

Addis Ababa University
Addis Ababa Institute of Technology
School of Mechanical and Industrial Engineering



AAiT

ADDIS ABABA INSTITUTE OF TECHNOLOGY

አዲስ አበባ ቴክኖሎጂ ኢንስቲትዩት

ADDIS ABABA UNIVERSITY

አዲስ አበባ ዩኒቨርሲቲ

Production Performance Improvement by Simulation of a Footwear
Manufacturing System in Tikur Abbay Shoe S.C

By: Abail Mulugeta

Advisor: Dr. Ameha Mulugeta

Co-Advisor: Daniel Ashagrie (PhD candidate)

A Thesis Submitted to the School of Mechanical and Industrial Engineering
Presented in Partial Fulfilment of the Requirements for the Degree of Master of Science in
Mechanical Engineering (Industrial Engineering Stream)

October 2020
Addis Ababa, Ethiopia

Addis Ababa University
Addis Ababa Institute of Technology
School of Mechanical and Industrial Engineering
Industrial Engineering Stream

This is to certify that the thesis prepared by Abail Mulugeta, entitled: *Production Performance Improvement by Simulation of a Footwear Manufacturing System in Tikur Abbay Shoe S.C.* and submitted in partial fulfillment of the requirements for the degree of Master of Science (Mechanical and Industrial Engineering) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by Examining Committee:

Dr. Kassu Jilcha	_____	_____
Internal Examiner	Signature	Date
Dr. Sakthivel S.	_____	_____
External Examiner	Signature	Date
Dr. Ameha Mulugeta	_____	_____
Advisor	Signature	Date
Mr. Daniel Ashagrie	_____	_____
Co-Advisor	Signature	Date
Dr. Yilma Tadesse	_____	_____
School Dean	Signature	Date

Declaration

I hereby declare that the work which is being presented in this thesis entitled “*Production Performance Improvement by Simulation of a Footwear Manufacturing System in Tikur Abbay Shoe S.C.*” is original work of my own and has not been presented for a degree of any other university and all the resources of references used for the thesis have been duly acknowledged.

Abail Mulugeta

Date

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

Dr. Ameha Mulugeta

Date

Daniel Ashagrie

Date

Acknowledgment

I am grateful to my thesis advisors Dr. Ameha Mulugeta and Daniel Ashagrie for their unreserved advice, guidance, and assistance in my thesis work starting from the proposal up to its completion. It is because of their genuine advice and encouragement that the work is completed. I would like to extend my gratitude to Nebil Ahmed (PPC head at Tikur Abbay Shoe Share Company), Mesgena Data (TASSC maintenance planner and controller), and Netsanet Zekharias who has made priceless moral and material support to me. Finally, I would like to appreciate all Tikur Abbay's management, employees, and individuals for their time and cooperativeness to respond to my questions, provide necessary documents, and valuable information about the company's production system.

Abail Mulugeta

Abstract

This study deals with capacity utilization and performance improvement using simulation modeling. Simulation is a powerful tool for bottleneck identification and analysis of the production lines in the footwear manufacturing system. The major problems of the case company are low output, high cycle time, high work in process, high waiting time, and low capacity utilization.

In this study, the Arena and POM software were employed to model and to analyze the performance of the existing production lines. A military shoe was selected for analysis and improvement as it has the highest demand and highest number of operations. For each operation, the researcher has taken 25 sampling observations using a stopwatch. Processing times, machine failure times, distance between workstations, and manning level data were collected. All the collected data were statistically analyzed using Arena input analyzer for statistical significance and determination of expressions. A standard simulation model was developed and run for 160 replications.

The simulation results show that the production lines are operating with capacity utilization of 55.67%, 55.47 %, 52.92%, and 54.22 % in cutting, stitching, lasting, and finishing production sections respectively. The researcher has revealed that bottlenecks have a high impact on performance and capacity utilization of the production facility. In the course of action, different types of scenarios have been developed and the best approach has been proposed. Thus, the simulation results demonstrate that the application of the proposed model could increase production output by 11.09%, 16.4%, 14.16%, 13.2%; decrease WIP by 54%, 39.9%, 44%, 23%; decrease cycle time by 9.98%, 14.13%, 16.39%, 11.6%; increase capacity utilization to 62.4%, 64.6%, 63.27%, 61.4% in the cutting, stitching, lasting, and finishing production sections. The cost-benefit analysis has also shown the addition of resources to bottleneck workstations could generate an additional annual minimum gross profit of 1,918,160 Birr.

The proposed model enables production and operation managers for measuring and improving capacity utilization and performance of production lines which is the originality and core value of this study. Finally, it is recommended that the addition of resources on bottleneck workstations should be considered to improve the production performance of the organization.

Keywords: - Performance, Simulation, Arena, Footwear Manufacturing System

Contents

Acknowledgment	iii
Abstract	iv
List of Table	viii
List of Figure	ix
List of Abbreviations	x
Chapter One	1
Introduction	1
1.1. Background of the Study	1
1.2. Problem Statements and Research Questions	4
1.3. Objectives	6
1.3.1. General Objectives	6
1.3.2. Specific objectives	6
1.4. Significance of the Study	6
1.5. Scope of the Study	7
1.6. Limitation of the Study	7
1.7. Organization of the Thesis	7
Chapter Two	8
Literature Review	8
2.1. Manufacturing System	8
2.1.1. Characteristics of a Manufacturing System	9
2.2. Performance	11
2.2.1. Performance Measurement	11
2.2.2. Manufacturing Performance	12
2.2.3. Manufacturing Performance Measures	12
2.3. Bottlenecks	14
2.3.1. The bottleneck in a Manufacturing	14
2.3.2. Performance-Based Bottleneck Detection	16
2.4. Capacity Utilization	17
2.5. Manufacturing Systems Modeling	19
2.6. Simulation	20
2.6.1. Application of Simulation	22
2.6.2. Simulation Frameworks	23

2.6.3. Simulation Tool.....	24
2.7. Summary and Literature Gap	25
Chapter Three	27
Research Methodology	27
3.1. Research Design	27
3.2. Overall Research Framework.....	27
3.3. Problem Formulation	30
3.4. Literature Survey.....	30
3.5. Conceptual Model Development.....	31
3.5.1. Product Selection	31
3.5.2. System Description	31
3.5.3. Process Flow	31
3.6. Data Collection and Input Analysis.....	33
3.6.1. Data Collection	33
3.6.2. Input Data Analysis.....	33
3.7. Model Building	34
3.8. Verification and Validation.....	34
3.9. Design the Experiment.....	35
3.10. Results and Analysis	35
3.11. Result Dissemination of the Study	35
Chapter Four.....	36
Overview of the Case Company & Input Data Analysis	36
4.1. Company Overview	36
4.2. System Characteristic.....	37
4.3. Data Collection.....	38
4.3.1. Primary and Secondary Data.....	38
4.4. Model Building.....	38
4.4.1. Model Elements	38
4.4.2. Data for Model Building.....	40
4.4.3. Data for validation	50
4.5. Model Results and Analysis	63
Chapter Five.....	70
Experimentation and Cost-Benefit Analysis.....	70

5.1. Experimentation	70
5.2. Cost-Benefit Analysis	84
5.3. Discussion	85
Chapter Six	87
Conclusions & Recommendations	87
6.1. Conclusions	87
6.2. Recommendations	88
Reference	89

List of Table

Table 4-1: Inter arrival of raw materials to the cutting section.....	42
Table 4-2: Inter arrival of components to the stitching section	42
Table 4-3: Inter arrival of uppers to the lasting section	42
Table 4-4: Inter arrival of lasted uppers to the finishing section	43
Table 4-5: Input analyzer distribution.....	45
Table 4-6: Monthly productions of shoes (2019/2020)	50
Table 4-7: Daily productions per sections (December 2019)	50
Table 4-8: Number of replication of production sections	59
Table 4-9: Model validation analysis.....	62
Table 4-10: Highest average waiting time and average waiting number	65
Table 4-11: Cutting production line balancing efficiency	68
Table 4-12: Existing system performance	69
Table 5-1: Causes of low capacity utilization.....	70
Table 5-2: Scenario 1 cutting section results	71
Table 5-3: Scenario 1 stitching section results.....	72
Table 5-4: Scenario 1 lasting section results.....	72
Table 5-5: Scenario 1 finishing and packing section results.....	73
Table 5-6: Scenario 2 cutting section results	74
Table 5-7: Scenario 2 stitching section results.....	74
Table 5-8: Scenario 2 lasting section results.....	75
Table 5-9: Scenario 2 finishing section results	75
Table 5-10: Scenario 3 cutting section results	77
Table 5-11: Scenario 3 stitching section results.....	78
Table 5-12: Scenario 3 lasting section results.....	78
Table 5-13: Scenario 3 finishing section results	79
Table 5-14: Comparison of different scenarios with the existing system	79
Table 5-15: Cost-benefit analysis	84

List of Figure

Figure 3-1: Research framework (Adopted from Winston & Goldberg, 2004).....	29
Figure 3-2: Reviewed literature by publication years	30
Figure 3-3: Production process flow chart (Source: Own)	32
Figure 4-1: (a) Rivet piercing (Source: Own) (b) heat setting operations (Source: Own)	44
Figure 4-2: Congestion at the floor (Source: Own, taken on Sept. 10, 2020).....	48
Figure 4-3: Existing production layout (Source: Own)	49
Figure 4-4: Cutting section model (Source: Own).....	53
Figure 4-5: Stitching section model (Source: Own)	54
Figure 4-6: Lasting section model (Source: Own).....	56
Figure 4-7: Finishing and packing section (Source: Own)	57
Figure 4-8: Cutting production line output analysis	64
Figure 4-9: Cutting production line capacity utilization	64
Figure 4-10: Stitching Production Section Capacity Utilization.....	66
Figure 4-11: Lasting Production Section Capacity Utilization	66
Figure 4-12: Finishing and packing production line capacity utilization	67
Figure 5-1: Proposed production layout.....	76
Figure 5-2: Production output comparison	80
Figure 5-3: WIP comparison.....	81
Figure 5-4: Maximum waiting time comparison	82
Figure 5-5: Maximum waiting number comparison	82
Figure 5-6: Capacity utilization comparison.....	83

List of Abbreviations

ALB:	Assembly Line Balancing
AO:	Actual Output
CFI:	Corporate Finance Institute
CU:	Capacity Utilization
DES:	Discrete Event Simulation
ELIDI:	Ethiopian Leather Industries Development Institute
K-S:	Kolmogorov-Smirnov
MOI:	Ministry of Industry
MTBF:	Mean Time between Failures
MTBR:	Mean Time between Repairs
OEE:	Overall Equipment Effectiveness
PO:	Potential Output
POM:	Production and Operations Management
TASSC:	Tikur Abbay Shoe Share Company
UNIDO:	United Nations Industrial Development Organization
WIP:	Work In Process

Chapter One

Introduction

1.1. Background of the Study

Manufacturing is the production of products for use or sale, using labor and machines, tools, and chemical or biological processing or formulation. The term may refer to a variety of human activity, from handicraft to high-tech, but is most commonly applied to industrial design, in which raw materials from primary industry are transformed into finished goods on a large scale (Velumani & Tang, 2017). The survival of any business in the market place depends mainly on response time, production cost, market price, and manufacturing flexibility (Groover, 2015). These parameters motivated continuous research in modeling and performance evaluation of manufacturing systems (Mulugeta, 2014). Improvement and innovation are needed to increase the efficiency of the operation and will be a big gain if companies can find and set a condition that improves their performance with a minimum cost (Chen & Chen, 2014).

Some of the past literature has demonstrated that the increase in production performance can reduce costs related to machinery setup, maintenance, inventory holding, shortage cost, and cost incurred by poor quality products (Kovacs, 2018; Iwao & Marinov, 2018). Findings on past research also suggested that better capacity utilization, efficient capacity measurement, and management are the key to improve production performance (Hon, 2005; Begashaw, 2015; Iwao & Marinov, 2018). However, most of the literature has only concentrated on developing and proposing improvement models by looking at the performance metrics without considering the cost that could be incurred to the system. The findings of these studies, however, are not useful for the production and operations manager in selecting a better improvement decision as it lacks cost-benefit analysis. These works are quite useful for operational and production managers in formulating production performance improvement decisions.

In recent years, Derbe (2018); Hensley et.al.,(2018); Yemane & Hailemichael (2020), have made significant advances in capacity utilization and performance measurement metrics.

Operations and production management literature have also reported about the advancements in production performance improvement decisions. Studies on production performance stated that higher capacity utilization and efficient resource management are highly associated with production performance (Nguyen, 2015; Agarwal et al, 2019). The studies demonstrated that research at performance improvement from the perspective of their metrics and associated costs is essential for achieving better decisions in the manufacturing business.

Based on the above-mentioned statement, it is possible to say that in previous studies, the emphasis was not given to costs related to performance improvement decisions, therefore a gap exists in this area. This is an important research topic because it addresses industrial production performance issues associated with benefits that previously did not get the right attention even though research in this field has moved from the conceptual domain to the empirical level.

The manufacturing system involves sets of tasks, materials, resources, products, and information. By doing performance and productivity analysis, there are benefits of understanding the manufacturing process, finding the problems and gaps between the existing performance with expected targets, and improvement (Herzegovina, 2012). In manufacturing assembly lines production performance improvement is the main element to produce high volume products in a fast and cost-effective manner (Yemane & Hailemicheal, 2020).

According to Kikolski, (2017) modern manufacturing system is characterized by a wide selection of products, reduction of the product's cycle time, production costs, and time between designing and launching products. In shoe manufacturing, the production line is dynamic, discrete, and stochastic. Its randomness is due to variable processing times, as well as random failures and subsequent repairs. Such randomness makes it difficult to control the production process or to predict their behavior. A simulation model that is established to understand and to analyze the structure of the manufacturing system reveals the relationships among the processes and provides statistics to realize the production performance of the system (Mohamad et al., 2016). Implementing computer solutions in the production system allows for reducing costs that an enterprise incurs due to erroneous

decisions while planning and modernizing production lines. And it also allows for a more effective manufacturing strategy selection by the enterprises. The application of simulation in production processes constitutes a form of experimenting on a computer model to provide an answer for the question of how the production system will react to various situations, based on different arranged scenarios (Kikolski, 2016). Computer simulation techniques have also been employed in many manufacturing organizations to design, develop, implement, and analyze manufacturing system's problems of interest (Silva et al., 2010; Cochran et al., 2011; Kikolski, 2016; Araya, 2018). Testing alternatives on a real production system is usually costly and time taking. Therefore, simulation enables us to do this testing and evaluation in a fast, cheap, and safe manner (Herzegovina, 2012).

The pressure from global competition has made manufacturing organizations improve their production performance as much as they can in all dimensions of performance measures (Elyazid, 2016; Cherkos, 2018). Thus, simulation has attracted many industrial organizations as a tool for improving capacity utilization and production performance (Kelton, 2010).

Due to its socio-economic development and employment, the footwear industry is one of the strategic sectors identified by the Industrial Development Strategy of Ethiopia (Arkebe, 2016). It is a very potential sector of Ethiopia's growing economy and plays a significant role in terms of its contribution to the export and domestic market (Kassaneh & Workalemahu, 2018). The export of leather footwear started in 2005 and its value has been growing progressively. ELIDI's 2018 annual report shows that footwear export sales have increased by 15% in the last five years. However, studies on Ethiopian leather footwear industries made by UNIDO, and other researches affirmed that the leather footwear export market activities are not satisfactory due to different challenges confronting the export firms (Addis et al., 2017).

Tikur Abbay shoe Share Company is one of the major shoe factories in Ethiopia. According to the 2018/19 case company's annual report, the company manufactures around 750,000 pairs of shoes per annum in three production units. The company produces over 50 shoe styles ranging from sandals to boots. From all types of shoes, military shoe production accounts for 83.5%, safety shoe production accounts for 6 %, and casual shoe production

accounts for 10.5 % (Tilahun, 2018). At this time the company has an average of 679 permanent and 87 contract employees. The production lines of the case company were identified as low efficiency, high cycle time, high work in process, low throughput rate, low capacity utilization, and soon.

The ultimate goal of this study is to identify the bottlenecks causes of capacity underutilization and to propose a simulation model that enables production and operation managers for measuring and improving the capacity utilization and performance of production lines. This paper would take these points into account and simulate Tikur Abbay's manufacturing system. Therefore, it will fill the gaps that are not considered in manufacturing system modeling & performance analysis and will add some value to the existing knowledge.

1.2. Problem Statements and Research Questions

Capacity underutilization has been a major challenge for manufacturing industries in today's competitive market which determines the manufacturing cost and the position of an organization (Iwao & Marinov, 2018). Operating below capacity results in unnecessarily high costs of production, leading to high selling prices, which in turn results in low domestic sales and loss of competitiveness (Tamás & Illés, 2017).

Researches show that Ethiopian footwear manufacturing industries are characterized by high production and maintenance cost, high machine downtime, low capacity utilization, demand deficiency, high work in process inventory, more idle resource, low line balancing efficiency, poor work standardization, delivery time delays, etc. (Mulugeta, 2011; Gebrewahid, 2015; Eshetu, 2017).

According to Solomon (2018), the average capacity utilization of manufacturing firms in Ethiopia ranges from 45 % to 55 %. Different studies show that most manufacturing companies considered 85% capacity utilization as an optimal rate even if some companies utilize their capacity beyond the optimal (CFI, 2019). When we compare Ethiopian shoe manufacturing industries' productivity with other manufacturers, Ethiopian footwear

manufacturing industries require significant improvement. For instance, Chinese manufacturing companies require 30 minutes to produce a pair of shoes whereas Ethiopian footwear manufacturing industries require 78 minutes (Cherkos, 2018).

According to the data from the 2018/19 TASSC performance report, it showed that the case company has a designed production capacity of 4,755 pairs of shoes per day in one shift but currently the company does not utilize more than 52.57 % of its capacity with an average daily production of 2,500 pairs of shoes in three different production units: Unit one frequently produces military with 52.5 % capacity utilization, unit two produces safety shoes with 53.3 % capacity utilization and unit three produces gents, ladies & children shoes with 52.74 % capacity utilization.

Production, quality, and machine maintenance 2018/19 reports collected from the company also showed that there was an average of 357 machine breakdowns with 533.91 hrs. of downtime per month, an average daily WIP of 164 in the cutting section, 437 in the stitching section, and 436 in lasting section 488 in finishing section and an average reject rate of 1.7 % in cutting, 1.8 % in stitching and 7% in lasting and packing line.

Furthermore, the same report showed the average labor productivity of Tikur Abbay shoe S.C is 3.85 pairs per person whereas an international benchmark is 16 pairs of shoes per person (Cherkos, 2011). Data from the 2018/19 annual report also showed that the production loss due to external factors: raw material unavailability (3 %), power interruption (0.5%), demand unavailability (0.5%), employee absenteeism (9 %), contributes insignificant role in capacity underutilization. This implies that the capacity utilization and production performance of the case company mainly relied on internal inputs or causes.

Generally, the above-listed figures showed that the performance and capacity utilization of the company is very low compared with the international benchmark. Therefore, to improve the production performance of TASSC capacity utilization of the manufacturing systems is one of the research areas that would be investigated intensively. To serve this purpose, the current study has been designed and look for answers to the following two main questions: “What are the internal causes of underutilization of Tikur Abbay’s production facility?” and “How can the performance and capacity utilization of the production lines be improved?”

1.3. Objectives

1.3.1. General Objectives

The general objective of this study is to explore the bottleneck causes of capacity underutilization, identify appropriate approaches for performance improvement, and experiment with the validity of the approaches using simulation.

