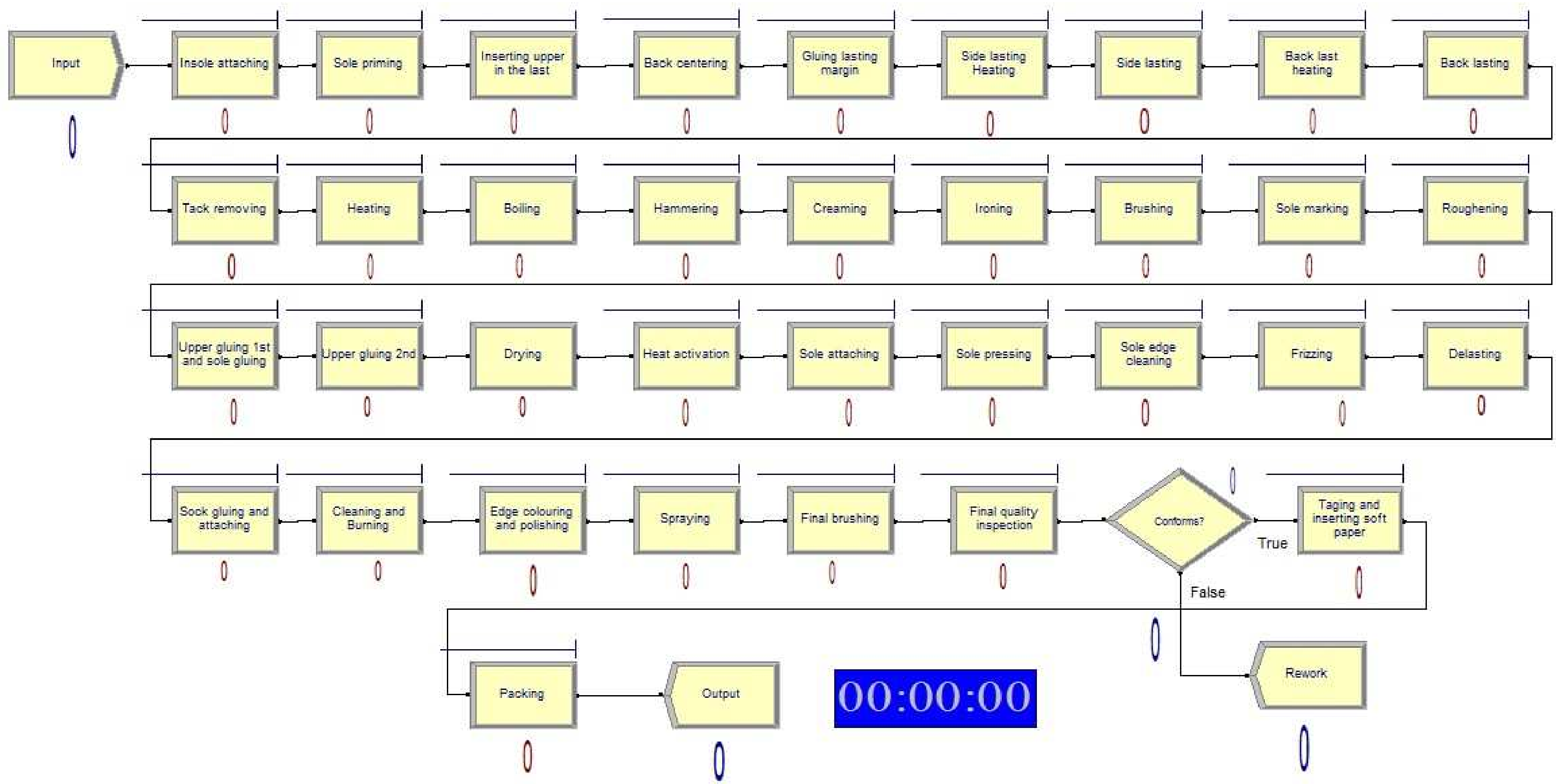

Figure.5.2. Proposed lasting assembly line simulation model for scenario 1 and 2

5.1.3. Increasing level of resource at bottle neck stations with high WIP (Scenario 3)

This scenario is concerned with changing the level of resources at stations with higher level of WIP. The level of WIP of each station of both lines is investigated and tabulated in (Appendix VIII).