1.3.2. Specific objectives

- ❖ To identify internal causes for capacity underutilization, develop means of mitigating causes and improving the current production lines performance
- ❖ To develop simulation models for existing and improved production lines.
- ❖ To make a comparative analysis of existing and improved manufacturing systems.

1.4. Significance of the Study

To cope up in today's competitive market, every company has to meet the customized dynamic need of its customers and this can be achieved through performance improvement of the manufacturing systems. This research is conducted to analyze and improve the capacity utilization of Tikur Abbay Shoe S.C as a result to increase the company's profitability and competitiveness. Therefore, shoe manufacturing companies can get benefit from this research by adopting the core concepts and making some minor adjustments to fit their production setup.

Also, university graduate students, undergraduate students, academicians, research institutions, and leather development institutes who are willing to conduct studies related to this topic will be benefitted.

1.5. Scope of the Study

This research mainly focuses on the performance and capacity utilization improvement of Tikur Abbay S.C production system. The data for analysis was collected from Tikur Abbay Shoe Share Company. Important factors such as processing time, distance between workstations, assembly line balance, material handling system (conveyors), and machine failure time are considered in the simulation model development. This study did not consider the ergonomic aspects and external causes of the production system. External causes are expected to be addressed as a strategic management issue that has not been considered in this research; therefore, this study emphasizes the internal causes of capacity underutilization for manufacturing system modeling and analysis.

1.6. Limitation of the Study

Due to a lack of adequate time and data, the study was limited to military shoe production unit performance improvement. The cost-benefit analysis was done by considering the minimum profit margin and costs from the selling shops. The current COVID 19 situation has also restricted the researcher to conduct focus group discussions. Thus, bilateral discussions were conducted to collect relevant data and information. However, these limitations did not affect the result or the quality of the research addressed within the scope.

1.7. Organization of the Thesis

The study report has six chapters. The first chapter discusses the background of the study, the problem statement intended to address, its objective, scope, and limitations. Chapter two discusses the reviewed literature to give background and context to the study. The research methodology used for the study is discussed in detail under chapter three while the case company overview and input data analysis of the study are discussed in chapter four. Chapter five discusses the experimentation, comparison of different scenarios, and discussion of the result. The last chapter of the report presents conclusions and recommendations made based on the findings of the study in chapter five.

Chapter Two

Literature Review

This section summarizes the literature review related to the manufacturing system, performance, bottlenecks, capacity utilization, modeling, and application areas of simulation. To get adequate information about the research topic a total of 71 literature were identified from journal articles, conference preceding, books, and unpublished master thesis. 53 were from the 2015 – 2020 publication years, 13 were from 2010 – 2014 publication years, 2 were from 2005 – 2009 publication years, 2 were from 2000 – 2004 publication years, and 2 were from 1995 – 1999 publication years.

2.1. Manufacturing System

Groover (2015), states the manufacturing system as a set of integrated equipment and human resources, whose function is to perform one or more processing or assembly operations. It consists of production machines and tools, material handling and work positioning devices, and computer systems. According to Goshu et al., (2017), a manufacturing system is a process that receives various inputs and transforms it into the desired outputs. The factory production system and fabrication facility are alternative terms for the manufacturing system. In a modern context, it can be also defined as the making of products from raw materials using various processes, equipment, operations, and manpower based on a comprehensive production plan (Revolution et al., 2003). Elements of manufacturing systems, which are themselves systems, are sometimes called cells, work centers, or workstations (Groover, 2015). In general terms, based on the above definition, a manufacturing system can be defined as: “a system in which raw materials are processed from one form into the another, known as a product, gaining a higher or added value in the process and thus creating wealth in the form of a profit” (Velumani & Tang, 2017).

Manufacturing has dramatically changed during the last twenty years, improvements in time to market, efficiencies, quality, cycle time, cost, customer satisfaction, and focus on

continual improvement. These changes in the environment have led manufacturing companies to study and analyze their overall systems (Elyazid, 2016). According to Derbe & Abeba (2018), the manufacturing company itself is a complex, dynamic, and stochastic entity consisting of several semi-independent subsystems interacting in an attempt to make the overall system function productively. The complexity emanates from the heterogeneous environment, a huge quantity of data, and the uncertainty of the external environment.

The manufacturing system's performance improvement plays a significant role in the competitiveness of companies (Tamás & Illés, 2017). This is possible only when continuous optimization of the working parameters and their internal organization for their production systems are carried out to simultaneously increase capacity, decrease costs of production and keep the quality of products unchanged and uncompromised (Neeraj et al., 2018). As a result, companies strive to increase the effectiveness of their manufacturing systems (Revolution et al., 2003). According to (Elyazid, 2016), many firms have launched ambitious programs to improve quality, flexibility, reduce set-up times, minimize machine breakdowns, and eliminate idle-time losses to win international and domestic competitions. Thus, manufacturing organizations need to measure and improve their performances (Addis et al., 2017).

Maintaining high performance for today's manufacturing systems requires implementing appropriate methods and tools to manage their performance throughout the system. During system design methods and tools model, analyze, and test the system so that expected manufacturing needs and operating conditions are investigated before the system is built. While in the operation of the system, methods and tools are employed to ensure that the system maintains planned performance through monitoring, assessing performance, and responding appropriately to performance deviations (Kibira et al., 2016)

2.1.1. Characteristics of a Manufacturing System

The modern manufacturing system is characterized by high levels of automation and integration, complex interactions among system elements, and high capital costs (Bodner & McGinnis, 2002). According to Orio (2016), today's manufacturing companies are caught between the growing needs for safety, reduced time-to-market that implies short

manufacturing time, minimal manufacturing costs through the efficient use of the resources, and, above all, high quality and highly customized products.

According to Revolution et al., (2003), all manufacturing systems have specific business objectives, an integrated set of sub-systems, means of controlling the system, a flow of information, and a decision-making process.

To meet these characteristics, the manufacturing companies need to operate their manufacturing environment efficiently and effectively by selecting the best set of manufacturing system parameters. Processing and assembly operations, material handling, inspection and test, coordination, and control are basic activities that have taken place during the conversion of raw materials to finished products (Groover, 2015).

A production system, like most real-life systems, consists of dependent events and variation. Regarding that things do not happen separately so a systems approach is required when deciding to get high manufacturing performance (Ortega et al., 2017). Groover (2015), pointed out an ideal manufacturing system should both have a high throughput and a low flow time or low WIP. Unfortunately, these goals cannot be met simultaneously. These two goals are conflicting, On the one hand, if high throughput is required, machines should always be busy. As from time to time disturbances (machine failures, breakdowns, defective materials, material starvation) happen, buffers between two consecutive machines are required to make sure that the second machine can continue if the first machine fails (or vice versa) (Araya, 2018). Therefore, for high throughput, many lots are needed in the manufacturing system, i.e. WIP needs to be high. When trying to control manufacturing systems, a trade-off needs to be made between throughput and flow time (Orio, 2016).

In manufacturing system improvement, it requires to decide diligently on the types of products to be produced, the types and numbers of resources (man, machines, materials), or material handling equipment in the system. Then, a layout of the system, potential routes for each independent components and entities, sequencing rules, buffer location and capacity, production process time, and production schedules should be thoroughly discussed and planned because these considerations might influence the cost and the performance of the production system (Nguyen, 2015).

2.2. Performance

In the changing economic environment, a global competition where the customer demands are changing continuously, the enterprises have to reorient their performance, process, procedures, and strategies which results in cost minimization, higher productivity, and profitability. According to Thawani (2016), yesterdays' business requirements were quality, productivity with reduced cost, and faster product development cycle times but today's business requirements are speed, flexibility, adaptability, accuracy, and ease of doing business, with high performance as a minimum requirement.

In the production system, the resources (raw materials, humans, machines, equipment, etc.) are always limited. Manufacturing companies need to produce cost-effective final products in a short lead-time (Kovacs, 2018) failure to do this may result in a lack of competitiveness and ultimately to the demise of the organization.

2.2.1. Performance Measurement

The basic concept of performance measurement involves (a) planning and meeting established operating goals/standards; (b) detecting deviations from planned levels of performance; and (c) restoring performance to the planned levels or achieving new levels of performance (Cherkos, 2011). Performance is a wide concept and can be assessed at different levels and using different measures. According to Hon (2005), the management school approach suggests that market valuation, financial measures, nonfinancial measures, and cost measures are the four types of metrics for a business organization:

In the context of manufacturing, for instance, researchers study the influence of strategies, priorities, activities, decisions, actions, etc. on a firm's manufacturing performance, market performance, and/or business performance. According to Begashaw (2015), manufacturing performance is a measure of performance only from a plant perspective; market performance is a measure of performance from customers' perspective, and business performance is a measure of performance from the perspective of the firm (business) as a whole. These three performance dimensions are interrelated with one another, while each

dimension has its unique measures. Manufacturing performance is a smaller sub-segment of performance, which focuses only on the manufacturing plant (Iwao & Marinov, 2018).

2.2.2. Manufacturing Performance

Araya (2018), defined manufacturing performance as the umbrella term of manufacturing excellence which includes profitability as well as non-cost factors such as quality, speed, delivery, and flexibility. Begashaw (2015), states manufacturing performance as the immediate outcome of factory operations is often used for factory performance appraisal: manufacturing cost, productivity, efficiency, conformance quality, cycle time, and manufacturing flexibility. Jilcha et. al., (2015), refers to performance as the way people or machinery do their jobs and the results of their work.

The above definitions indicate that the three measures of performance are interrelated, though their scope varies. The scope of manufacturing performance is the narrowest as it focuses only on the measures of plant (operational) performance, while business performance is an overall measure that is directly affected by market performance and indirectly by manufacturing performance.

2.2.3. Manufacturing Performance Measures

According to Jilcha et. al, (2015), many companies fail to improve their performance due to a lack of knowledge on how to improve it. In turn, it fails to meet customer requirements in their product on-time delivery and product quality. Measurement is the first step to control and improvement. Performance measurement provides management with the opportunity to make the right allocation of resources and to set the right priorities for improvement.

Effective performance measurement can help a firm make comprehensive decisions regarding capacity, process choice, technology, quality, and manufacturing planning, and control systems (Hensley & Utley, 2018). (Hon, 2005), summarized the generic functions of measuring manufacturing performance to reflect the current state of the manufacturing situation, to monitor and control operational efficiency, to drive improvement program, and to gauge the effectiveness of manufacturing decisions.

Performance measurement is the ongoing monitoring and reporting of program accomplishments, particularly progress towards pre-established goals (Thomas Cherkos, 2011). The classical view of manufacturing based on man, machine, material, and method is no longer adequate in the present environment as the coverage is too constrained. Today, the general approach for performance measurement is based on measuring input and output, and yet there are other relevant dimensions for consideration (Hon, 2005).

Manufacturing performance is frequently measured in terms of multiple dimensions in the literature often ranging from three to fifteen measures. For instance, (Romain, 2019) measure manufacturing performance in terms of fifteen dimensions (criteria), while (Ahmed, 2018), used three dimensions in measuring operational performance. According to Hon (2005), the measures of manufacturing performance include aspects like “cost, superior quality, timely delivery, productivity, and flexibility. The use of six measures of manufacturing performance is also common in the literature. For example, (Araya, 2018), mentioned six performance measures: cycle time, mean time between failure, utilization, mean waiting time, mean time to repair, and overall equipment effectiveness (OEE) in his study. According to Almour (2018), the measures of operational performance include the following four aspects/dimensions: productivity, quality, efficient utilization of resources, and high service level. Others, for instance, Addis et al., (2017), also measure operational performance in terms of twelve dimensions: downtime, work in process inventory, quality, rapid product introduction, delivery, working environment, cost, human resource management, bottleneck workstations, standard time for the process, flexibility and process layout. (Zhu et al., 2017), underscore sufficient flexibility, high-quality standards, productivity, and sustainability as key criteria to achieve their full economic potential. In the majority of the literature, manufacturing performance is measured in terms of cost, quality, delivery time, and flexibility dimensions (Romain, 2019).

It is indicated in the above review that the measures of manufacturing performance vary from literature to literature, and despite these variations, it is noted that there is an agreement in the literature concerning the use of multiple measures of this concept (Randhaw, 2017).

2.3. Bottlenecks

Performances of a production system, such as the throughput, the cycle time, and the average delay, etc., are affected by the capacities of machines and resources available in the system. Some of them may affect the system performances more than others. Usually, the limitation of a system can be traced to the limitation of one or two machines or one or two kinds of resources, commonly called bottlenecks. From a system point of view, bottlenecks are the congestion points of the system, which slow down the whole operation (Wang et al., 2016). According to Rooda (2015), the performance of a complex manufacturing system such as footwear is mainly determined by its bottleneck. Therefore, to improve its performance, the bottleneck behavior has to be improved. Wang et al., (2016), points out the factors of a system that contribute to the bottlenecks as the machine capacity and the number of operators. Even if there is still not an agreement on the definition of bottlenecks common sense of bottleneck is “something” that limits the system’s production rate (Wang et al., 2016). Several basic definitions of bottlenecks are summarized by (Roser et al., 2014; Skotnicka-zasadzień & Gębalska-kwiecień, 2018) as a facility, operator, etc. that limits the output, a resource whose capacity is lower than the demand, or the process that limits throughput/department, facility, machine, a resource already working at its full capacity which cannot handle any additional demand placed on it, a point where an operation meets or exceeds the capacity of the facility, the machine whose production rate in isolation is the smallest among all the machines in the system, and the machine with the largest work-in-process inventory in the preceding buffer or a congestion point in the production.

From these definitions, we can see a variety of bottlenecks. They are not only caused by physical constraints, such as resources, processes, facilities, etc. but also influenced by the function, operator, etc.

2.3.1. The bottleneck in a Manufacturing

All manufacturing systems are constrained by one or more bottlenecks. Improving the bottleneck will improve the system. Yet, finding the bottleneck is not a trivial task. Bottlenecks can be difficult to find and correct because their causes are diverse and often subtle. According to (Aregawi et al., 2017), bottlenecks in the production line involve long

queues, long waiting times, poor performance, and overall inefficiency of the system. Such a system should work under capacity. According to (Skotnicka et al., 2018), the bottleneck in production is a point where an operation meets or exceeds the capacity of the facility or department, facility, machine, resource already working at its full capacity and which, therefore, cannot handle any additional demand placed on it. In general, bottlenecks are processes that influence the throughput of the entire system. The larger the influence, the more significant the bottleneck (Roser, 2015). Correctly and efficiently identifying bottleneck locations can improve the utilization of the manufacturing resources, increase the system throughput, and minimize the total cost of production (Aregawi et al., 2017). However, a bottleneck does not necessarily have to be in a production process itself. It can also be in a logistics process that supplies processes. Furthermore, it can even be a process within the information flow regardless of push or pull systems (Roser et al., 2014).

There are four main ways to find the bottleneck in a system: analytically, simulation, using the data itself, or manually looking at the buffer level (Ericson, 2017). According to (Kikolski, 2016), simulation models are a common approach that has gained substantial popularity since the 1980s. Simulation models allow evaluating different variants of production and their effectiveness. Besides, the simulation allows to use new strategies and procedures, verification of the production in the revised system, locate bottlenecks in the flow of materials, increase productivity while reducing inventory, and reduce the cost of the implemented changes (Kikolski, 2016).

The main benefit of the simulation model is that it can give very detailed information about production performance measures such as average queue sizes or utilization as well as statistics of failures and maintenance activities. Another benefit is that it is easy to try out new changes and see how they affect the system. The downsides are that it is indeed very time consuming to perform a simulation. Also, a model is never a true representation of the system which means those wrong assumptions or misinterpretations can yield a very different result. Besides, the model easily gets outdated as the production system is changing, and keeping it up to date is expensive (Ericson, 2017).

2.3.2. Performance-Based Bottleneck Detection

Bottleneck detection in manufacturing is the first and most essential step to improve overall manufacturing capacity (Roser et al., 2014). According to Rogowska (2018), the first step taken to identify a bottleneck is the observation of the company's production system. Therefore process bottlenecks can be detected based on:

2.3.2.1. Cycle Time

The cycle time at a station is the time interval between the completions of the starting of work on successive items, and, therefore includes both productive and nonproductive work as well as any idle time (Patel, 2014). The cycle time may also be interpreted in the following ways: the time between consecutive releases of finished assembly's from the last station of the line or the time between consecutive releases of semi-finished products between any two adjacent stations (Parvez et al., 2017)

Ideally, it would be sufficient to look at the cycle times and thus the production rates for the machines in the system. The machine with the longest cycle time would have the lowest capacity and therefore be the bottleneck (Shamuvel et al., 2016). And indeed, this is how many in the industry are finding bottlenecks today.

2.3.2.2. Machine Utilization

According to (Rooda, 2015), utilization denotes the fraction a machine is not idle. The machine with the highest workload or utilization is considered to be the bottleneck (Ericson, 2017). Process time, as well as downtime, setup-time, and preventive maintenance time all, contribute to the utilization. However, more than one machine may have a similar percentage of being active, the difference between the workloads of the machines may be very small. Thus, it is often hard to decide which entity is the bottleneck (Wang et al., 2016). According to Rooda (2015), utilization has no dimension and never exceeds 1.0.

2.3.2.3. Work in Process

Johnston et al., (2007) define work in process (WIP) as the number of units within a process waiting to be processed further. WIP is a type of inventory, this type of inventory is located between raw material and finished goods. According to (Rooda, 2015), work in process denotes the total number of lots in the manufacturing system, i.e. in the factory or the machine

2.3.2.3. Waiting Time / Queue Length

Another frequently used method is one that analyses the queue lengths or waiting time. The machine with the longest average queue length or average waiting time is considered to be the bottleneck (Wang et al., 2016; Ericson, 2017). Measuring the average waiting time and average queue length are spontaneous and easy in implementation (Wang et al., 2016). According to Ericson (2017), an advantage of this method is it can be applied even to systems without buffers. The main shortcoming of waiting times is when the amount of incoming material exceeds the capacity of the system the queue times and waiting lengths will not be able to show where the bottleneck is (Thour, 2016).

2.4. Capacity Utilization

Capacity utilization is an important factor to be considered when an increase in productivity and expansion of a firm's production. It plays an important role in evaluating the performance of manufacturing firms (Oluwaseun, 2018). (Lee, 2013) also states capacity utilization as an important factor for the production manager and also deeply related to operations management in measuring production and operations related performance. Therefore, capacity utilization is a key indicator that tells about the operating performance of production parameters, because it relates to machine operators, machinery operation, level of maintenance, operating environment, and technology level (Shahidul et al., 2013). On the other hand, capacity utilization depends on production operating parameters such as the technology level of machinery, facility layout of production levels, production planning,

and others (Lee, 2013). According to (Rimo, 2017) capacity utilization is determined by machinery factors such as processing time, machinery set-up time, yield, and downtime.

Different works of the literature indicated that the productivity and performance of manufacturing firms are strongly dependent on machinery capacity utilization (Lee, 2013; Rimo, 2017). Ortikmirzaevich (2017), states that the production capacity of the enterprise is characterized by the maximum quantity of products of the appropriate quality and assortment that can be produced by it in a unit of time with the full use of the basic production assets in the optimal operating conditions. According to Lee (2013), capacity utilization is used to explain some important factors of manufacturing such as productivity, profit, assessing growth, future investment, and employment generation. The most used definition of "capacity utilization" is the ratio of the actual output to potential output (Shahidul, et al., 2013).

According to Tan (2017), capacity measurement is the most important task for a manufacturing system. A manufacturing system that fails to manage its resources, to ensure that capacity is available and is being used efficiently, risks losing its competitive advantage. In theory, capacity utilization is measured at 100% efficiency level, however, in a practical sense, capacity utilization may not exceed 90% maximum level especially in developing economies due to some setbacks in the production process such as lack of proper labor monitoring and supervision, wastages in the process and machine breakdown. Over or under-utilization of plant capacity can reduce plant competitiveness by increasing operating costs (Oluwaseun, 2018). Production cycle time optimization has a significant connection with maximizing capacity utilization and minimization of the capacity gap. On the other hand, to improve capacity utilization, set-up time of machinery, product defective rate, waiting times, and machinery breakdown should be minimized (Rimo, 2017).

The mathematical expression for the engineering perspective of capacity utilization is shown in expression (Rimo, 2017).

$$\text{Capacity Utilization (CU)} = \frac{\text{Actual Output (AO)}}{\text{Potential Output (PO)}}$$

2.5. Manufacturing Systems Modeling

According to Andradóttir et al., (1997), a model is a representation of the construction and working of some system which is similar to but simpler than the system it represents, while modeling is the process of producing a model. Yemane & Hailemicheal (2020), point out modeling is the process of developing a simplified representation of a complex system to provide and predictions of the system's performance measures of interest. In general, models are simplified concepts, which embrace only the scope and level of detail needed to satisfy specific study goals. It represents the dynamics and behaviors of the system, allowing a better understanding of it and helping to predict the impact of changes in a system (Silva et al., 2010)

When an investigation of the actual system is impractical or prohibitive, models are employed for a better understanding of the system. This might be because the direct investigation is expensive, slow, disruptive, unsafe, or even illegal. Indeed, models can be used to study systems that exist only in concept (White & Ingalls, 2014). Computer models can be freely improved, and further simulations can be applied to various variants and settings expected by the user (Kikolski, 2016). Therefore According to (Velumani & Tang, 2017; Araya, 2018), the model can be used to analyze current operations and identify the problem area, test various scenarios for improvement, design new manufacturing systems, and to gain information without disturbing the actual system

According to Kikolski (2016), manufacturing system modeling involves the creation of a virtual production process that allows conducting a simulation and collecting statistics. The system may be modulated through a physical or a mathematical model. In a physical model, the imitation of the system is made using physical resources while in mathematical models, system behavior is expressed in logical and quantitative relationships. According to Silva et al., (2010), there are two types of mathematical models: analytical solutions and simulation.

Simulation is a more appropriate tool as compared to analytical and physical approaches for performance improvement of manufacturing systems with dynamic, discrete, and stochastic natures (Kelton, 2010).

2.6. Simulation

The term “Simulation” refers to a broad collection of methods and applications to mimic the behavior of a real system (Kelton, 2010). According to (White & Ingalls, 2014), simulation is a particular approach to studying models, which are fundamentally experiential or experimental. Simulation can be used to model both conceptual and existing systems (Gashaw et al., 2014). This is normally performed by developing a simulation model on a computer with the appropriate software. In principle, simulation is much like running field tests, except that the system of interest is replaced by a physical or computational model. As it does not interrupt the existing system, it is a preferable tool to be used in large areas (White & Ingalls, 2014).

In many applications, simulation also involves testing and comparing alternative designs and validating, explaining, and supporting simulation outcomes and study recommendations (White & Ingalls, 2014). Simulation modeling was also used to study throughput, bottlenecks, and utilization of the system as it facilitated to identify the processes that were susceptible to becoming bottlenecks and to determine the appropriate settings which increased throughput (Kikolski, 2016). According to Gashaw et al., (2014), it is an indispensable problem-solving methodology for many real-world problems. It is also used to describe and analyze the behavior of a manufacturing system, ask what-if questions, and aid in the design of a real system.

The major attribute of simulation is its methodology in the context of cost-effectiveness because it allows performance evaluation and improvement without the actual application or disruptions to the ongoing production (Mohamad et al., 2016).

Simulation models can be classified into three different dimensions: (Silva et al., 2010; Cochran et al., 2011; Araya, 2018)

- Static vs dynamic – when a model is static it only concerns the system at a fixed time or the system is not influenced by time; when a model is dynamic it shows how the system evolves.
- Deterministic vs stochastic – when a model is deterministic no randomness is induced or the system has probabilistic characteristics; when a model is stochastic

one or several sources of randomness are modeled or the system behaves in an unpredicted form

- Continuous vs discrete – when a model is continuous the change of the system state is calculated continuously or the system state changes continually over time; when a model is discrete the system state changes at certain intervals or the system state only changes in some particular moments in time.

Analyzing manufacturing processes helps to identify their weak points, and creates possibilities for their improvement. Conducting computer simulations allows the company to assess whether the system was properly designed or not. A simulation ensures a total, complex view of the studied process or product, facilitates a multi-criterion analysis, and tests various scenarios (Kikolski, 2016). Simulation plays a vital role in various sectors, especially in the manufacturing industry. It has the advantage of being applicable almost anywhere, irrespective of the complexity of the system (Neeraj et al., 2018). According to Kłos & Patalas-maliszewska (2016), using simulation software is possible to design or redesign a manufacturing system to implement new production processes within a relatively short period. Mulugeta (2014), points out several strengths of simulation including the ability to simulate years of real system operation in a shorter time, the ability to integrate complex system components to study their behavior, hypothetical or potentially risky systems can be studied without the financial or physical loss that could be involved in studying a real system, the ability to study much larger or smaller varieties of a system, the ability to study various systems in identical environments or the same system in different environments, and everything in a simulated environment can be accurately monitored and precisely controlled.

In general, simulation allows for arranging a form of a system with the use of experiments directly conducted on the studied mode, for quick preparation of decisions thanks to analyzing the effects of experiments conducted for many alternating periods. It provides an answer to the what-if questions – simulation experiments allow for analyzing various decisional options, and it allows for analyzing correlations of the effects of variable elements of a model that can influence the decision chosen in extreme conditions (Kikolski, 2017).

Therefore, if it is used effectively and efficiently, the life of the whole manufacturing system or production company can be modeled and simulated as it can accommodate stochastic variation, analyze discrete or continuous variables, or both, and provide visualization through animation (Neeraj et al., 2018). On the other hand, simulation has a weakness to imitate the actual manufacturing process one hundred percent for the inconsistent variables which cause a percentage of an error. Besides, it does not take into account human error or skills which are difficult to measure; therefore, it is considered as qualitative data (White & Ingalls, 2014). Kikolski (2017), summarized the drawbacks of simulation: a long time for model preparation, its solutions cannot be used for analyzing other decisional issues as every simulation model represents a unique system, there are not optimal solutions for all conditions; therefore, it allows for alternative decisional solutions preparation in the following experiments and simulation models generate answers to the questions which are related to specific conditions.

2.6.1. Application of Simulation

According to White & Ingalls (2014), applications of simulation can be categorized broadly into two. The first one is the so-called man-in-the-loop simulations that are used for training and/or entertainment. The second category includes the design and analysis of objects and manufacturing processes. It is the technical category in which engineers and operations researchers are most commonly associated with simulation.

Simulation stands in contrast to analytical approaches to the solution of models. In an analytical approach, the model is expressed as a set of equations that describe how the system state changes over time. We solve these equations using standard mathematical methods-algebra and calculus-to determine the distribution of the state at any particular time. The result is a general, closed-form solution, which gives the state at any time as a function of the initial state, the input, and the model parameters. When models can be solved analytically this is always the preferred approach. However, for complex systems, this is rarely the case (White & Ingalls, 2014).

Simulation practically does not have limits and can be applied to any system that fits the concepts of simulation modeling. However, the application's areas are only limited by the

imagination of the user. Silva et al., (2010), summarizes its application areas as in manufacturing systems (optimization of production lines and logistics), public systems (emergency vehicle dispatch and weather forecast), military systems (warfare scenarios and training), transportations systems (railroad and air transportation), constructing systems (test buildings), and computer systems (computer networks and computer games).

According to Bodner & McGinnis (2002) simulation is one of the most widely used methods to study, model, analyze, design, and improve complex manufacturing systems.

Dr. George (2014), summarizes the application of simulation in designing of new process, implementing a new manufacturing concept, improving the existing process, improving resource utilization, reducing work-in-process (WIP), production scheduling.

Industrial experiences also show that simulation is an excellent tool for communication among various user groups in a company. This is because it provides a logical and often a graphical description of the system under investigation. In this way, ideas can be presented to the design team and management much more effectively (Dr. George, 2014).

2.6.2. Simulation Frameworks

In the manufacturing system modeling area, a great amount of research has been done on creating models using simulation. And so, the following simulation frameworks were considered (Tiago & Covas, 2014):

- **Arena** – developed in 2000 by system modeling and acquired by Rockwell automation, Arena is a discrete event simulation where the user builds an experiment by placing models (boxes of different shapes) that can represent either processes or logic, connected by lines that also specify the flow of entities. These models can do specific actions to entities, flow, and timing. So it is actually up to the user how to represent each model and entity. Statistical data, such as cycle time and WIP levels, can be recorded and outputted as reports.
- **Flexsim** – this framework was developed by Flexsim Software Products, Inc. The FlexSim family includes both the basic FlexSim simulation software and

FlexSim Healthcare Simulation (FlexSim HC). It uses an Open GL environment to create real-time 3D rendering.

- **Simio** – It's a simulation tool, developed in 2007 by Dr. C. Dennis Pegden, and it represents a new approach in simulation – object orientation. Modeling is based on describing the system's objects and the evolution of system behavior by the interaction of these objects.

2.6.3. Simulation Tool

The arena is built on the SIMAN simulation language which is used by organizations to develop production line, to balance assembly line, to detect bottleneck(s) in the assembly line, to develop or modify plant layout, and also help to manage productive hours of men power (Chaudhari, 2018). The basic process, advanced process, and advanced transfer modules will be used to build the production system. The setup of uncertainties, for instance, operation time, customer orders, base stock levels can be set up in different scenarios.

According to Velumani & Tang (2017), the two most common criteria for selecting simulation software are modeling flexibility (ability to model any system regardless of its complexity or uniqueness) and ease of use. Arena software is a flexible and powerful tool that allows analysts to create simulation models virtually that represent the real system correctly (Othman, 2017).

Kelton (2010), also states Arena as simulation software that has flexible model building capability and advanced process transfers to help to model from strategic business decisions as supply chain network, to operational planning improvement or more details in the production process and inventory control. It accurately represents virtually any system with the help of animation and simulation. Arena automatically calculates the 95% confidence interval unless the user specifies otherwise (Rahman, 2015).

Discrete event simulation is selected to analyze the system because it is perfectly suited for a production system that could describe the complex interactions among different resources and operations within the production line. At a discrete event simulation, the state of a system changes only at discrete points in simulated time. Thus, Arena simulation software is selected for this study.

2.7. Summary and Literature Gap

In a global competition where customer demands are changing continuously, manufacturing companies have to improve their production performance that results in high productivity at a minimum cost. In the production system raw materials, humans, machines, equipment, storage spaces, etc. are always limited. All manufacturing systems are constrained by one or more bottlenecks. Bottlenecks in the production line involve long queues, long waiting times, poor performance, and inefficiency and generally contribute to reducing the capacity utilization and performance of the production systems significantly.

Studies on production performance stated that higher capacity utilization and efficient resource management are highly associated with production performance. Thus, capacity utilization is an important factor for measuring production and operations related performance. Capacity gap is an unused part of the production facility recognized as non-value-added inputs and generally contributes to reducing performance and economic efficiency of production systems. On the other hand, capacity utilization is used to explain some important factors of manufacturing such as productivity, profit, assessing growth, future investment, and employment generation. It highly depends on production operating parameters such as workstation resource level, facility layout, working methods, and others.

Simulation models are a common approach that has gained substantial popularity in measuring and improving the performance of manufacturing systems. The major advantage of simulation is its methodology in the context of cost-effectiveness. It allows performance evaluation and improvement without the actual application or disruptions to the ongoing production.

The Arena modeling software is a flexible and powerful tool that allows analysts to create models that accurately represent any system virtually. It allows to identify system constraints and the reasons behind specific system conditions. It was designed to provide analysis and an insight into changes that could or should be done with regard to company's business processes and provides system-specific quantities to measure performance. Arena includes a large library of pre-defined building blocks to model the manufacturing process without the need for custom programming. It also has a complete range of statistical

distribution options to accurately model process variability. The other important benefits of Arena simulation software are its ability to define object routes for simulation and its good interactions with other computer tools such as Visual Basic, Excel, etc. Because of these advantages, Arena simulation software is a preferable tool to model a complex manufacturing system. Consequently, Arena simulation software is selected for this research work.

In the above literature, the authors clearly stated the importance of capacity utilization and performance improvement. In recent years, researchers have made significant advances in capacity utilization and performance measurement metrics. The studies demonstrated that researches on performance improvement from the perspective of their metrics and associated costs is essential for achieving better decisions in the manufacturing business. Previous studies on this field have only concentrated on developing and proposing improvement models by looking at the performance metrics without considering the cost that could be incurred to the system. Moreover, most of the reviewed literature does not consider the impact of preventive maintenance and layout on performance improvement of footwear manufacturing systems.

In this study, the behavior of the military shoe production unit of the case company was simulated and the model outputs were used as the raw data for developing different performance improvement scenarios. The selection and recommendation of the better scenario are based on a cost-benefit analysis and performance comparison. Therefore, this study will fill this knowledge gap and contribute towards the performance improvement of Tikur Abbay Shoe Share Company.

Chapter Three

Research Methodology

3.1. Research Design

A research design is the ‘procedures for collecting, analyzing, interpreting, and reporting data in research studies’(Boman et al., 2017). The choice of the research design; however, is based on the objectives of the research, an issue being addressed, the researcher’s personal experience, and the audience for the study (Araya, 2018).

The experimental research method was conducted to have a better understanding of the existing production situations and to analyze the effect of resources, layout rearrangement, and work method change on performance parameters using Arena simulation.

To meet the research objectives, arena simulation software was selected as a suitable tool to deal with the research problems and research questions of this study. Arena simulation software allows the researcher to identify system constraints and limitations and the reasons behind specific system conditions. Due to the number and sequential nature of footwear manufacturing operations, experimenting with the actual system is costly. Thus, Arena helps the researcher to experiment with different scenarios remotely and provides system-specific quantities to measure with a minimum cost.

3.2. Overall Research Framework

The research starts with a problem formulation, literature review, and setting of objectives that indicate the questions that are to be answered by the study. After that, the actual production system has been converted into a conceptual model. In this stage, the basic model such as workstations, the sequence of operations, and material handling is constructed. At the same time, important data such as arrival time, processing time, machine failure, conveyor speed, the distance between workstations, manning level, working days & hours, etc were collected. Arena simulation software was used to construct and to code the conceptual model into a computer recognizable form. Next is to verify the model which is extremely important in determining whether the computer implementation of the conceptual

model is working correctly. Then the output from the simulation was validated by comparing it to the actual system. Once validated, design the experiments were performed to understand the impact of different scenarios on the performance of the system. Proper experimentation planning was carried out to determine the length of the simulation run and the number of runs (replication) for each simulation. Once the results are analyzed and satisfactory, conclusions and recommendations were extracted from the findings.

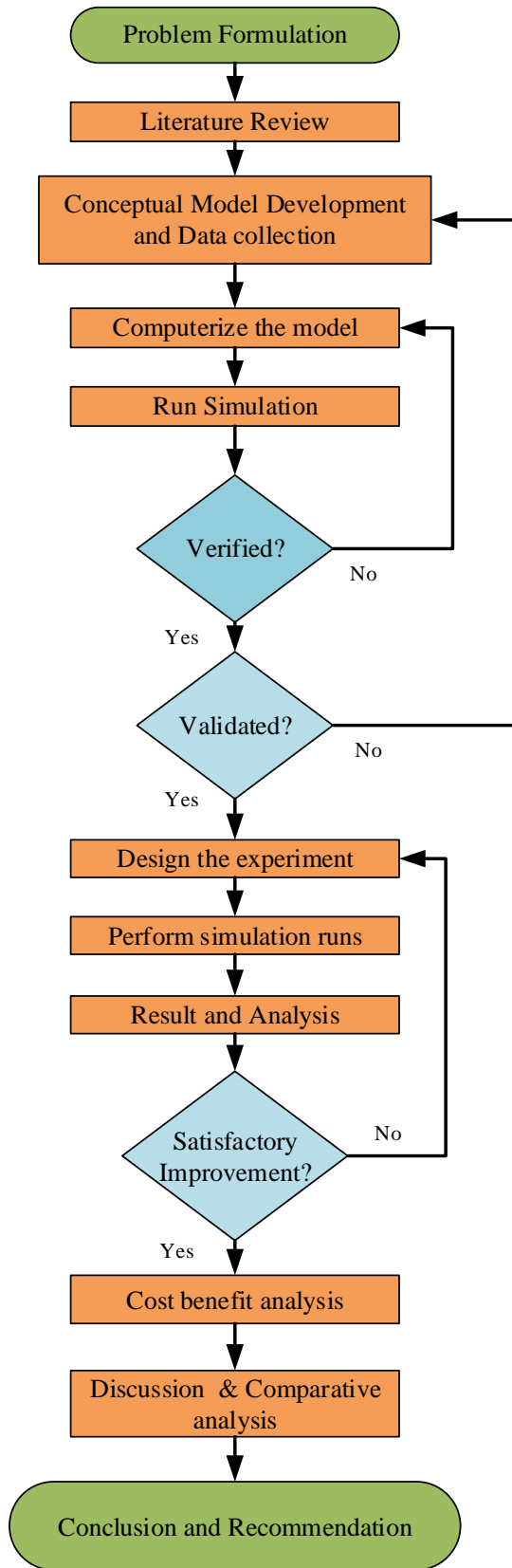


Figure 3-1: Research framework (Adopted from Winston & Goldberg, 2004)

3.3. Problem Formulation

A simulation study is effective when a good simulation model is developed and meets the objectives set by the decision-makers. The production performance of Tikur Abbay Shoe Share Company was understood from the company's annual reports and company production process visits. International and national benchmarks regarding capacity utilization, production output, machine failure frequency, and duration data were used as inputs for identifying the existing gaps. Then the problem was defined and formulated. It considers into account the objectives of the study, questions to be answered, and causes for the existing problem, etc. People who work with the system were also involved initially and asked different questions in defining and formulating the problem.

3.4. Literature Survey

Reviewing the relevant literature was initiated by searching several sources using common key phrases and obtaining books and articles that were most relevant based on their abstracts. A total of 100 literature were downloaded from it 85 were selected and 71 were acquired and reviewed from books, proceedings, articles, and unpublished thesis. The percentage of reviewed literature by publication years is shown in Figure 3-2.