From the stitching assembly line hand stitch registered high level of WIP equal to 22.56. Next to hand stitch it is skiving station with relatively high level of WIP equal to 3.5800 then marking station follows.

Therefore, adding resource to these stations would decrease the level of WIP and increase the output of the line.

For instance, adding one stitcher to the hand stitching station and one skiver to the skiving station; we have the following simulation result.

- Input= 658
- Manning level is 67
- Production output is increased from 561 to 593
- Average WIP is decreased from 68.17 to 52.94
- Average WIP is decreased from 22.5 to 8 at hand stitch work station
- Production rate increases (R_p) = P/480 = 1.235 shoes /min
- Make span or total work content time T_{wc} remain the same 1825.96 sec
- Line balance efficiency E_b increases from 58.7% to 61.7%
- Production efficiency (E_p) increase from 85.4% to 92%

However, the Line balance efficiency E_b increases from only 58.7% to 61.7% which is so small. Adding one more stitcher to hand stitching station will take the maximum station service time to vamp upper gluing station equal to 41.7 sec.

Hence; Eb = 1825.96/(69*41.7) = 63.5%

Again adding one more gluer to vamp upper gluing station and one more resource to Apron stitching station, the next station with maximum station service time; the maximum station service time goes to vamp lining gluing station with service time equal to 36.6 sec. manning level of the line is increased from 65 to 70

Hence; Eb = 1825.96/(70*36.6) = 71.27%

Based on this the simulation model give us the following:

- Input= 657
- Manning level is 70
- Production output is increased from 561 to 606
- Average WIP is decreased from 68.17 to 46.5
- Average WIP is decreased from 22.5 to 2.6 at hand stitch work station
- Production rate increases (R_p) = P/480 = 1.26 shoes /min
- Make span or total work content time T_{wc} 1825.41 sec
- Line balance efficiency E_b increases from 58.7% to 71.27%
- Production efficiency (E_p) increase from 85.4% to 92%
- Capacity utilization: the instantaneous capacity utilization for each station of the line is increased on average (Appendix VIII)

Unlike stitching assembly line, all stations in lasting assembly line registered low level of WIP. A maximum of WIP equal to 4 with very minimal average WIP was registered at station edge coloring in simulation running of 41 replications. This shows that the line is loaded below its capacity. So it can be loaded more entities per production cycle time. In other word, we can increase the rate at which entities are loaded on the line. The rate at which entities are loaded or time between loadings of entities for the existing production system is 52 seconds. Reducing this to 45sec on average, we have the following simulation result.

- Input increases from 577 to 641
- Manning level is 36
- Production output (P) is increased from 531 to 575
- WIP increases from 22.73 to 45.1
- Production rate (R_p) = P/480 = 1.2 shoes /min
- Make span or total work content time T_{wc} remain the same 1227.22
- Line efficiency E_b remain the same 67.6%
- Production efficiency (E_p) = Output /Input = 575/641 = 79.9%

As shown in the above, the average WIP of the lasting assembly line is increased significantly from 22.73 to 45.1. A maximum average WIP equal 10.7 is registered at drying station and average 8.9 WIP is registered at boiling station. Therefore, adding 1 resource at boiling station, we have the following result:

- Production output 575
- WIP 44.88

The Line balance efficiency E_b also remains the same. High E_b can be achieved either by decreasing manning level or decreasing maximum station service time as shown above in stitching assembly line. The maximum service time can be decreased by adding resource to stations. For instance; by adding one resource to Insole attaching, sole marking and side lasting station the maximum service time goes to hammering station equal to 34.8 sec. by doing so, the manning level of the line will be increased from 36 to 40.