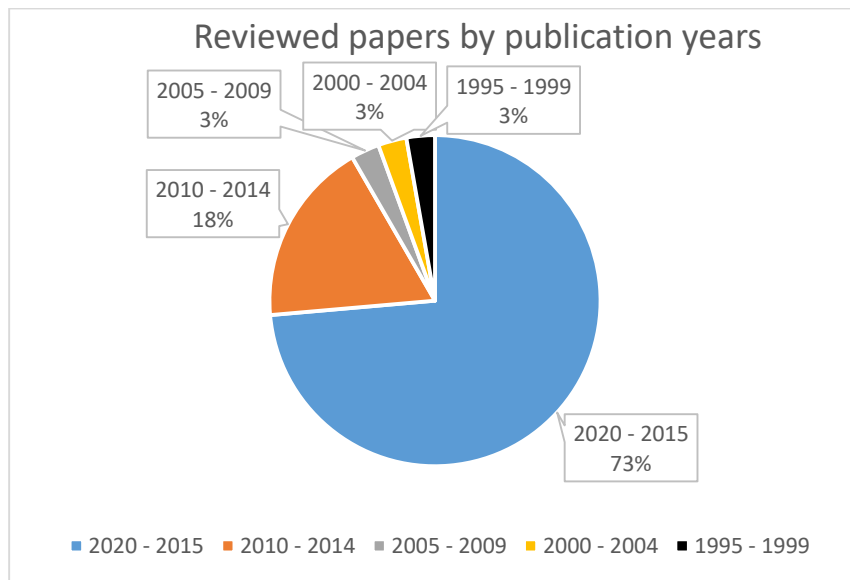


Figure 3-2: Reviewed literature by publication years

3.5. Conceptual Model Development

3.5.1. Product Selection

Product selection refers to the process of classifying a “product” or “family” of similar products to be the target of an improvement project or study. In Tikur Abbay Shoe Share Company production units and products are categorized based on the similarity of operations they have. Military shoes, safety shoes, and casual shoes are produced in three different units. Trying to solve all problems at the same time creates confusion, inefficient use of resources, and delays. Therefore, focusing on a single product provides emphasis on the study and produces tangible improvements in an effective manner.

According to Yemane & Hailemicheal (2020), a product with the highest number of operations and length are prone to problems. Therefore, model 927 military shoe was selected for analysis and improvement as it has the highest number of operations and demand in the market from all products in the factory.

3.5.2. System Description

To understand the manufacturing process accurately first knowledge of the complete flow of the process is required (Chaudhari, 2018). Process mapping is a common logical modeling technique. It is used to model all processes associated with data and information. Process maps for production lines were developed based on the sequence and precedence of operations. More than that, the study needs actual operational data for simulation and verification, which were collected by direct observation and interviewing the responsible person.

3.5.3. Process Flow

The company’s production process flow is shown in figure 3-3 and the description is as follows: Production planning and control dispatches production plan to all production sections. The operation stages include cutting, preparation, stitching, lasting, and finishing activities. At the end of the cutting, stitching, and finishing operations there is a quality

inspection that checks the product. Semi processed products that cannot meet the quality inspection will go through rework and another quality checking to proceed to the subsequent operation or to be rejected. Products that meet the requirements will go to the packing section and be ready for delivery to the customer or the shops.

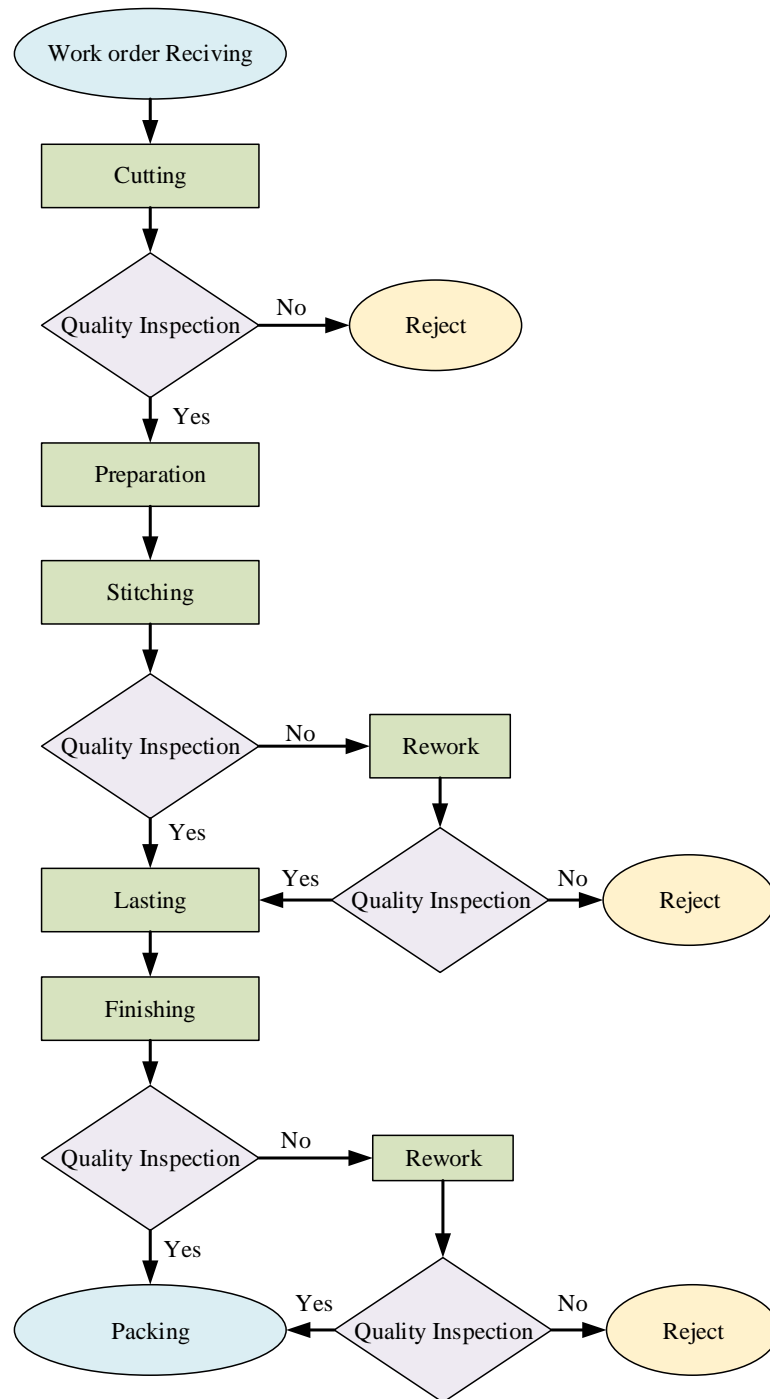


Figure 3-3: Production process flow chart (Source: Own)

3.6. Data Collection and Input Analysis

3.6.1. Data Collection

Both qualitative and quantitative; primary and secondary data collection methods, that are essential to model and analyze the current performance, were implemented for data collection. The data collected were based on how to detail the simulation model is expected in representing the real system. It includes:

Primary data

- Operation sequence and entities arrival time
- Processing time
- Number of machines and manning level
- Distance between workstations
- Conveyor speed

Secondary data

- Machine failure time including a preventive maintenance schedule
- Rework and reject rate
- Design capacity and daily production output
- Number of working days and hours

3.6.2. Input Data Analysis

After collecting all the necessary information to carry out the study, statistical analysis was used to check the mean and variance of the raw data. Arena input analyzer was used to find the probability distribution that fits the collected data and their parameters for each operation.

According to Herzegovina (2012), a sample size of 10 should be used for Arena input analyzer. But to increase the validities of input data twenty-five data sets were utilized for processing time. The sample sizes were sufficient enough to generate corresponding p values of the distribution summary.

Using Arena input analyzer expressions of each operation were obtained. The same procedure was followed to collect the inter-arrival expressions and machine failure expressions. Conversion of the raw failure data to mean time between failures and mean

time to repairs was conducted before the Arena input analyzer. After analyzing all the data in the required format and specifying the appropriate replication number, model building, and running the simulation was the next step.

3.7. Model Building

Discrete event simulation models were created for production lines using Arena simulation software. Models for cutting, stitching, lasting, and finishing production sections were developed. It has taken several times to redesign the models to make sure that the model works in the same way as the initial model description. The sequence of operations, Inter arrival time, processing time, number of machines, manning level, mean time between failures, conveyor speed, the distance between workstations, and working hours were used to model the existing production line. Similarly, create module, assign module, process module, set module, decide module, record module, and dispose module were used from the basic process panel. Enter module, leave module, station, sequence, conveyor, and segment were used from advanced transfer panel. Similarly, a failure module was used from an advanced process to model both the existing and improved production systems.

3.8. Verification and Validation

After developing the complete logic model, verification and validation are crucial. Verification is the task of ensuring that the model behaves as the modeler intended. The model was verified by using code verification. Therefore, it is assumed that the computer model represents the conceptual model faithfully.

Validation is the task of ensuring that the developed model behaves in the same way as the real system. Thus, model validation was done by comparing the output of the real system with the simulation output. Z score value calculation and different percentages were carried out for cutting, stitching, lasting, and finishing production sections. The results from the z value calculation and different percentages have shown that the created models satisfied both validity tests.

3.9. Design the Experiment

Bottleneck identification was started by running the simulation model of an existing system to collect data based on machine utilization and queue length. A simulation experiment with different scenarios (layout rearrangement, changing work method, and resource addition) was designed and conducted to search for a feasible solution that could improve the performance and capacity utilization of the production lines. Then, running the experiment and designing to extract the statistics in terms of output, cycle time, resource utilization, work in process, the maximum average time in a queue, and the maximum average number in a queue. The output of the simulation is taken from the automatic report from the software.

3.10. Results and Analysis

After conducting several simulations runs, alternative scenarios were tested to determine the impact of changes on the performance of the system in terms of performance measures. The production line utilization was also calculated for each simulation result. Then the results were analyzed and the design of experiments continued until it reaches a satisfactory level. Finally, conclusions and recommendations were drawn from a comparison between existing and improved manufacturing system performance and capacity utilization.

3.11. Result Dissemination of the Study

To ensure the outputs from the research informs practice and thereby maximize the benefit to the manufacturing companies, this study considers the footwear production sector and academia as target audiences. The researcher understands that research is most effectively disseminated using multiple ways, ideally with face to face interaction. So, in addition to giving written reports to the case company, dissemination activities will include the use of websites, social media, and publications.

Chapter Four

Overview of the Case Company & Input Data Analysis

4.1. Company Overview

Tikur Abbay Shoe Share Company (TASSC) is one of the biggest shoe manufacturing companies in Ethiopia. It was established in 1948 to produce footwear for local and export markets with a capital of 200,000 Birr and 500 pairs of production capacity. It was re-established in 1992 as an autonomous public enterprise with a capital of 4,416,000 Birr.

The company manufactures around 750,000 pairs of shoes per annum which are spread over 50 styles ranging from sandals to boots (Tilahun, 2018). From all types of shoe production military shoe accounts for 83.5%, safety shoes 6 %, and casual shoes 10.5 %. At this moment the company has an average of 679 permanent and 87 contract employees.

The creation of a pair of shoes goes through several stages mainly cutting, stitching, lasting, finishing, and packing processes. To perform these activities five production sections are arranged in the factory based on the product type:

- Cutting Section: Cutting is the first stage of shoe production. Upper, lining, and soaks are cut to the shape of the cutting dies based on size and style requirements using hydraulic swing arm cutting machines.
- Insole and Outsole Production Section: soles and insoles are prepared which are inputs for the lasting section
- Stitching Section: leather upper components and linings are sewn together. Stitching is probably the most complex stage and most difficult line to balance because each part must go through a lot of different operations in different machines along the line.
- Lasting Section: upper and bottom components are joined together using lasts to give the final shape to the shoes.
- Finishing and packing Section: final operations such as cleaning, labeling, spraying, etc. are carried out to improve the appearance of the shoes.

4.2. System Characteristic

Tikur Abbay Shoe Share Company production facility is taken as the system and its production sections as subsystem or system elements. The interaction between the system elements in the form of input-output relationships determines and affects the overall manufacturing performance.

The footwear manufacturing in the case company is a labor-intensive process that consists of an average of 766 employees. It requires craftsmanship in each phase of the production. Military and safety shoes are produced in dedicated lines but casual shoes are produced in batches. In the production process, various shoe styles are manufactured requiring the same materials. The sequence and the number of operations for military shoes and safety shoes are fixed. But for casual shoes, it changes when there is a change in a shoe model. The effects of the product properties along with the technological requirements of the product are reflected in the traditional classification of the production systems as continuous and intermittent production systems.

The characteristics of the shoe manufacturing sections under Tikur Abbay Shoe Share Company are:-

- Continuous production for military and safety shoes
- Changing product mix for casual shoe production
- Skilled human resource
- Flexible resources
- A large volume of inventories

Since the number and sequence of operations as well as their operation times are similar to the type of the product, the number and organization of the resources do not vary accordingly with different production sections.

4.3. Data Collection

4.3.1. Primary and Secondary Data

For all operations in cutting, stitching, lasting, and finishing sections both primary and secondary data were collected. The main input for Arena software is the processing time. 25 observations have been made to each operation during data collection. Appendix 1 shows the processing time for each operation. It includes the type of activity, machine ID, operator or machine quantity, average, and standard deviation of the processing time.

Similarly, machine failure data consists of machine ID, failure frequency, uptimes, downtimes, etc. The details of the inter-arrival time, processing time, and machine failure data are found in appendix 1, 2, and 3 respectively.

4.4. Model Building

4.4.1. Model Elements

Every model contains some combination of entities called model elements. These model elements are components, variables, parameters, functional relationship constraints, and criteria. Within the framework of the simulation model of the shoe factory these elements are described and identified as follows:

Parameters: The following parameters are the elements of the model which affect the performance of the system modeled and their values are known with certainty and can be controlled:

- Number of machines
- Sequence of operations
- Operation times
- Number of working hours

Besides these parameters, another set of parameters which are named as the study parameters, are defined. These parameters are used to initiate and terminate the experimentation on the model and to identify the experimental analysis. These parameters are:

- Replication counter
- Number of days to be simulated
- Experiment time limit

Variables:

Functional Relationship:

Performance Criteria: The performance criteria are the measures by which the performance of the system under the selected operating policies are evaluated. The results obtained by experimentation on the model should give insight into understanding the behavior of the system and the bottlenecks in the system. The results should also provide a basis to balance the level of in-process inventory, the level of resource utilization while maintaining planned order completion times. The study requirements lead to multiple criteria selection which is defined as follows:

- Minimum cycle time
- Increased daily production output
- Maximum capacity utilization
- Minimum jobs waiting time
- Minimum number waiting for jobs

Model Assumptions

A compromise needs to be made in simulation modeling such that the model must be simple enough to perform experiments on it and accurate enough to represent the system modeled. Simplification is a necessity to avoid the model to become as complex as the actual system. Using assumptions is a way of achieving this simplicity to eliminate the difficulties in

running the model. However, the assumptions need to be made realistically such that the validity of the model should be retained. In this study the following assumptions were made:

- No labor absenteeism
- No inter-sectional resource transfer
- Fixed designed capacity in all the sections
- Alternative routing is not permitted
- Each component of the shoes are considered as a single entity
- Each workstation has input in front of it so that it never starves
- 100 % performance rating and 15 % allowance for each worker
- Constant conveyor speed
- Overall performances of the production lines are analyzed using the output of the selected product

These assumptions were reviewed with the technical personnel in the factory and they were found to be acceptable. These assumptions helped in reducing the simulation requirements as to computer time and computer storage which were essential for running the computer program.

4.4.2. Data for Model Building

The change of operating techniques and methods in one section would create a different pattern of output and this different input pattern to the next section. Therefore, there is a possibility of having a non-stationary arrival pattern which may be reflected in different arrival probability distributions. Thus, the collected data through direct observation, interviews, and company records were analyzed. Fitting input distribution using the input analyzer is used to identify the fitted statistical distribution (Jilcha et al, 2015). It is used to evaluate the distribution's parameter and calculates several measures of the data. The selection of the type of distribution to use is based on a comparison of the square error of each distribution. The larger the square error value, the further away the fitted distribution is from the actual data. The data was analyzed by using real recorded time from the operation areas of the selected product in Tikur Abbay Shoe Share Company.

4.4.3. Inter Arrival Distribution

Production lines in the case company are categorized into four groups based on the type of input each production line used. The first group includes cutting of uppers, linings, toe puff reinforcement, counter reinforcement, sock lining, and insole cutting. In this section raw materials are provided to cutting operators to complete a maximum of 160 pairs daily per operator.

The second section includes preparation and stitching. The input to this section includes a fraction of the output in the cutting section. The arrival of entities to this section is in batches; however, loading to the conveyor is in pairs. The output of the stitching section forms the input to the lasting section. The outputs of the stitching section are transferred to a waiting station before moving to the lasting section for temporary storage.

The third section includes the lasting production line. The input for the lasting production line consists of a fraction of the stitching section output or accumulated uppers from the temporary storage.

Lastly, the inputs for the finishing section consist of lasted uppers from the lasting section and outsoles either purchased from the market or outsole preparation section. The arrival times of the finishing and packing section is determined by the completion times in the lasting section.

The probability distribution of job arrival times was generated by the Arena input analyzer using ten data sets of each entity loaded to the sections. The hourly production and inter-arrival rate of the four groups or sections are shown in Appendix A.

Inputs for the cutting section inter-arrival time is shown in Table 4:1. The arrival of upper leather, lining leather, toe puff material, counter material, insole material, and sock lining leather is in a batch of 160 pairs, 230 pairs, 85 pairs, 82 pairs, 80 pairs, 60 pairs respectively.

Table 4-1: Inter arrival of raw materials to the cutting section

	Name	Entity Type	Type	Expression	Units	Entities per Arrival
1	Upper Leather Arrival	Upper	Expression	$NORM(30.2,0.653)$	Minutes	160
2	Lining Leather Arrival	Lining	Expression	$NORM(44.9,0.573)$	Minutes	230
3	Toe Puff Material Arrival	Toe Puff	Expression	$NORM(15.1,0.442)$	Minutes	85
4	Counter Material Arrival	Counter	Expression	$NORM(14.9,0.573)$	Minutes	82
5	Insole Material Arrival	Insole	Expression	$13.5+2*BETA(1.42,1.33)$	Minutes	80
6 ▶	Sock Lining Leather Arrival	Sock Lining	Expression	$NORM(10.4,0.23)$	Minutes	60

The movement of entities from one workstation to the other in the stitching section is by using an accumulating conveyor. Components for four pairs were loaded to the conveyor following $0.575+0.04*BETA(9.23,9.4)$ expression and with an average velocity of 1 mm/s. Table 4-2 shows the inter-arrival of components to stitching the section.

Table 4-2: Inter arrival of components to the stitching section

	Name	Entity Type	Type	Expression	Units	Entities per Arrival	Max Arrivals
1 ▶	Upper Components Arrival	SA001	Expression	$0.575+0.04*BETA(9.23,9.4)$	Minutes	4	Infinite

The lasting production section is subdivided into two production units. Unit one uses an accumulating conveyor for upper movement with an average velocity of 1 mm/s whereas movement of upper in unit two is manual. It requires an average of 18-19 seconds to load that follows an exponential distribution. Inter arrival of uppers to the lasting section is shown in Table 4-3.

Table 4-3: Inter arrival of uppers to the lasting section

	Name	Entity Type	Type	Value	Units	Entities per Arrival	Max Arrivals
1	Upper Arrival	SA001	Random (Expo)	0.30	Minutes	1	Infinite
2 ▶	Upper Arrival 2	SA001	Random (Expo)	0.325	Minutes	1	Infinite

Pallet trucks are used to transport lasted uppers from one workstation to the other in the finishing and packing production section. Entities are arriving at this production section in batches of 110 pairs and follow Expo (18.15) distribution as shown in Table 4-4.

Table 4-4: Inter arrival of lasted uppers to the finishing section

Create - Basic Process							
	Name	Entity Type	Type	Value	Units	Entities per Arrival	Max Arrivals
1 ▶	Lasted Shoe Arrival	Entity 1	Random (Expo)	18.15	Minutes	110	Infinite

4.4.2.2. Processing Time

Simulation models cannot accurately simulate production lines unless the processing time required by an average skilled operator, working at a normal pace, and perform a specified task using a prescribed method is considered. Thus, the collected processing time of each operation was converted to standard time by adding a 15 % allowance for fatigue, delay, setup, loading, and unloading times and assuming a 100 % performance rating. The standard processing time for each operation is shown in Appendix 2.

Arena input analyzer is used to determine the right statically distribution function for operations and to determine associated parameters. The software has different integrated distribution functions, which automatically fit the histogram of the actual data. The one with minimum square error is considered as the best fitting distribution function.

Figure 4-1(a) and (b) have shown processing time distribution summary for rivet piercing and heat setting operations. Rivet piercing operation shows that the distribution function for this particular data is expressed as TRIA (6.5, 9.24, 11.5) with a minimum square error of 0.000728 and corresponding p-value > 0.75 which is acceptable as it is greater than 0.1. Similarly, heat setting operation shows the distribution function for this particular data is expressed as $85.5+13*BETA$ (1.32, 1.24) with a minimum square error of 0.014532 and corresponding p-value equal to 0.737 which is acceptable as it is greater than 0.1. Therefore, it can be concluded that rivet piercing operation is following triangular distribution with parameters TRIA (6.5, 9.24, 11.5) and heat setting operation is following beta distribution with parameters $85.5+13*BETA$ (1.32, 1.24).

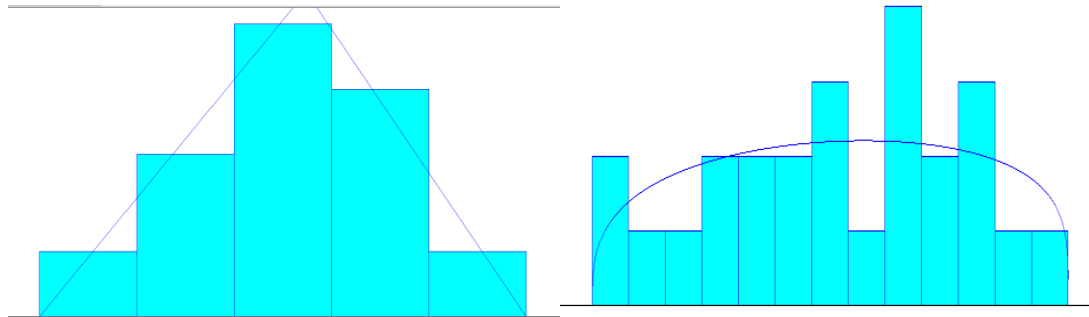


Figure 4-1: (a) Rivet piercing (Source: Own) (b) heat setting operations (Source: Own)

Distribution Summary

Distribution:	Triangular	Distribution:	Beta
Expression:	TRIA(6.5, 9.24, 11.5)	Expression:	$85.5+13*BETA(1.32, 1.24)$
Square Error:	0.000728	Square Error:	0.014532
Chi-Square Test		Chi-Square Test	
Number of intervals	3	Number of intervals	4
Degrees of freedom	1	Degrees of freedom	1
Test Statistic =	0.0372	Test Statistic	0.121
Corresponding p-value	> 0.75	Corresponding p-value	0.737
Data Summary		Data Summary	
Number of Data Points	25	Number of Data Points	25
Min Data Value	7	Min Data Value	86
Max Data Value	11	Max Data Value	98
Sample Mean	9.08	Sample Mean	92.2
Sample Std Dev	1.08	Sample Std Dev	3.44
Histogram Summary		Histogram Summary	
Histogram Range	= 6.5 to 11.5	Histogram Range	= 85.5 to 98.5
Number of Intervals	5	Number of Intervals	13

Table 4-5 shows that input analyzer data distribution best fits for operations in cutting, stitching, lasting, and finishing production sections.

Table 4-5: Input analyzer distribution

Section	Operation	Best fit distribution	Sq error
CUTTING	Upper Cutting	$38.5 + 33 * \text{BETA}(0.656, 0.639)$	0.042286
	Lining Cutting	$26.5 + 33 * \text{BETA}(0.659, 1.49)$	0.045166
	Toe puff Cutting	$5.5 + 5 * \text{BETA}(1.24, 1.65)$	0.035595
	Counter Cutting	$0.5 + 4 * \text{BETA}(1.96, 3.1)$	0.000179
	Insole Cutting	$2.5 + \text{LOGN}(2.86, 1.74)$	0.011288
	Sock Lining Cutting	$3.5 + \text{GAMM}(3.4, 1.84)$	0.039873

Section	Operation	Best fit distribution	Sq. error
Preparation & Closing (Stitching)	Marking	$9.5 + \text{WEIB}(3.41, 2)$	0.021911
	Tongue to eyelet zigzag stitching	$\text{UNIF}(8.5, 16.5)$	0.075000
	Counter zig-zag stitching	$\text{TRIA}(10.5, 12.8, 17.5)$	0.035917
	Vamp to tongue stitching	$17.5 + 17 * \text{BETA}(1.26, 1.11)$	0.024733
	Counter stripe stitching	$\text{NORM}(48.3, 3.45)$	0.025591
	Inner part folding stitching with upper	$\text{TRIA}(15.5, 34, 41.5)$	0.052782
	Size labeling on the upper	$\text{NORM}(40.5, 6.88)$	0.059189
	Quarter to counter stitching	$63.5 + 35 * \text{BETA}(1.05, 1.18)$	0.046215
	Eyelet trimming	$22.5 + 12 * \text{BETA}(1.27, 0.864)$	0.032848
	Eye letting	$\text{NORM}(17.3, 3.17)$	0.033815
	Vamp to quarter stitching	$26.5 + \text{WEIB}(7.36, 1.26)$	0.080745
	Thread burning	$24.5 + \text{GAMM}(4.49, 1.76)$	0.026220
	Quality inspection & trimming	$\text{NORM}(17.8, 5.25)$	0.033434
	Piercing for rivet	$\text{TRIA}(6.5, 9.24, 11.5)$	0.000728
	Rivet inserting	$26.5 + 13 * \text{BETA}(0.983, 1.23)$	0.049373
	Riveting	$\text{TRIA}(4.5, 8.36, 8.5)$	0.087452
	Lacing	$\text{POIS}(41.6)$	0.061061
	Arranging and tying with rope	$\text{NORM}(48.5, 10.7)$	0.061356

Section	Operation	Best fit distribution	Sq. error
LASTING	Toe puff glue pasting & inserting	UNIF(16.5, 28.5)	0.023867
	Counter glue pasting & inserting	$35.5 + 29 * \text{BETA}(1.16, 0.913)$	0.033308
	Inner side glue pasting	$28.5 + 22 * \text{BETA}(0.919, 0.992)$	0.036140
	Needle tacking	UNIF(8.5, 18.5)	0.010400
	Insole glue pasting	$19.5 + 8 * \text{BETA}(1.14, 1.02)$	0.026004
	Heat setting	$85.5 + 13 * \text{BETA}(1.32, 1.24)$	0.014532
	Toe lasting	POIS(25.6)	0.07014
	Side lasting	$21.5 + 15 * \text{BETA}(1.4, 1.1)$	0.046128
	Nail removing	UNIF(16.5, 24.5)	0.0238
	Bounding	TRIA(7.5, 13, 14.5)	0.060248
	Glue pasting	TRIA(4.5, 6, 9.5)	0.08915
	Back part lasting	POIS(19.1)	0.043054
	Manual hammering	POIS(10.7)	0.030145
	Roughing with sandpaper	TRIA(5.5, 10.1, 11.5)	0.00745
	Roughing with wire 1	UNIF(12.5, 20.5)	0.0238
	Roughing with wire 2	$19.5 + 10 * \text{BETA}(1.11, 1.21)$	0.041989
	De lasting	TRIA(8.5, 11, 25.5)	0.022374
	Tithing pair by pair	TRIA(15.5, 18, 25.5)	0.037848

Section	Operation	Best fit distribution	Sq error
FINISHING & PACKING	Volcanizing	UNIF(138, 162)	0.041174
	Trimming	TRIA(19.5, 27, 29.5)	0.013587
	Manual overflow cutting	$58.5 + 54 * \text{BETA}(1.19, 1.44)$	0.030802
	Insole inserting	$8.5 + \text{LOGN}(6.39, 7.43)$	0.039859
	Decoration	$19.5 + 31 * \text{BETA}(0.939, 0.934)$	0.041565
	Spraying	UNIF(2.5, 5.5)	0.048323
	Lacing	NORM(23.5, 4.63)	0.044591
	Quality inspection	$12.5 + 17 * \text{BETA}(0.786, 0.876)$	0.030045
	Packing	$19.5 + \text{GAMM}(1.46, 3.67)$	0.043633

4.4.2.3. Machine Failure

The failure data were collected from the company's three-month failure records. Random machine failures can be modeled using the time between machine breakdowns and the time to repair it, these random variables follow a certain probability distribution. Usually, the exponential distribution function is appropriate for random machine breakdowns (Kelton, 2010).

Simulation can help the modeler to understand the impact of machine failures on system performance. In the cutting section travel head machine 1 failed 8 times in three months. It is the highest frequency from the section with MTBF (89) hours and travel head machine 4 requires the highest time to repair MTTR (80) minutes. In the stitching section counter side stitching machine failed 17 times, which is the highest, in three months with MTBF (42) hours. In the lasting section pounding machine failed in every MTBF (89) hours, 8 times in three months and back part molding machine requires MTTR (150) minutes. Similarly, trimming machine, from the finishing section, failed 24 times within three months with MTBF (30) hours and vulcanizing machine 19 requires MTTR (300) minutes to repair. Appendix 3 showed that the average failure frequency of cutting, stitching, lasting, and finishing sections per three months.

From all production sections, vulcanizing machines were idle for a longer time than other machines, as a result, the finishing production section has the highest average machine failure frequency and the highest average downtime while the cutting production section has the average lowest downtime. Even if the mean time between failures is very small, it should be considered during footwear production system modeling as material handling among workstations is by using conveyors so a single machine breakdown will stop the entire production line.

4.4.2.4. Layout Rearrangement

Machines and/or workers arranged following the sequence of operations for a given product is a typical characteristic of product layout. A good layout has advantages to reduce bottlenecks in moving people or material, utilizes labor efficiently, utilizes available space

effectively and efficiently. The workstation layout arrangement could determine the performance of production lines. Therefore, the layout arrangement of TASSC was investigated to reduce the bottlenecks due to the unnecessary movement of materials and employees from one workstation to the other. The existing production lines configuration of cutting, stitching, lasting, and finishing lines were studied and the distance among workstations was measured.

Accordingly, there are 10 workstations in the cutting production section, 18 in the stitching production section, 18 in the lasting production section, and 14 in the finishing production section. Hydraulic machines for upper and lining cutting are located in the same room with the stitching production line while toe puff, counter, insole, and sock lining cutting is done in a different room. Lasting and finishing sections are also located in the same building as the stitching section.

The existing workstations layout arrangement is not well organized. Congestion of raw materials and semi-processed products were seen within and between production lines. This causes a delay in the movement of materials. Therefore, considering production layout improvement could increase the performance of the system.



Figure 4-2: Congestion at the floor (Source: Own, taken on Sept. 10, 2020)

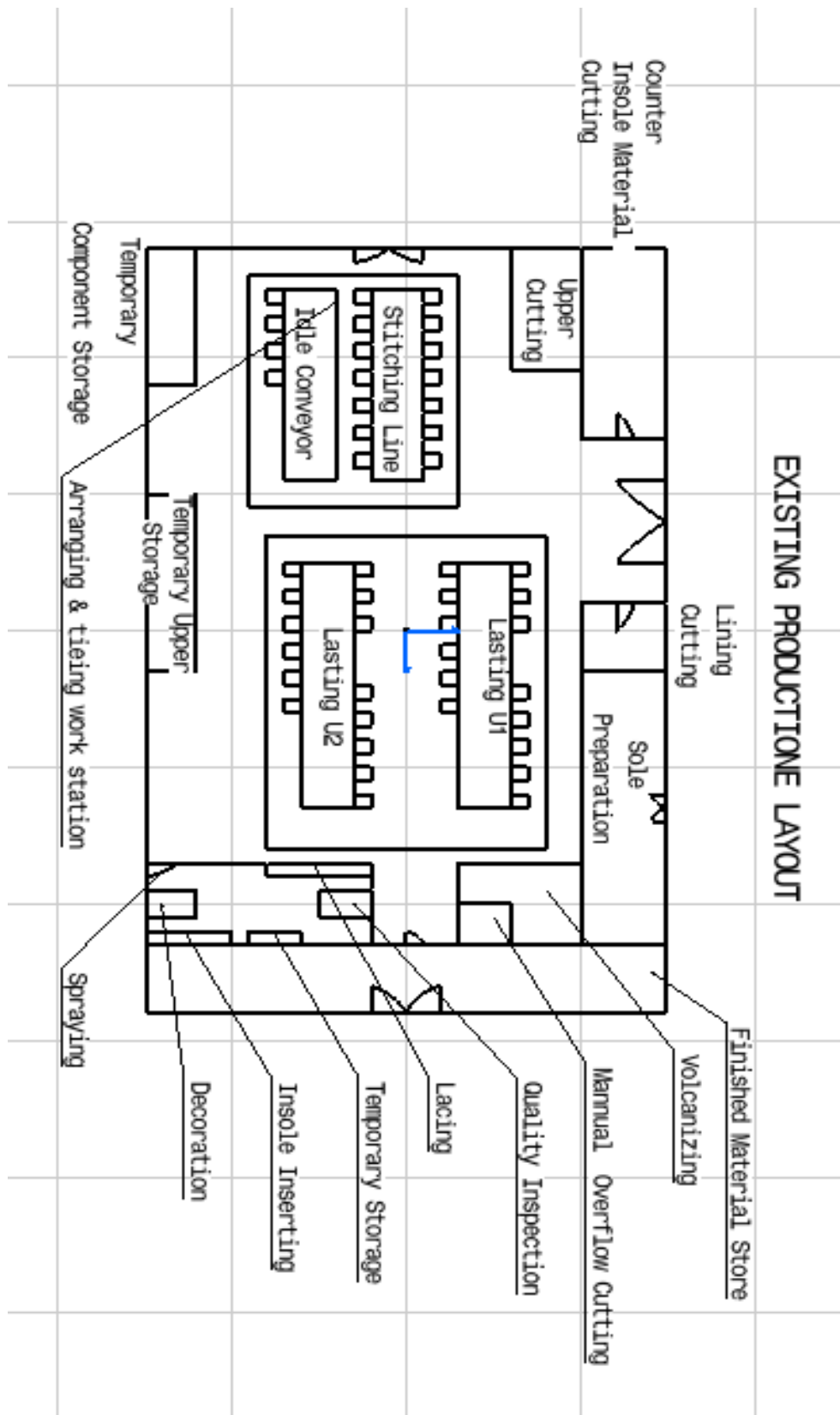


Figure 4-3: Existing production layout (Source: Own)

4.4.3. Data for validation

A simulation model provides a detailed and realistic representation of a complex system. Its claim for the realistic representation of a system must be validated subjectively. The data on the existing performance of the production lines were to be used for validation purposes. The only data available and suitable for this purpose were the sectional monthly and daily production output reports. These figures have been recorded in gross terms from which the tracing of the individual operations was not possible. So, the case company's average daily production of December 2019 was used for comparison with the output obtained from the simulation. The observations in the factory to obtain the statistics on jobs throughput times, waiting times, and operations queue sizes were not possible due to the complexity and impracticality of these tasks. Tables 4-6 and 4-7 were used for validation of the models.

Table 4-6: Monthly productions of shoes (2019/2020)

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
67,150	50,498	60,577	72,371	69,709	71,552	66,597	63,599	55,329	61,773	59,718	55,514	754,387

Table 4-7: Daily productions per sections (December 2019)

Date	Unit 1 Production				Total Units Production			
	Cutting	Stitching	Lasting	Finishing	Cutting	Stitching	Lasting	Finishing
1-Dec-19	Sunday							
2-Dec-19	1940	2455	2860	2207	2480	3069	3451	2603
3-Dec-19	2120	2535	2817	2700	2560	2953	3288	3016
4-Dec-19	2240	2206	2855	2701	2670	2690	3314	2943
5-Dec-19	1060	2436	858	1360	1175	2606	1100	1601
6-Dec-19	1530	2548	429	680	1587	2633	650	1000
7-Dec-19	2590	2365	1120	732	3206	2925	1644	1105
8-Dec-19	Sunday							
9-Dec-19	2670	2535	2759	2540	3224	3099	3457	3057
10-Dec-19	2590	2410	2549	2504	3026	2970	3124	2835
11-Dec-19	3010	2500	1874	2607	3730	3231	2334	2969

12-Dec-19	1390	2200	1209	1206	1656	2531	1389	1425
13-Dec-19	2200	2534	4216	4132	4175	3952	5538	4756
14-Dec-19	2700	2382	2642	2597	3312	3086	3443	3345
15-Dec-19	Sunday							
16-Dec-19	2940	2285	2600	2198	3567	3109	3301	2738
17-Dec-19	2785	1750	1438	1625	3641	2542	2124	2077
18-Dec-19	2730	2100	2749	2327	3664	2953	3548	3115
19-Dec-19	1240	1962	1453	1106	1600	2376	1931	1363
20-Dec-19	2083	1950	2365	1548	2541	2300	2777	1548
21-Dec-19	2010	2230	1531	2034	2518	2409	1916	2331
22-Dec-19	Sunday							
23-Dec-19	2497	2215	1564	2648	2847	2472	1714	2721
24-Dec-19	1905	2500	2945	2650	2295	2948	3394	2983
25-Dec-19	2030	2045	2994	2605	2726	2830	3709	2935
26-Dec-19	2292	1182	1556	1120	2522	1525	1945	1437
27-Dec-19	1800	1880	1915	1500	2390	2220	2275	1840
28-Dec-19	2120	1885	2645	325	2900	2299	3272	437
29-Dec-19	Sunday							
30-Dec-19	2600	2240	2410	2513	3220	2813	2582	2796
31-Dec-19	2440	2015	1843	2431	3295	2893	2424	2725
Total	57512	57345	56196	60486	72931	80222	67991	71552
Average	2212	2206	2161	2023	2789	2747	2679	2373

4.4.4. Cutting Production Model

The main operations performed in the cutting section are cutting of upper, lining, toe puff reinforcement, counter reinforcement, insole, and sock lining. Finished leather and reinforcement materials from the raw material store are the inputs for the section. Cutting is done using hydraulic cutting machines and different cutting dies. The type of cutting dies differ based on the type of model to be cut. For the construction of the simulation model different arena flow modules have been used. The create module creates an entry into a simulation model. Upper leather, lining leather, toe puff, counter reinforcement, insole, and

sock lining entities are created based on arrival times. The route model moves the created entities to the stations. The station module defines a station corresponding to a physical or logical location where processing occurs. The assign module is used for assigning new values of process time, arrival time, entity sequence, and entity types. The process module is the main processing method in the simulation and the processing time of each activity included in this module. The decision to reject the upper and lining is made by the decide module. The record module is used to collect statistics related to the number of shoes produced. The dispose module is used as the ending point for entities in a simulation model.

Data modules are used to the set of objects in the spreadsheet view of the model that defines the characteristics of various process elements.

- The entity module defines the various entity types.
- The queue module may be utilized to change the ranking rule for a specified queue. The default ranking rule for all queues is First In, First Out.
- The resource module defines the resources in the simulation system, resource availability, capacity, failures, and states specified in this module.
- The set module defines various types of resource sets assigned at each process.
- Failure module is used to define breakdown information of a machine.