Hence: E_b = 1127.4/(34.8*40) = 88.17%

Hence based on this, the simulation model gives us the following result:

- Input 641
- Manning level is 40

- Production output (P) is 576
- WIP is 45.6
- Production rate (R_p) = P/480 = 1.2 shoes /min
- Make span or total work content time T_{wc} remain the same 1127.4
- Line efficiency E_b remain the same 81%
- Production efficiency (E_p) = Output /Input = 576/641 = 89.9%
- Capacity utilization: the instantaneous capacity utilization for each station of the line is increased on average (Appendix IX)

5.1.4. Changing work method (Scenario 4)

In the lasting assembly line, after upper gluing 2nd operation they let the glued upper part before attaching it to the external sole to dry conventionally on the conveyor. This technique requires long conveyor and more time to reach the required state. However, if we install a dryer machine with a capacity of 16 shoes, the length of the conveyor will be shorten by 13.60m and the time required for this operation can be decreased from 1138 sec to approximately 420sec.

Therefore changing the work method and running the simulation model we have the following result:

- Input 554
- Production output (p) 532
- WIP remain the same 22.16
- The number of workers of the line is 36
- Production rate (Rp) = P/480 = 1.108 shoes /min
- Make span or total work content time Twc is decreased from 1227.4 to 1105.61
- Line balance efficiency Eb is decreased from 67.6% to 66.4%
- Production efficiency (Ep) = Output /Input = 532/554 = 96%

- Capacity utilization: the instantaneous capacity utilization for each station of the line is increased on average (Appendix X)

5.1.5. Combination of all the above scenarios

Combining all the above scenarios we have the following results:

5.1.5.1. Stitching assembly line:

- Manning level is 59
- Input remain the same 657
- Production output is increased from 561 to 605
- Average WIP is decreased from 68.17 to 48.74
- Production (R_p) rate is increased = P/480 = 1.26 shoes /min
- Make span or total work content time T_{wc} remain the same 1825.96 sec
- Line balance efficiency E_b is increased from 58.7% to 84.6%
- Production efficiency (E_p) is increased from 85.4% to 92.1%
- Capacity utilization: the instantaneous capacity utilization for each station of the line is increased on average (Appendix XI)

5.1.5.2. Lasting assembly line

- Manning level of the line 37 (demerging upper gluing 1st and sole gluing station)
- Input is increased from 577 to 641
- Production output (p) increased from 531 to 614
- WIP is increased from 22.73 to 25.87
- Production rate (Rp) = P/480 = 1.28 shoes /min
- Make span or total work content time Twc is decreased from 1227.4 to 1111.39
- Line balance efficiency Eb is increased from 67.6% to 86.3%
- Production efficiency (Ep) = Output /Input = 573/577 = 95.8%

- Capacity utilization: the instantaneous capacity utilization for each station of the line is increased on average (Appendix XII)

The line balance efficiency of both assembly lines is improved significantly. However, the value is still below the typical values of good line balance efficiency. Hence;

For stitching assembly line:

Adding one more resource to each marking, skiving, sorting, vamp pasting, vamp marking and vamp gluing stations; the maximum station service time goes to Apron gluing station with average processing time equal to 30. This will increase the manning level of the line to 65 which is the manning level of the existing system. Hence:

Eb = 1823.8/(65*30) = 93.5%.

Hence this gives us the following result:

- Manning level is 65
- Average Input 639
- Production output is 611
- Average WIP is 45.12
- Production (R_p) rate is increased = P/480 = 1.27shoes /min
- Make span or total work content time T_{wc} remain the same 1823.8 sec
- Line balance efficiency E_b is increased from 58.7% to 93.5%
- Production efficiency (E_p) is increased from 85.4% to 95.6%
- Capacity utilization: the instantaneous capacity utilization for each station of the line is increased on average (Appendix XIII)

For lasting assembly line:

Adding resource to stations with high maximum station service time; line balance efficiency can only increase by small. For example; adding one more resource to hammering station will take the maximum service time station to ironing station with average processing time of

34.27 sec. However Eb decreases. Doing the same thing to other subsequent stations, Eb is showing decreasing. Therefore, it is recommended to leave the lasting assembly line with Eb equal to 86.3% and manning level 37.