4.4.5. Stitching Production Line Model

Upper components and lining components are assembled to produce the final upper. The components are considered as a single entity. In the construction of the assembly simulation model for the stitching section, the following modules have been used in addition to those used for cutting model development.

- The sequence module is used to define a sequence for entity flow through the model. A sequence consists of an ordered list of stations that an entity will visit.
- The segment module defines the beginning and the next station of entities. It also determines the distance between two stations in a conveyor.
- The conveyor module allows the definition of accumulating conveyor for entity movement between stations. The velocity of the conveyor is expressed in terms of cells. The average velocity for the stitching section is adjusted to 1 cm per second.

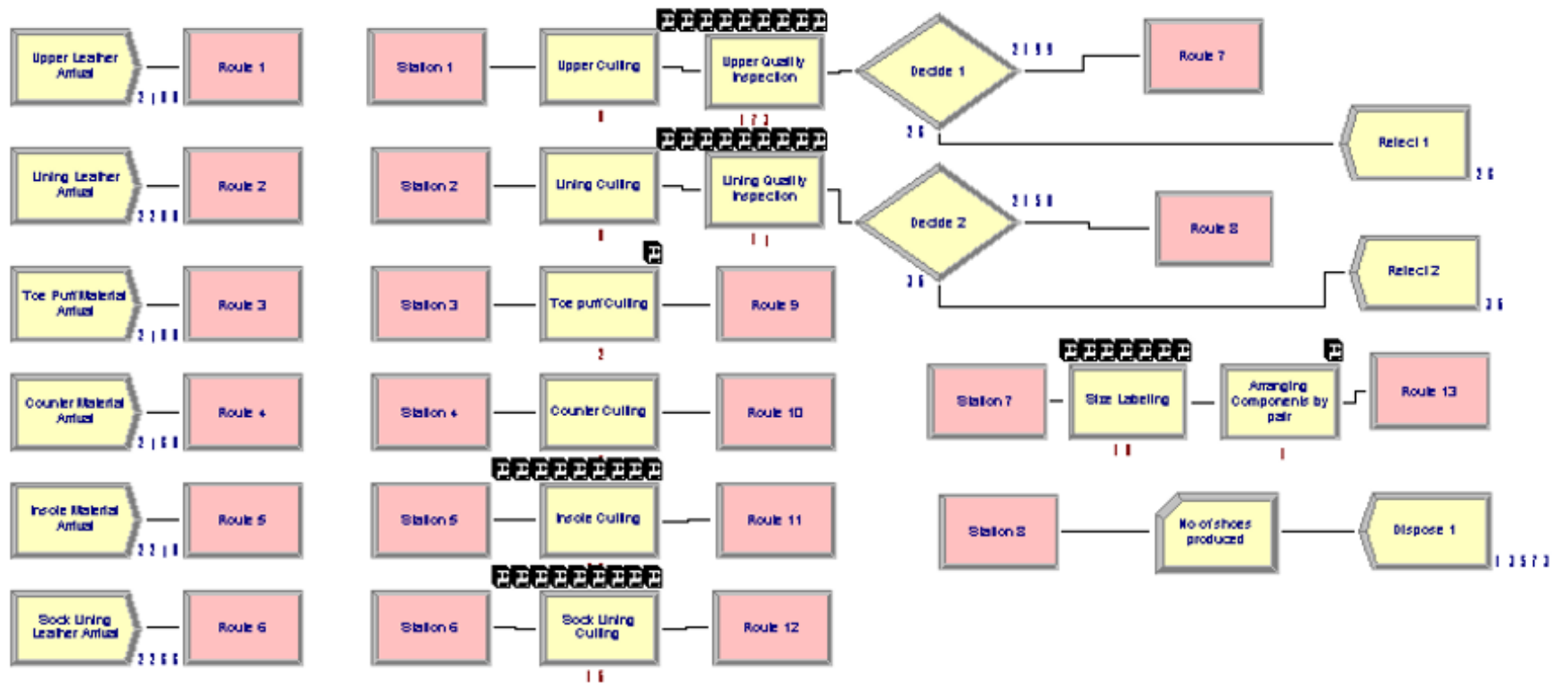


Figure 4-4: Cutting section model (Source: Own)

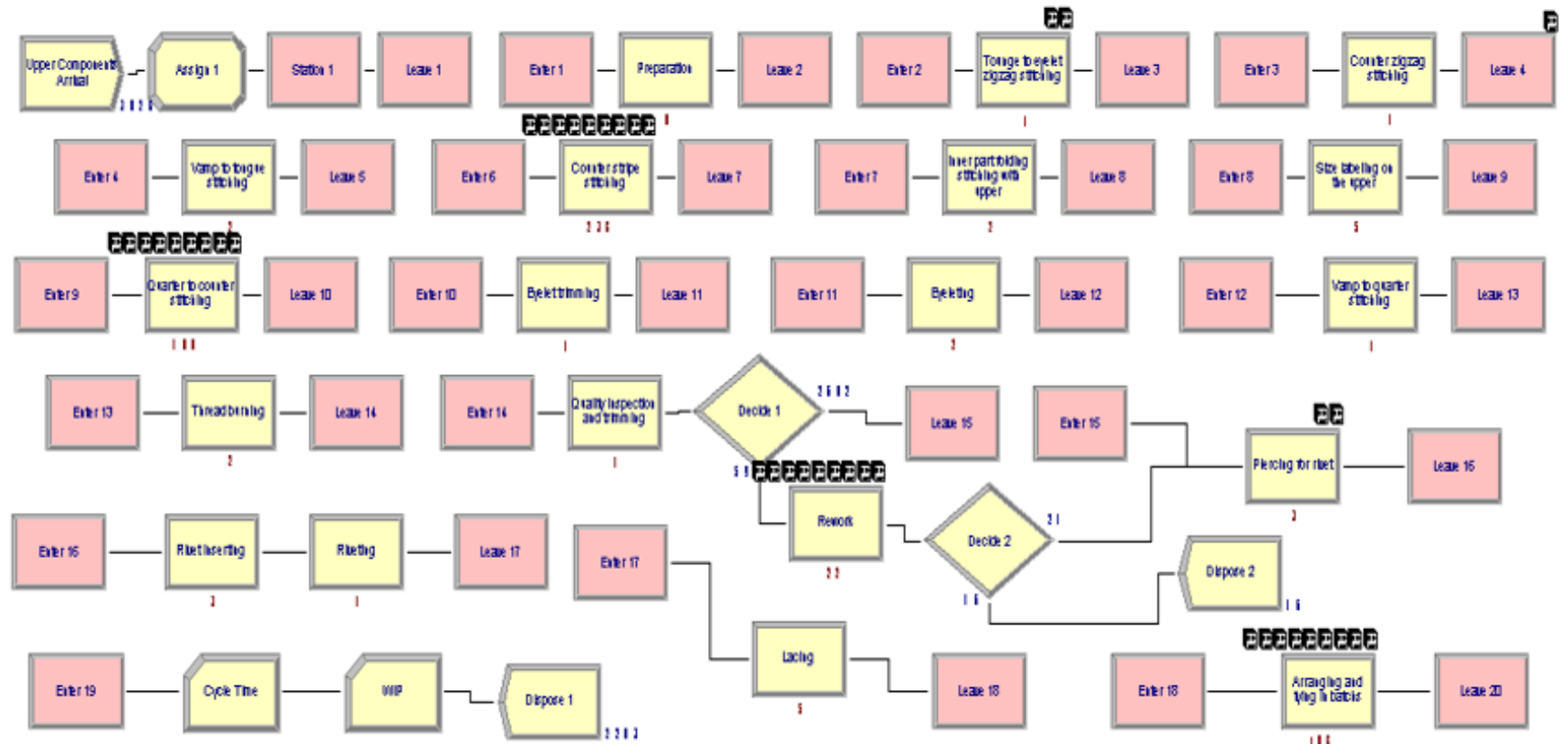


Figure 4-5: Stitching section model (Source: Own)

4.4.6. Lasting Production Line Model

In the lasting assembly line, upper, toe puff reinforcement, and counter reinforcement are assembled. For ease of modeling, these elements are considered as one entity. There are two lasting production units, unit one and unit two, both units are engaged in producing the same product style. The main difference between unit 1 and unit 2 is their material handling system. Unit one uses conveyors while unit two uses manual handling for transporting from one workstation to the subsequent workstation. Conveyor speed is adjusted on average at 1 cm per second; however, it can be adjusted according to the type of model to be produced. The lasting production line model is shown in figure 4-6.

4.4.7. Finishing and Packing Production Model

Sole vulcanizing, overflow cutting, trimming, insole inserting, decoration, spraying, and packing are the main operations in the finishing and packing production section. The lasted uppers are the main input for this section. Before the finished shoes are packed there is always a quality inspection. Shoes that do not fulfill the requirements will go through the rework process for correction. Record modules are used to gather statistics on WIP and cycle time. The finishing and packing production model is shown in figure 4-7.

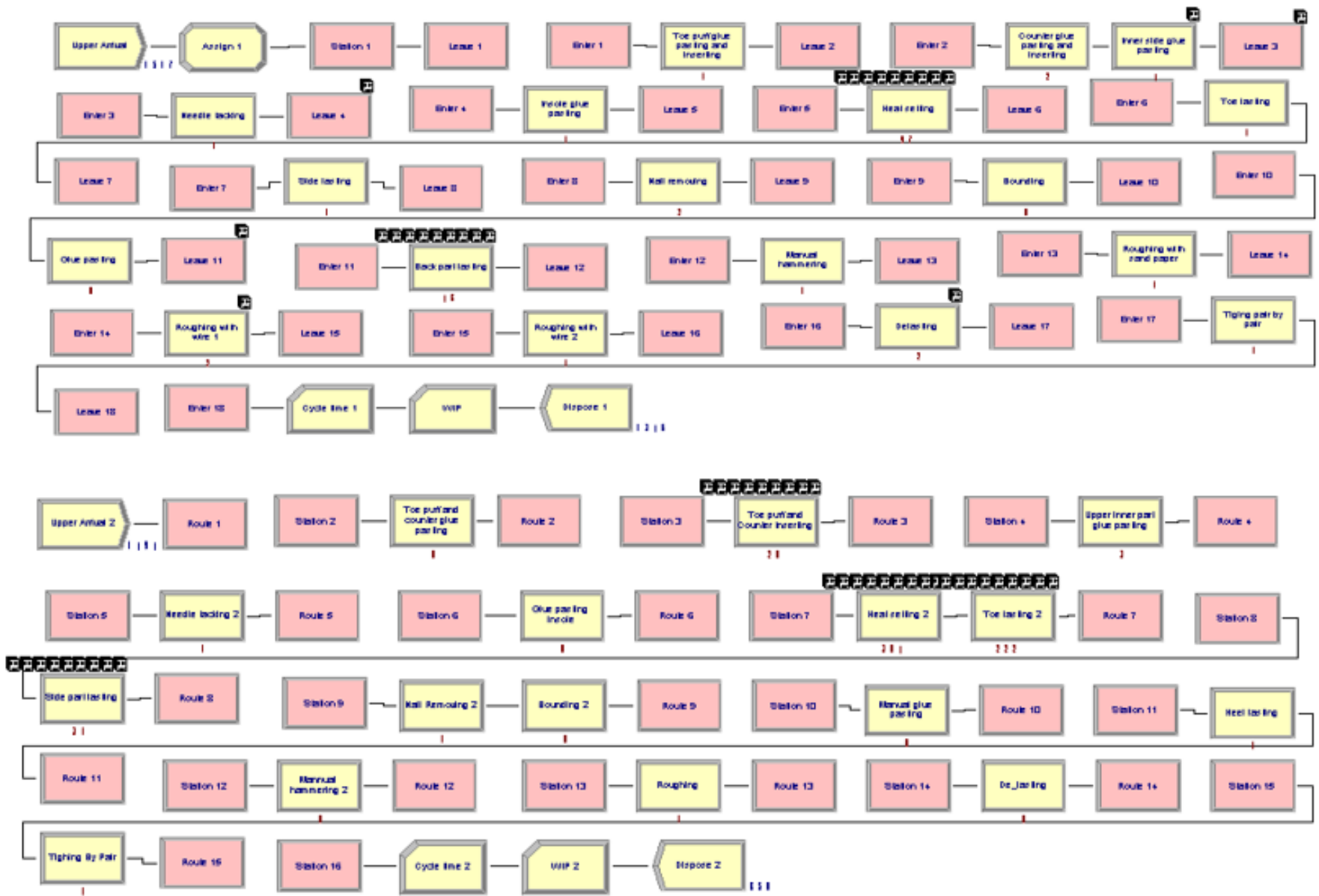


Figure 4-6: Lasting section model (Source: Own)

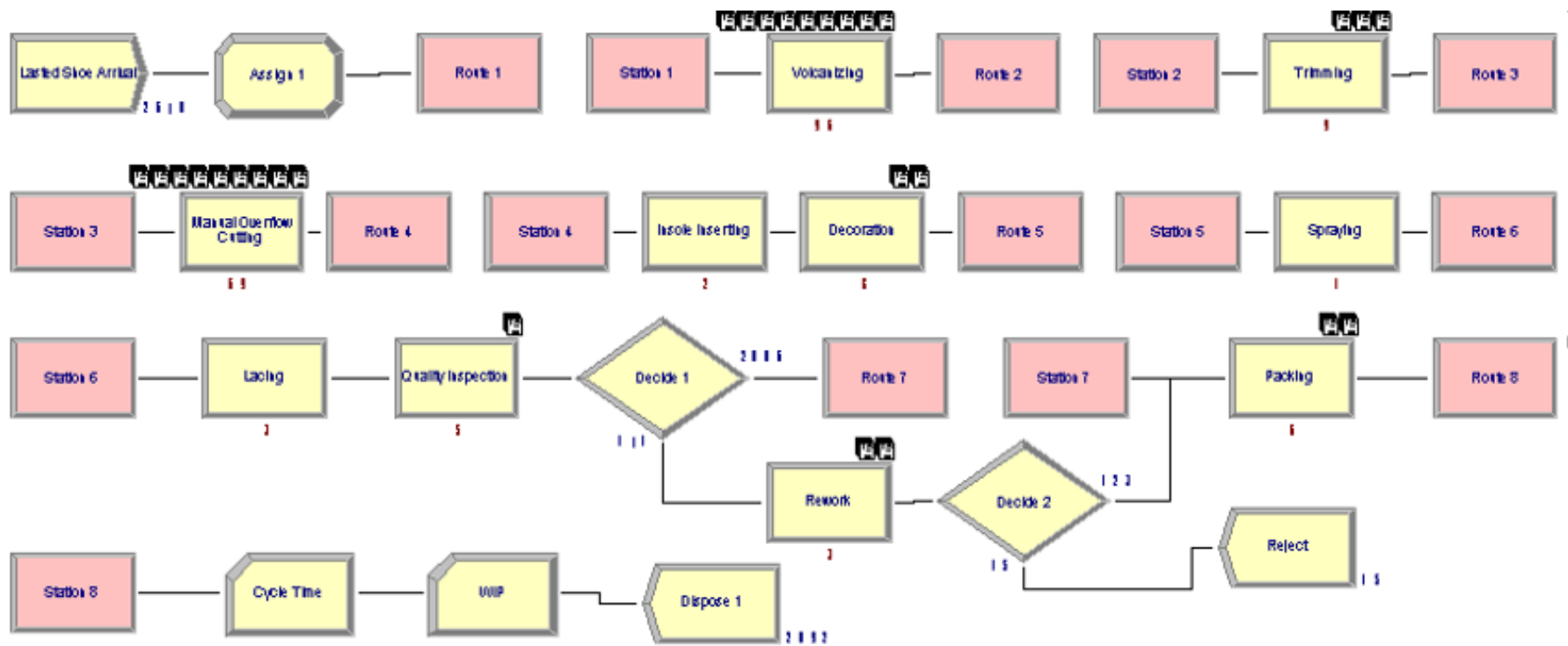


Figure 4-7: Finishing and packing section (Source: Own)

Run Length

A good design of simulation replications allows the analyst to obtain the most statistical information from simulation runs. Particularly, minimizing the number of replications and their length is necessary to obtain reliable statistics. To decide the number of replication the model must run some initial set of replication so that sample average, standard deviation, and confidence interval are computed.

The input distributions of simulation models are usually probabilistic. 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 several simulation replications and then make the recommendations based on all of the available data (Nahom, 2014).

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.

Table 4-8 shows the average output and standard deviation for ten replications in the cutting, stitching, lasting, finishing, and packing sections.

The standard error of the data can be calculated by:

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

Where t: probability distribution value for $1 - \alpha/2$ from table

n-1: degrees of freedom

s: standard deviation of the replication (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 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:

$$S = \sqrt{\frac{\sum_1^n xi - x}{n - 1}}$$

Where

s: standard deviation of the sample

xi: the replication average

x: an average of the replication

n: number of replications

Table 4-8 summarizes simulation results after the first 10 replications

Table 4-8: Number of replication of production sections

No Replications	Cutting	Stitching	Lasting	Finishing & Packing
1	2220	2219	2223	2306
2	2206	2192	2189	1980
3	2218	2201	2211	1709
4	2212	1772	2153	2341
5	2228	2207	2208	2388
6	2226	2208	2238	1768
7	2228	2194	2182	2369
8	2222	2185	2118	1671
9	2236	2194	1489	2257
10	2205	1948	2229	2410

Mean	2220	2132	2124	2120
Std deviation (s)	10.07	155.27	226.11	304
Half-width (h_o)	7.20	106.97	161.74	217.77
$n \cong z_{1-\alpha/2}^2 \frac{s^2}{h^2}$	121	121	121	121
$n \cong n_o \frac{h_o^2}{h^2}$	160	160	160	160

The initial replication (n_o) is 10 for all production lines and the initial half-width (h_o) is 7.20, 32.68, 161.74, and 111.81 for cutting, stitching, lasting, and finishing sections respectively. Assuming that $h = 1.8$ for cutting 16.34 for stitching, 40.44 for lasting, and 27.95 for finishing sections by taking 95% confidence level which is 1.96 from z table the final half-width can be calculated as follows:

$$n \cong z_{1-\alpha/2}^2 \frac{s^2}{h^2}$$

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

$$n \cong n_o \frac{h_o^2}{h^2}$$

Where, n_o is the number of initial replications we had and h_o is the half-width.

$$n \cong 1.96^2 \frac{10.07^2}{1.8^2} = 120.23 = 121 \text{ replications}$$

$$n \cong 10 \frac{7.20^2}{1.8^2} = 160 \text{ replications}$$

Thus, 160 replications are taken to get a low acceptable error for the cutting section. The number of replications is done similarly for the stitching, the lasting, and the finishing sections.

4.4.8. Model Verification

Verification ensures that the conceptual model is reflected accurately in the computerized representation.

- One easy verification method is to allow an entity to enter the system to check the function of the model under extreme conditions. For this simulation, the verification was done by comparing the model logic with the product routings. One entity was entered into each stitching, lasting, and finishing production systems. The entities behave similarly to the operation sequences as intended. Therefore, it indicates that this simulation modeling is worked and verified.
- Code verification: when arena simulation runs checking SIMAN code for all models can be viewed using the Run/SIMAN/View menu option and there are no dead ends that trap entity flow through the model.

4.4.9. Model Validation

The overall process of comparing the model and its behavior to the real system is critical to the construction of credible models. The standard approach to validate a model is to collect relevant data (parameter values, performance metrics, etc.) from the existing system under study, and compare them to their model counterparts. These parameters will ascertain the validity of the data and the model.

If there is no statistically significant difference between the existing system output and the simulation results, then the model is considered valid. On the contrary, if there is a significant difference, then the model is not valid and needs additional effort to validate it. Therefore, a hypothesis test was conducted to check the validity of the model. The first step of hypothesis testing is the conversion of the research question into null and alternative hypotheses.

Null hypothesis $H_0 = x$ the simulation result and actual production output is equivalent so the hypothesis is true and accepted.

Or alternative hypothesis $H_a \neq x$ the simulation result and actual production output are not equivalent so the hypothesis is false and rejected.

The z score value can be calculated using the following formula

$$z = \frac{x - \mu}{\sigma/\sqrt{n}}$$

Where

μ - the actual amount of shoes produced per day

δ -population standard deviation

n- number of observation

x-the average amount of shoes produced using simulation models per day. It is assumed that two tail sample 2. 5% significance level and 95% confidence level. December 2019 monthly production report was used to compare the simulation results with the actual output. 26 replications were used by considering the working days of the month.

Table 4-9: Model validation analysis

Production section	Actual production data (26 days)			Simulation result (26 replications)		
	μ	δ	Z value	Production	calculated z value	Different (%)
Cutting	2212	505.6	± 1.96	2223	0.11	0.49
Stitching	2205	310	± 1.96	2216	0.18	0.5
Lasting	2161	823.3	± 1.96	2129	-0.198	- 1.48
Fin & Packing	2023	832	± 1.96	2086	0.386	3.11

Z-score value is calculated for cutting as $Z = (2223 - 2212) / (505.6 / 5.1)$, $z = 0.11$. The z score is therefore in between +1.96 and -1.96. The p-value will be larger than 0.05. Thus, we cannot reject our null hypothesis. The z value for other models is calculated similarly and shown in table 4-9.

Model validation can also be done by calculating the difference between the simulation output and the actual data. It is computed using the formula stated below:

$$Different(\%) = \frac{Simulation\ output - Actual\ data}{Actual\ data} * 100\%$$

According to (Othman, 2017), the value of the difference between simulation output and actual data must be around $\pm 10\%$ or less, to satisfy the validity level of the built model to the actual system. The different (%) can be calculated as follows

$$Different(\%) = \frac{2223-2212}{2212} * 100\% = 0.49\%$$

Hence, the cutting model used and the replication made by the model can be used and acceptable (value = $0.49\% < 10\%$). The same calculation is done for the other sections and the results are shown in Table 4-9.

4.5. Model Results and Analysis

Replication length is the duration the modeler wants to simulate for. Seconds were set for the time units and the model was run for 160 replications to eliminate variations that could be brought by the software during the simulation. From the total of eight working hours, 30 minutes has been left for employees' tea break. Thus, the replication length was set to 7.5 hours to imitate the real production system.

Based on the output of the simulation model the performance measures were analyzed for the existing manufacturing system and for different proposed scenarios to increase output, minimize production time, minimize work in process, increase line balance efficiency, minimize waiting times, and improve capacity utilization. The design capacity of each production line is set to 4,000 pairs of shoes per day at normal working hours.

4.5.1. Cutting Section Simulation Result

The company policy limits the maximum number of upper and lining that could be cut by the operators to 320 pairs. The existence of bottlenecks in the cutting section is due to differences in the arrival rate and processing times of each entity. From the simulation results, the overall performance of the cutting production section the minimum average number produced is upper leather. Therefore, the performance of the production section is determined by the output of the upper leather. Figure 4-8 shows the average output of the cutting section in terms of incoming entities.

Number Out	Average	Half Width	Minimum Average	Maximum Average
Counter	2477.47	7.25	2050.00	2542.00
Insole	2474.37	5.24	2154.00	2519.00
Lining	2300.00	0.20	2291.00	2307.00
Sock Lining	2584.24	7.83	1980.00	2640.00
Toe Puff	2517.61	11.68	1660.00	2550.00
Upper	2227.79	1.55	2202.00	2252.00

Figure 4-8: Cutting production line output analysis

The existing cutting section simulation result shows that 22 operators are assigned to 10 workstations. The production section has an average daily production output of 2227.79 shoe component sets with 55.69% capacity utilization, WIP 170 pairs, cycle time 12.12 seconds. The maximum average waiting time is 5000 seconds in the upper-quality inspection workstation and the maximum number waiting for average in the same station is 97.25 pairs. The capacity utilization ranges from 19.01 % for counter cutting (Resource 2) to 99.59% for upper-quality inspection (Resource 5). The capacity utilization of resources in the cutting production section is shown in appendix 4. Figure 4-9 shows graphically cutting production capacity utilization.

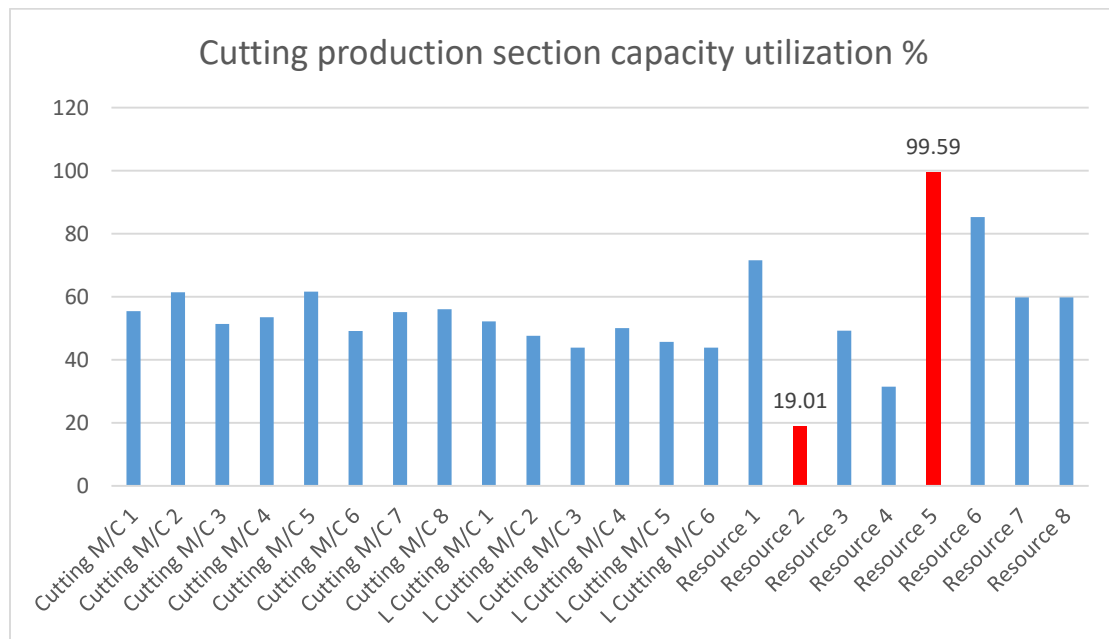


Figure 4-9: Cutting production line capacity utilization

4.5.2. Stitching Section Simulation Result

The existing stitching production line simulation result shows that 73 operators are assigned at 19 workstations, the production section has 2219 uppers average daily output, 55.47 % production line capacity utilization, 428 pairs of work in process per day, cycle time 12.17 seconds at the end of replication day. The capacity utilization of individual resources ranges from 27.44 % for marking operator 2 to 99.13 % for counter stripe stitching machine 5. The highest average utilization of workstations in this section is 90.98 % at tying workstation. Capacity utilization of each resource in the stitching section is shown in Appendix 5. Table 4-10 shows the maximum values of the average waiting time and average waiting number in the stitching production line.

Table 4-10: Highest average waiting time and average waiting number

Workstation	Average waiting time	Average waiting number
Arranging and tying in batches. Queue	2014.97	195.62
Rework.Queue	4117	8.56
Counter stripe stitching.Queue	1049.37	117.26

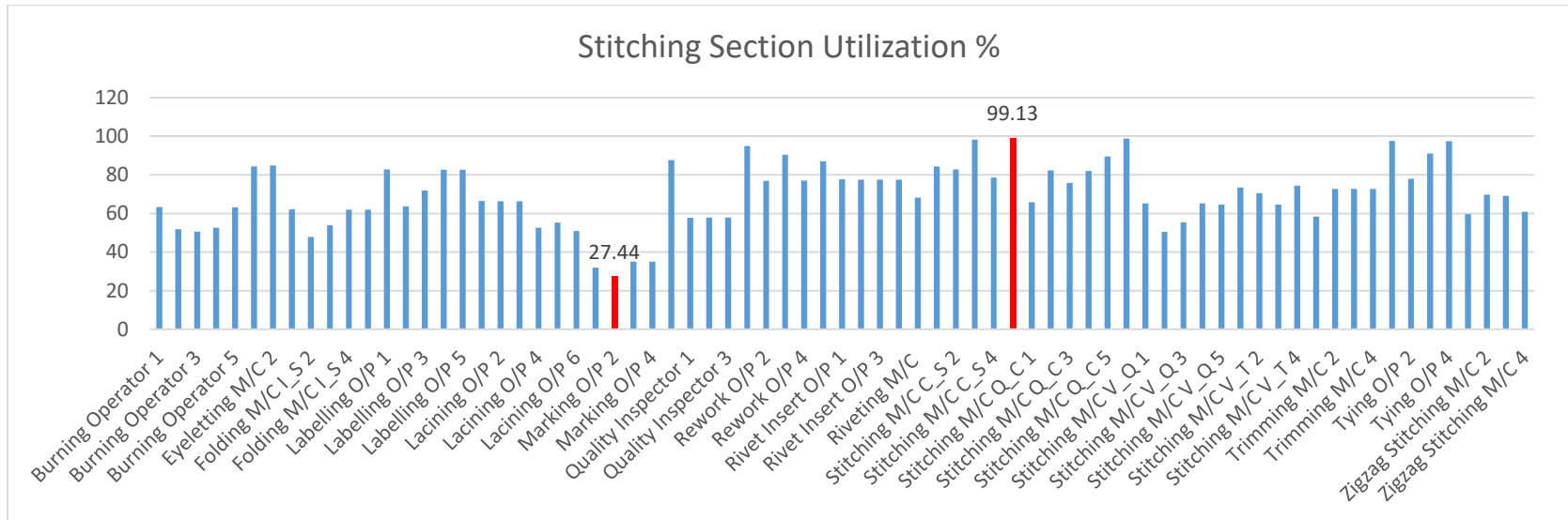


Figure 4-10: Stitching Production Section Capacity Utilization

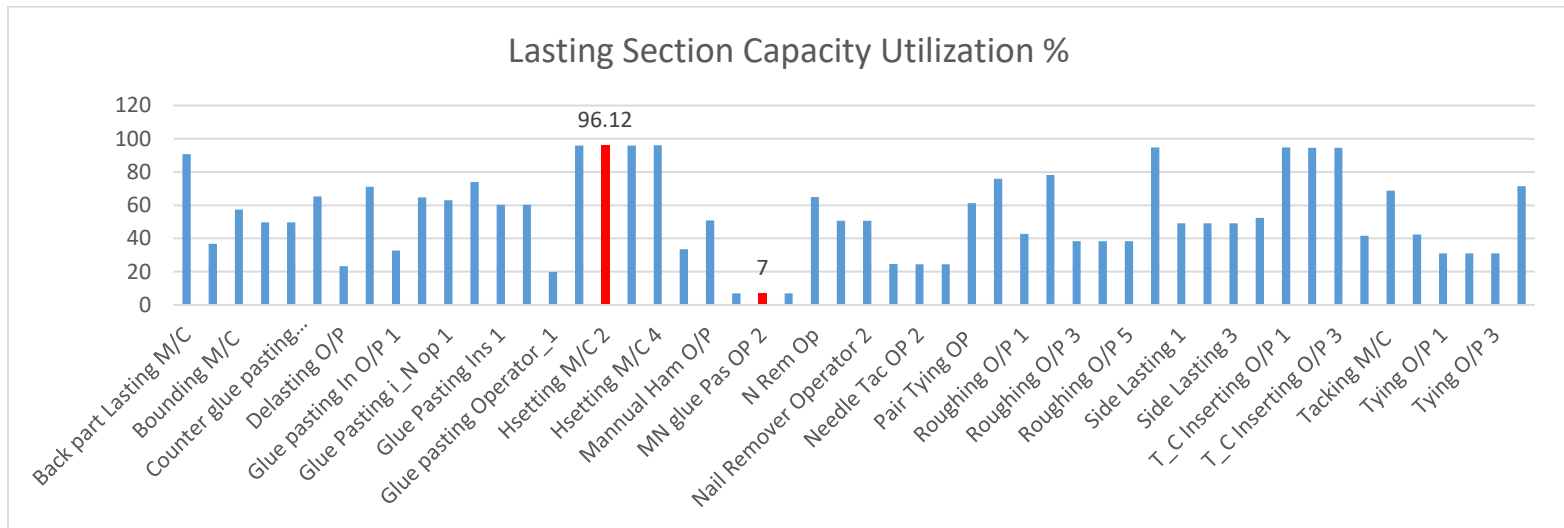


Figure 4-11: Lasting Production Section Capacity Utilization

4.5.3. Lasting Section Simulation Result

The existing lasting production line simulation result shows that 52 operators are assigned to 34 workstations. The production section has 52.92 % line capacity utilization, 420 work in process pairs per day, 12.75 seconds cycle, 2117 lasted shoe output at the end of replication day. The highest average waiting time is 2919 seconds inside the part lasting queue and the highest average waiting number is 119 pairs of shoes. The resource utilization ranges from 7% to 96.2% for the heat setting machine and manual glue pasting operators respectively. The utilization of each resource in the lasting section is shown in Appendix 6.

4.5.4. Finishing and Packing Section Simulation Result

The existing finishing and packing production line simulation result show that 37 operators are assigned to 10 workstations. The production section has 54.22 % utilization, 476 work in process pairs per day, 12.44 seconds cycle time, 2169 pairs of shoe output at the end of replication day. The maximum average waiting time is 1475.28 seconds and the maximum average waiting number is 160 pairs at the manual overflow cutting station. The capacity utilization of resources in the production section ranges from 19.23 % to 57.78 %. Capacity utilization of each resource in the finishing and packing section is shown in Appendix 7. Figure 4-12 shows the capacity utilization of the finishing and packing section graphically.

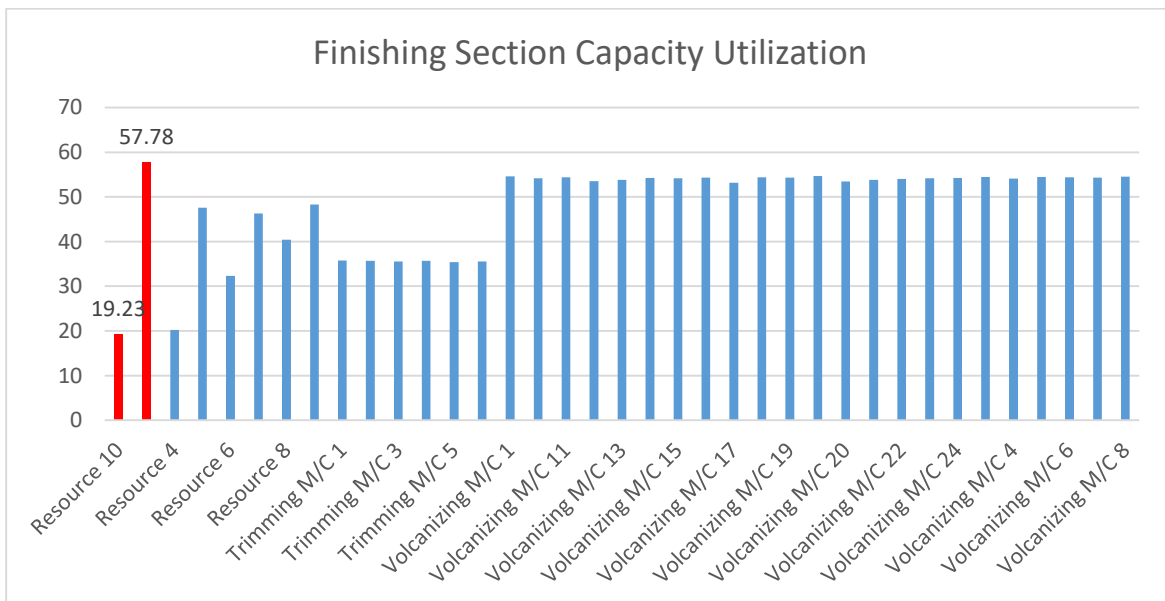


Figure 4-12: Finishing and packing production line capacity utilization

Generally, underutilization of the resources in all sections and uneven distribution of work explains that resources are not consumed efficiently. Some of the workers are busy with value-adding activities while others are not. In other words, operators are spending most of their time on non-value adding activities like unnecessary movements on the production floor or waiting for work. The most basic cause of waiting time is a bottleneck operation. When one part of a process runs faster than other parts, there will be waiting in the process; the processes immediately after a slower process have to wait for work from the slower process. It can be seen from the capacity utilization report that there is an imbalance of resource usage in all production sections. For instance, figure 4-9 shows resource 5 works at 99.59 % capacity that indicates the bottleneck.

4.5.5. Line Balancing Efficiency

Assembly line balancing technique is generally used to identify the bottleneck process and to determine the number of workstations, the objective of line balancing is to distribute the total workload on the assembly line as evenly as possible among the workers and to reduce resource idleness, nearly impossible to reach a perfect balance. Table 4-11 shows the cutting production line balancing efficiency from PoM QMv5 software.

Table 4-11: Cutting production line balancing efficiency

Cutting Production Line Solution					
Station	Task	Time (Seconds)	Time left (Seconds)	Ready tasks	
				1, 2, 3, 4, 5, 6	
1	6	9		1, 2, 3, 4, 5	
	4	2		1, 2, 3, 5	
2	3	8		1, 2, 5	
3	1	6.75		2, 5, 7	
	5	5		2, 7	
4	7	12		2	
5	2	6.17		8	
6	8	10		9	
7	9	3		10	
	10	3			

Summary Statistics					
Cycle time	12.12	Seconds	6.12		
Min (theoretical) # of stations	6				
Actual # of stations	7				
Time allocated (cycle time * # stations)	84.87	Seconds/cycle			
Time needed (sum of task times)	64.92	Seconds/unit			
Idle time (allocated-needed)	19.95	Seconds/cycle			
Efficiency (needed/allocated)	76.5%				
Balance Delay (1-efficiency)	23.5%				

From the table, it is seen that the Actual # of stations is 7 but the actual number of workstations for the existing system is 8. Therefore, the line balancing efficiency of the production section is recalculated by the following formula (Batool, 2015):

$$\text{Line Efficiency} = \frac{\Sigma \text{Task times}}{\text{No of work stations} * \text{Largest Cycle time}} * 100\% = \frac{64.92}{(12.12 * 8)} * 100\% = 66.9 \%$$

The line balance efficiency for stitching, lasting, finishing, and packing production lines was calculated in the same way as cutting production line using POM QMv5 software.

Table 4-12: Existing system performance

Production Sections	No in	No out	WIP (Pairs)	Max waiting time (Sec)	Max No waiting (Pairs)	Capacity utilization	Cycle time (%)	Line balance efficiency (%)
Cutting	2417	2227	170	5000	97.25	55.67	12.12	66.9
Stitching	3028	2219	428	2014	195	55.47	12.17	65.3
Lasting	2888	2117	420	2919	119	52.92	12.75	50.8
Fin & Packing	2786	2169	476	1475	160	54.22	12.44	56.5

Chapter Five

Experimentation and Cost-Benefit Analysis

5.1. Experimentation

Capacity underutilization has been a common problem for all production sections. The number of unit waiting and high work in process was also a problem in specific workstations. There were also congestions between production lines. The more the number of waiting unit, the flow of a production line will be slower.