5.2. Comparison of scenarios

Table 5.3 Comparison of scenarios of stitching assembly line

No.	Scenarios	Input	Output	WIP	Make span	Manning level	Line balance efficiency
1	Existing System	657	561	68.2	1825.25	65	58.7%
2	Scenario 1 & 2	655	563	64.4	1825.5	54	70.6
3	Scenario 3	657	606	46.5	1825.41	70	71.3%
4	Combinations of all Scenarios	657	605	48.7	1825.9	59	84.6%
5	Adjustment to Combinations of all Scenarios	639	611	45.12	1823.8	65	93.5%

Table 5.4 Comparison of scenarios of lasting assembly line

No.	Scenarios	Input	Output	WIP	Make span	Manning level	Line balance efficiency
1	Existing system	554	531	22.73	1127.7	36	67.6%
2	Scenario 1 & 2	577	552	24	1132.9	32	76.45%
3	Scenario 3	641	576	45.6	1127.4	40	81%
4	Scenario 4	554	532	22.16	1105.6	36	66.4%
5	Combinations of all scenarios	641	614	25.8	1111.4	37	86.3%

From the above comparison tables of both assembly lines, we can see how the different performance measurements of the manufacturing process for the proposed scenarios are improved with respect to the existing manufacturing system. Among the proposed scenarios the last scenario, Combination of all scenario give us better performance measurement for both assembly lines. Therefore, it is recommended that the company to take into consideration all the developed scenarios in combination.

Chapter six

Conclusions and recommendations

6.1. Conclusions

Simulation modeling is a powerful and an interactive technique in which we can imitate the real manufacturing system to understand how it behaves if something is altered and evaluates the performance of various strategies and scenarios of manufacturing system.

This thesis is concerned with the modeling and simulation of assembly line of footwear manufacturing process where the case study is taken on Ramsey Shoe Factory focusing the production department. Within the production department, this thesis is mainly concerned with the modeling and simulation of the two assembly lines: Stitching and Lasting assembly line. For simplicity and limitation of student version Arena software, a simple shoe model called moccasin 7101 is selected for the study. This shoe model has 19 parts to be assembled on both assembly lines (stitching and lasting assembly lines). Collecting and analyzing all the necessary data using input analyzer of Arena, the simulation model is developed for the existing manufacturing system of this model shoe.

After verifying and validating the developed simulation model, it is simulated for 8 hour working time with 41 replications. After analyzing the result of the simulation run, problems of existing manufacturing system are identified. Problems that are identified in simulation model analysis are: Line balance efficiency for both assembly lines is low, Relatively high level of WIP is observed in some work station of stitching assembly line, low production output with respect to the installed capacity, and the output of stitching assembly line is significantly higher than that of the lasting assembly line which causes WIP of different model shoes to be piled up in between the two assembly lines.

To solve these identified problems, five possible scenarios are developed. These are: Avoiding unnecessary duplication resource from station with low capacity utilization, merging similar operations with low resource utilization together and assign to one worker, increasing level of resource at stations with high WIP, changing working method, and combination of all the above alternatives. Among the five developed scenarios, the last one, 'Combination of all the above alternatives' gives better performance of footwear manufacturing for the selected model shoe.

6.2. Recommendations

Based on the result of this study, I would like to recommend the following specific points.

- As mentioned above, Simulation modeling plays a great role in designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and evaluating various strategies and scenarios for the operating or manufacturing system. However, this technique is not adapted in most of the manufacturing industries of the country. Even the awareness of using commercial software in most of the manufacturing industries is under question. Therefore, I strongly recommend the Ethiopian manufacturing industry to use and adapt the commercial simulation software like Arena for their business come to success.
- With regard to the case study company; in order to solve all the above stated performance related problems, the company should revise the proposed scenarios and apply it for better performance of the selected shoe model manufacturing system.
- The student version Arena software has limitation in modeling of complex manufacturing system. Therefore, I recommend the company to use and adapt the commercial version Arena software for modeling and simulating of the manufacturing processes of other complicated shoe models with many parts.
- This research invites other interested researchers to make similar research on related manufacturing processes.

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Appendix I

Input analyzer data distribution function of each operation of stitching assembly line and lasting assembly line:

Stitching assembly line		
No.	**Operations**	**Data distribution function**
1	Marking	126 + 41 * BETA(0.583, 0.847)
2	Skiving	Uniform (186, 225)
3	Printing size number	Normal (15.3, 1.65)
4	Sorting	24 + 25 * BETA(0.918, 1.05)
5	Apron gluing (upper)	19 + 27 * BETA(0.697, 1.08)
6	Apron gluing (lining)	20 + ERLA(4.6, 2)
7	Vamp gluing (upper)	Triangular (30, 44.6 ,46)
8	Vamp gluing (lining)	Triangular (31, 35.2, 45)
9	Sponge attaching to the apron	9 + LOGN(4.47, 7.45)
10	Sponge attaching to the vamp	10 + 7.95 * BETA(1.62, 2.23)
11	Apron pasting	20 + WEIB(8.73, 1.65)
12	Vamp pasting	Normal (33.6, 6.26)
13	Vamp and Apron pressing	18 + 11 * BETA(1.31, 1.05)
14	Recutting Vamp and Apron	31 + 19 * BETA(0.671, 1.47)
15	Vamp marking	Normal (32.2, 4.01)
16	Vamp skiving	9 + EXPO(3.96)
17	Back sime stitch (on M/C 141)	17 + GAMM(3.16, 1.27)
18	Back sime taping (on M/C 49)	10.1 + 2.77 * BETA(0.772, 0.766)
19	Apron stitch (on M/C 139)	10.1 + 2.77 * BETA(0.772, 0.766)
20	Vamp stitch (on M/C 143)	13 + ERLA(3.82, 3)
21	Counter roughening and gluing	23 + EXPO(5.37)

22	Stiffener gluing	12 + GAMM(1.08, 3.45)
23	Pasting Stiffener on counter	19 + GAMM(2.71, 2.18)
24	Vamp gluing	9 + 5 * BETA(0.937, 0.692)
25	Pasting Counter on vamp	10 + LOGN(4.7, 4.67)
26	Hill grip (counter lining) gluing and	5.29 + WEIB(1.92, 1.3)
27	Hill grip pasting on the vamp	Normal (8.89, 1.29)
28	Counter stitch	35 + 61 * BETA(0.431, 0.458)
29	Hill grip trimming	11 + 5.53 * BETA(0.623, 0.625)
30	Binding taping	19 + 10 * BETA(1.1, 0.761)
31	Binding stitch 1	72 + WEIB(24.7, 1.04)
32	Binding hammering	18 + 10 * BETA(1.42, 1.01)
33	Binding stitch 2(opposite side)	36 + 42 * BETA(1.05, 0.906)
34	Edge coloring of Apron	20 + ERLA(1.65, 2)
35	Burning Apron	11 + 15 * BETA(1.19, 1.69)
36	Back molding	17 + GAMM(1.79, 1.3)
37	Hand stitch	470 + EXPO(104)

Lasting assembly line		
No.	**Operations**	**Data distribution function**
1	Insole attaching	27 + 32 * BETA(0.697, 0.844)
2	Sole praiming	Triangular (14.5, 19.3, 20)
3	Inserting upper in the last	24 + 22 * BETA(0.616, 1.08)
4	Back centering	27 + EXPO(6.12)
5	Gluing lasting margin	26 + LOGN(3.46, 3.57)
6	Side lasting heating	29 + 28 * BETA(0.476, 1.76)
7	Side lasting	31 + 24 * BETA(0.822, 0.956)
8	Back lasting heating	23 + EXPO(4.83)
9	Back lasting	24 + 18 * BETA(0.568, 0.821)
10	Tack removing	12.2 + ERLA(0.429, 5)
11	Heating	Constant (4.69)
12	Boiling	35 + WEIB(12.5, 1.61)
13	Hammering	Triangular (24, 31.4, 49)
14	Creaming	27 + ERLA(1.99, 3)
15	Ironing	25 + 16 * BETA(1.59, 1.15)
16	Brushing	Triangular (23, 28, 30)
17	Sole marking	Triangular (33, 46.3, 52)
18	Roughening	Triangular (60, 67.7, 71)
19	Upper gluing 1st	26 + 9 * BETA(0.676, 1.17)
20	Sole gluing	8 + 7 * BETA(1.05, 1.25)
21	Upper gluing 2nd	26 + 10 * BETA(1.38, 1.48)
22	Drying	Constant (48)
23	Heat activation	Constant (24)
24	Sole attaching	Triangular (13.2, 16.9, 20)
25	Sole pressing	26 + WEIB(6.29, 1.58)

26	Sole edge cleaning	Normal (26.8, 1.49)
27	Frizzing	Constant (23)
28	Delasting	13 + ERLA(1.01, 2)
29	Sock gluing	13 + LOGN(2.89, 2.4)
30	Sock attaching	16 + ERLA(2.04, 2)
31	Cleaning and burning	Triangular (40, 62.5, 115)
32	Edge coloring	26 + LOGN(7.4, 8.05)
33	Spraying	Normal (15.4, 1.5)
34	Brushing	Normal (27.9, 3.52)
35	Final quality inspection	33 + ERLA(5.58, 2)
36	Taging and inserting soft paper	Uniform (50, 67)
37	Packing	26 + GAMM(2.15, 2.17)

Appendix II

‘t’ probability distribution table 899999

df	t0.100	t0.050	t0.025	t0.010	t0.005
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.604
5	1.476	2.015	2.571	3.365	4.032
6	1.440	1.943	2.447	3.143	3.707
7	1.415	1.895	2.365	2.998	3.499
8	1.397	1.860	2.306	2.896	3.355
9	1.383	1.833	2.262	2.821	3.250
10	**1.372**	**1.812**	**2.228**	**2.764**	**3.169**
11	1.363	1.796	2.201	2.718	3.106
12	1.356	1.782	2.179	2.681	3.055
13	1.350	1.771	2.160	2.650	3.012
14	1.345	1.761	2.145	2.624	2.977
15	1.341	1.753	2.131	2.602	2.947
16	1.337	1.746	2.120	2.583	2.921
17	1.333	1.740	2.110	2.567	2.898
18	1.330	1.734	2.101	2.552	2.878
19	1.328	1.729	2.093	2.539	2.861
20	1.325	1.725	2.086	2.528	2.845
21	1.323	1.721	2.080	2.518	2.831
22	1.321	1.717	2.074	2.508	2.819
23	1.319	1.714	2.069	2.500	2.807
24	1.318	1.711	2.064	2.492	2.797
25	1.316	1.708	2.060	2.485	2.787
26	1.315	1.706	2.056	2.479	2.779
27	1.314	1.703	2.052	2.473	2.771
28	1.313	1.701	2.048	2.467	2.763
29	1.311	1.699	2.045	2.462	2.756
30	1.310	1.697	2.042	2.457	2.750
40	1.303	1.684	2.021	2.423	2.704
60	1.296	1.671	2.000	2.390	2.660
120	1.289	1.658	1.980	2.358	2.617
	1.282	**1.645**	**1.960**	**2.326**	**2.576**

Appendix III

Standard normal probability distribution table (z-table)

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	0.0000	0.0040	0.0080	0.0120	0.0160	0.0199	0.0239	0.0279	0.0319	0.0359
0.1	0.0398	0.0438	0.0478	0.0517	0.0557	0.0596	0.0636	0.0675	0.0714	0.0753
0.2	0.0793	0.0832	0.0871	0.0910	0.0948	0.0987	0.1026	0.1064	0.1103	0.1141
0.3	0.1179	0.1217	0.1255	0.1293	0.1331	0.1368	0.1406	0.1443	0.1480	0.1517
0.4	0.1554	0.1591	0.1628	0.1664	0.1700	0.1736	0.1772	0.1808	0.1844	0.1879
0.5	0.1915	0.1950	0.1985	0.2019	0.2054	0.2088	0.2123	0.2157	0.2190	0.2224
0.6	0.2257	0.2291	0.2324	0.2357	0.2389	0.2422	0.2454	0.2486	0.2517	0.2549
0.7	0.2580	0.2611	0.2642	0.2673	0.2704	0.2734	0.2764	0.2794	0.2823	0.2852
0.8	0.2881	0.2910	0.2939	0.2967	0.2995	0.3023	0.3051	0.3078	0.3106	0.3133
0.9	0.3159	0.3186	0.3212	0.3238	0.3264	0.3289	0.3315	0.3340	0.3365	0.3389
1.0	0.3413	0.3438	0.3461	0.3485	0.3508	0.3531	0.3554	0.3577	0.3599	0.3621
1.1	0.3643	0.3665	0.3686	0.3708	0.3729	0.3749	0.3770	0.3790	0.3810	0.3830
1.2	0.3849	0.3869	0.3888	0.3907	0.3925	0.3944	0.3962	0.3980	0.3997	0.4015
1.3	0.4032	0.4049	0.4066	0.4082	0.4099	0.4115	0.4131	0.4147	0.4162	0.4177
1.4	0.4192	0.4207	0.4222	0.4236	0.4251	0.4265	0.4279	0.4292	0.4306	0.4319
1.5	0.4332	0.4345	0.4357	0.4370	0.4382	0.4394	0.4406	0.4418	0.4429	0.4441
1.6	0.4452	0.4463	0.4474	0.4484	0.4495	0.4505	0.4515	0.4525	0.4535	0.4545
1.7	0.4554	0.4564	0.4573	0.4582	0.4591	0.4599	0.4608	0.4616	0.4625	0.4633
1.8	0.4641	0.4649	0.4656	0.4664	0.4671	0.4678	0.4686	0.4693	0.4699	0.4706
1.9	0.4713	0.4719	0.4726	0.4732	0.4738	0.4744	0.4750	0.4756	0.4761	0.4767
2.0	0.4772	0.4778	0.4783	0.4788	0.4793	0.4798	0.4803	0.4808	0.4812	0.4817
2.1	0.4821	0.4826	0.4830	0.4834	0.4838	0.4842	0.4846	0.4850	0.4854	0.4857
2.2	0.4861	0.4864	0.4868	0.4871	0.4875	0.4878	0.4881	0.4884	0.4887	0.4890
2.3	0.4893	0.4896	0.4898	0.4901	0.4904	0.4906	0.4909	0.4911	0.4913	0.4916
2.4	0.4918	0.4920	0.4922	0.4925	0.4927	0.4929	0.4931	0.4932	0.4934	0.4936
2.5	0.4938	0.4940	0.4941	0.4943	0.4945	0.4946	0.4948	0.4949	0.4951	0.4952
2.6	0.4953	0.4955	0.4956	0.4957	0.4959	0.4960	0.4961	0.4962	0.4963	0.4964
2.7	0.4965	0.4966	0.4967	0.4968	0.4969	0.4970	0.4971	0.4972	0.4973	0.4974
2.8	0.4974	0.4975	0.4976	0.4977	0.4977	0.4978	0.4979	0.4979	0.4980	0.4981
2.9	0.4981	0.4982	0.4982	0.4983	0.4984	0.4984	0.4985	0.4985	0.4986	0.4986
3.0	0.4987	0.4987	0.4987	0.4988	0.4988	0.4989	0.4989	0.4989	0.4990	0.4990

Appendix IV

Category overview simulation report for existing stitching assembly line's simulation model

Appendix V

Category overview simulation report of existing lasting assembly line's simulation model

Appendix VI

Category overview simulation report of scenario 1&2 stitching assembly line's simulation model

Appendix VII

Category overview simulation report of scenario 1&2 lasting assembly line's simulation model

Appendix VIII

Category overview simulation report of scenario 3 stitching assembly line's simulation model

Appendix IX

Category overview simulation report of scenario 3 Lasting assembly line's simulation model

Appendix X

Category overview simulation report of scenario 4 Lasting assembly line's simulation model

Appendix XI

Category overview simulation report of combination scenario of stitching assembly line's simulation model

Appendix XII

Category overview simulation report of combination scenario of lasting assembly line's simulation model

Appendix IIIX

Ramsey Shoe Factory Production Department Layout