Table 5-1 summarizes the identified problems from the output, WIP, capacity utilization, the number waiting, and the waiting time analysis of the simulation runs in each section.

Table 5-1: Causes of low capacity utilization

Causes of low capacity utilization	Cutting Section	Stitching Section	Lasting Section	Finishing & section
Uneven distribution of jobs	X	X	X	
High variations in entities output	X			
High average waiting time	X	X	X	
High average number waiting		X	X	X
High variations in waiting time	X	X	X	
High work in process		X	X	X
High cycle time	X	X	X	X
Congestion of working places	X	X	X	X
High processing time	X	X	X	X

Thus, to improve the performance of the existing production line, three possible solution alternatives have been identified and then one among them has been selected as the best alternative based on performance measurements and cost-benefit analysis.

Scenario 1:

Changing the work method by merging or splitting workstations to minimize the processing time of operations.

Cutting Section

Upper and lining cutting is performed by different operators at different workstations. But it is technically possible to cut the upper and lining part by the same operator at the same workstation. The possibility of this improvement was discussed and approved by cutting operators and cutting section supervisor. Therefore, arranging upper and lining cutting at the same station utilizes a total of 14 machines for cutting both upper and lining at 2 workstations. Quality inspection for both upper and lining components could be done at a single workstation. Consequently, the total number of workstations of the cutting section could be decreased from 10 to 9. Table 5-2 shows the performance statistics at the end of the simulation run from this scenario.

Table 5-2: Scenario 1 cutting section results

Number out average	Upper WIP average	Maximum average waiting time	Maximum average number waiting	Cycle time	Line balancing efficiency	Utilization
2430	138	820.6	78	11.11	91.35 %	60.75 %

Stitching Section

Subsequent workstations within the stitching section do not require preparation activities completion. Separating preparation activities from the stitching section and creating a new section for it could create a WIP that will be used as an input for the stitching section. This scenario provides an opportunity for the stitching section to better utilize idle resources because it minimizes input starvation. In the meantime, this scenario would give additional

place to the arranging and tying operation to be done within the stitching conveyor. The possibility of this improvement was discussed and approved by the stitching section supervisor. Table 5-3 shows the results after considering this improvement.

Table 5-3: Scenario 1 stitching section results

Number out average	Upper WIP average	Maximum average waiting time	Maximum average number waiting	Cycle time	Line balancing efficiency	Utilization
2301	391	1494	143	11.73	66.29 %	57.52 %

Lasting Section

The lasting section is divided into two subunits. Both unit 1 and unit 2 produces the same shoe type. Due to the availability of enough floor space, the two lasting units could be merged. The possibility of this improvement was also discussed and approved by the lasting section supervisor. Therefore, merging two different lasting sections will result

Table 5-4: Scenario 1 lasting section results

Number out average	WIP average	Maximum average waiting time	Maximum average number waiting	Cycle time	Line balancing efficiency	Utilization
2274	685	4103	514	11.87	73.26 %	56.85 %

Finishing and Packing Section

The utilization of an insole inserting operator (resource 4) and decoration operator (resource 5) is 20.25 % and 47.55 % respectively. Insole inserting operator is the second underutilized resource from the production line. Thus, it is technically possible and discussed with the

finishing section supervisor about the possibility of combining the two workstations. Thus, merging of these two resources would result as shown in table 5-5.

Table 5-5: Scenario 1 finishing and packing section results

Number out average	WIP average	Maximum average waiting time	Maximum average number waiting	Cycle time	Line balancing efficiency	Utilization
2270	525	1772	194	11.89	51.7 %	56.75 %

Scenario 2: Layout rearrangement

Due to the improper positioning of workstations, over traveling of materials and operators has been observed which in turn increased the time due to unnecessary movement. To rectify the problem as well as to improve the performance, layout rearrangement of production sections has been proposed.

Cutting Section

Counter cutting, insole cutting, sock lining cutting, and toe puff cutting machines are placed in the same room while uppercutting and lining cutting machines are placed in different rooms. Lining cutting machines are located near the sole preparation section while the upper cutting section is located in the same room as the stitching section. The pairwise arrangement of the components is done within the lining cutting area to make ready for preparation or temporary storage. Therefore, relocating the lining cutting section near to uppercutting section minimizes the traveling distance or waiting time of the upper components for the pairwise arrangement.

Table 5-6: Scenario 2 cutting section results

Number out average	WIP average	Maximum average waiting time	Maximum average number waiting	Cycle time	Line balancing efficiency	Utilization
2237	398	527	56	12.06	72.16 %	55.92 %

Stitching

Arranging and tying operation of uppers from the stitching section is done at the nearby idle conveyor. Placing the arrangement workstation near to the lacing workstation and extending the existing conveyor by 5 meters to accommodate arranging and tying operation together with other stitching operations could decrease the distance between the two workstations. The results of this approach are shown in table 5-7.

Table 5-7: Scenario 2 stitching section results

Number out average	WIP average	Maximum average waiting time	Maximum average number waiting	Cycle time	Line balancing efficiency	Utilization
2257	449	599	64	11.96	69.5 %	56.42 %

Lasting

To give a stronger bond between the upper and the outsole, a pasted adhesive on the upper part has to pass through the drying process by the atmospheric air. It requires an average of 3 to 4 minutes to achieve a good result. Incorporating one heat activator in each lasting unit reduces the distance between glue pasting workstation and heat setting workstation by 18 -

24 meters without affecting the quality of the bond. Table 5-8 shows the simulation results of this approach.

Table 5-8: Scenario 2 lasting section results

Number out average	WIP average	Maximum average waiting time	Maximum average number waiting	Cycle time	Line balancing efficiency	Utilization
2170	387	2974	125	12.44	51.38 %	54.25 %

Finishing and Packing

It is possible to reduce the ten minutes transfer time for a batch (110 pairs) to two minutes by making manual overflow cutting workstation and insole inserting workstation at the same place. The simulation results of this approach are shown in table 5-9.

Table 5-9: Scenario 2 finishing section results

Number out average	WIP average	Maximum average waiting time	Maximum average number waiting	Cycle time	Line balancing efficiency	Utilization
2232	423	1435	149	12.09	51.04 %	55.8 %

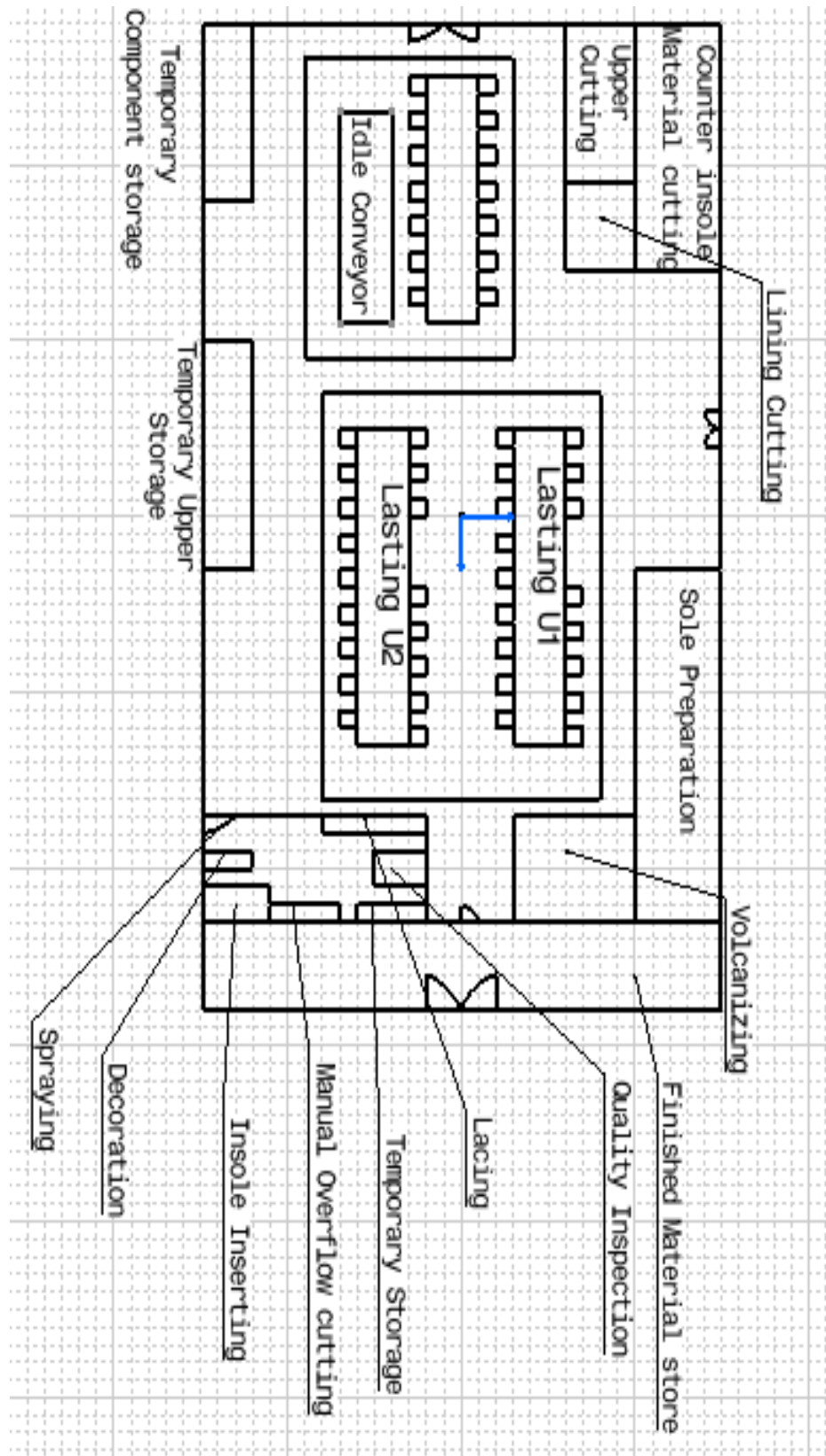


Figure 5-1: Proposed production layout

Scenario 3:

Addition of resources (machine and labor) on bottleneck operations. This scenario is concerned with increasing the level of resources at bottleneck workstations with a higher level of waiting time and utilization.

Cutting Section

Existing production system simulation result shows that the maximum average waiting time is found at the upper-quality inspection workstation with the utilization of 99.59% while resource 6 at lining quality inspection workstation is utilized for 85.29 %. These are the maximum seized resources in the cutting section. Therefore, adding three operators in the upper-quality inspection workstation and one hydraulic cutting machine with an operator improves the production performance as shown in table 5-10. Appendix 4 shows the capacity utilization of resources in the cutting section.

Table 5-10: Scenario 3 cutting section results

Number out average	WIP average	Maximum average waiting time	Maximum average number waiting	Number of newly added machines	Number of newly added operators	Cycle time	Line balancing efficiency	Utilization
2474	78	544	49.9	1	4	10.91	68.3 %	62.4 %

Stitching Section

Existing production system simulation result shows that arranging and tying queue is the second-highest average waiting time next to the rework queue and the maximum average waiting number (195.62 pairs) with maximum average capacity utilization of 90.98 %. Tying operator 1, tying operator 2, tying operator 3, and tying operator 4 are utilized for 97.51 %, 77.97 %, 91.06 %, and 97.38% respectively. This indicates arranging and tying workstation is a bottleneck. To overcome the bottleneck appearing in this workstation

adding two operators will improve the production performance as shown in table 5-11. Appendix 5 shows the capacity utilization of resources in the stitching section.

Table 5-11: Scenario 3 stitching section results

Number out average	WIP average	Maximum average waiting time	Maximum average number waiting	Number of newly added machines	Number of newly added operators	Cycle time	Line balancing efficiency	Utilization
2584	257	2816	120	0	2	10.45	74.3 %	64.6 %

Lasting Section

The existing lasting production simulation result shows that the highest average waiting time and waiting number is found in side part lasting queue of unit two and in the heat setting machine of unit one. Therefore, the addition of one side part-lasting machine with one operator to unit two and an addition of one heat setting machine with one operator to unit one increases the daily output to 2335 but it is not sufficient to balance with other production sections. Thus, the addition of 2 roughing machines with 2 operators to unit 2 will improve the production performance of the lasting section as shown in table 5-12.

Table 5-12: Scenario 3 lasting section results

Number out average	WIP average	Maximum average waiting time	Maximum average number waiting	Number of newly added machines	Number of newly added operators	Cycle time	Line balancing efficiency	Utilization
2531	235	1145	58	4	4	10.66	77.7 %	63.27 %

Finishing and Packing section

The existing lasting production simulation result shows that the highest average waiting time and waiting number are found in manual overflow cutting workstation. Therefore, the addition of 5 manual overflow cutting operators would improve the production performance of the section meaningfully as shown in table 5-13.

Table 5-13: Scenario 3 finishing section results

Number out average	WIP average	Maximum average waiting time	Maximum average number waiting	Number of newly added machines	Number of newly added operators	Cycle time	Line balancing efficiency	Utilization
2457	366	333.5	35.7	0	5	10.99	52.3 %	61.4 %

Table 5-14: Comparison of different scenarios with the existing system

Scenarios	No out per day	WIP	Max waiting time	Max No waiting	New MC added	New OP added	Cycle time	Line balance Efficiency	Capacity utilization
Existing system									
Cutting	2227	170	5000	97.25			12.12	66.9	55.67
Stitching	2219	428	2014	195			12.17	65.3	55.47
Lasting	2117	420	2919	119			12.75	50.8	52.92
Fin & Packing	2169	476	1475	160			12.44	56.5	54.22
Scenario 1									
Cutting	2430	138	820	78			11.11	91.35	60.75
Stitching	2301	391	1494	143			11.73	66.29	57.52
Lasting	2274	685	4103	514			11.87	73.26	56.85
Fin & Packing	2270	525	1772	194			11.89	51.7	56.75
Scenario 2									
Cutting	2237	398	527	56			12.06	72.16	55.92

Stitching	2257	449	599	64			11.96	69.5	56.42
Lasting	2170	387	2974	125	2		12.44	51.38	54.25
Fin & Packing	2232	423	1435	149			12.09	51.04	55.8
Scenario 3									
Cutting	2474	78	544	49.9	1	4	10.91	68.3	62.4
Stitching	2584	257	1072	120		2	10.45	74.3	64.6
Lasting	2531	235	1145	58.42	4	4	10.66	77.7	63.27
Fin & Packing	2457	366	333.5	35.7		5	10.99	52.3	61.4

Table 5-14 shows how the different production performance measurements of the existing manufacturing system are improved by the proposed scenarios. The first performance criteria were the analysis of the daily average production rate. Figure 5-2 showed that the highest average production output is obtained by the addition of resources on bottleneck workstations. The cutting production section increased the average daily output from 2227 to 2474. So, there is an increase of 11 % from the existing production system. Similarly stitching production section increased from 2219 to 2584. The lasting production section increased by 19.6 %. The finishing section average production output increased from 2169 to 2457 which is an increment of 13.27 % from the existing production system.

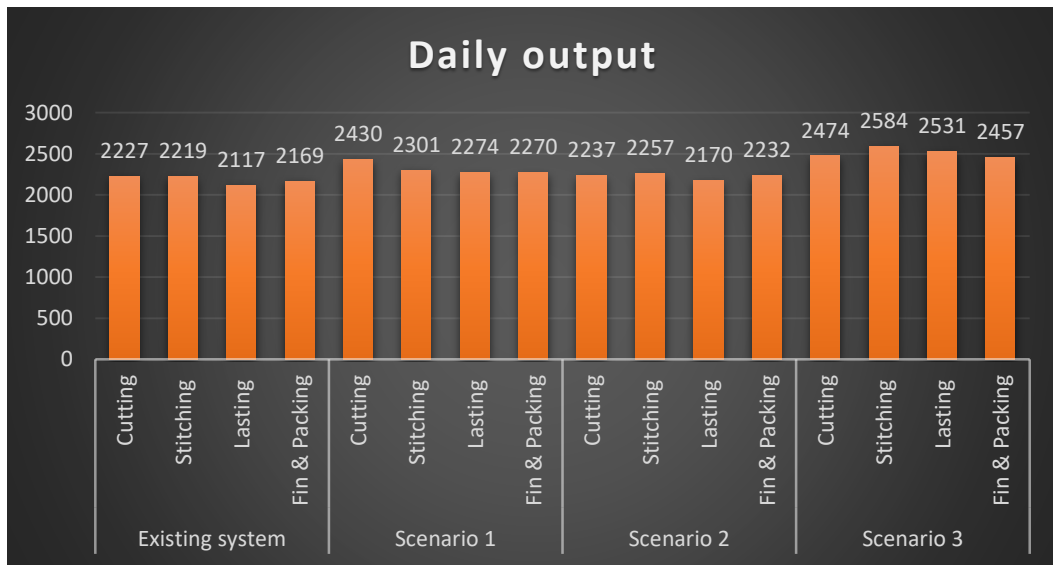


Figure 5-2: Production output comparison

The second performance criteria were the work in process within the production section s. It is seen in figure 5-3 the minimum work in process is obtained by applying scenario 3. The overall WIP in four section s decreased by 37.3 % from 1494 pairs of shoes to 936 pairs of shoes. The cutting production section decreased by 92 pairs, the stitching production section decreased by 171 pairs, the lasting production section decreased by 135 pairs, and the finishing section decreased by 110 pairs of shoes.

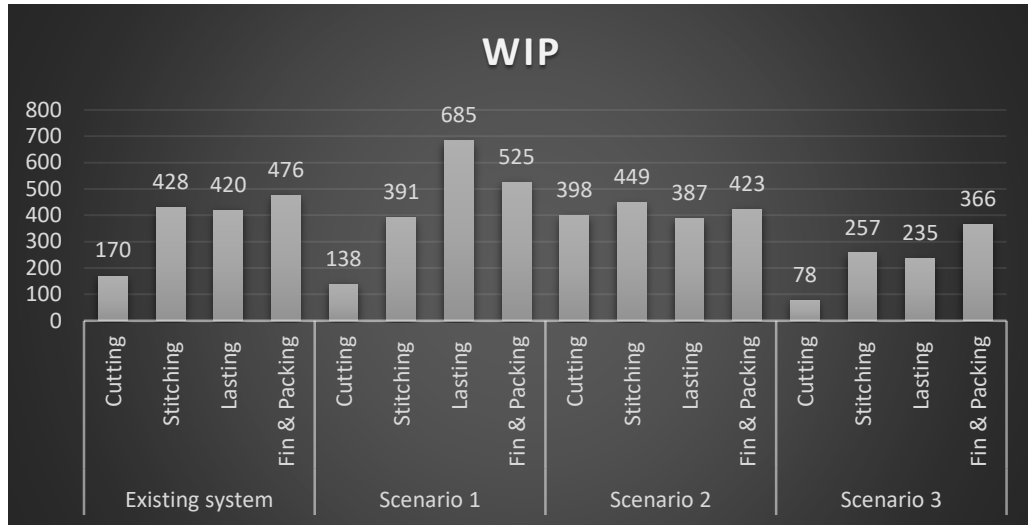


Figure 5-3: WIP comparison

Thirdly, the maximum waiting time was the analyzed production performance criteria. As figure 5-4 represents the maximum waiting time reduces as we add additional resources to the bottleneck workstation. Thus, the cutting production section has decreased from 5000 seconds to 527 seconds. The stitching production line has decreased from 2014 seconds to 1072 seconds, the lasting production line decreased to 1145 seconds and the finishing & packing section has decreased from 1475 seconds to 333.5 seconds.

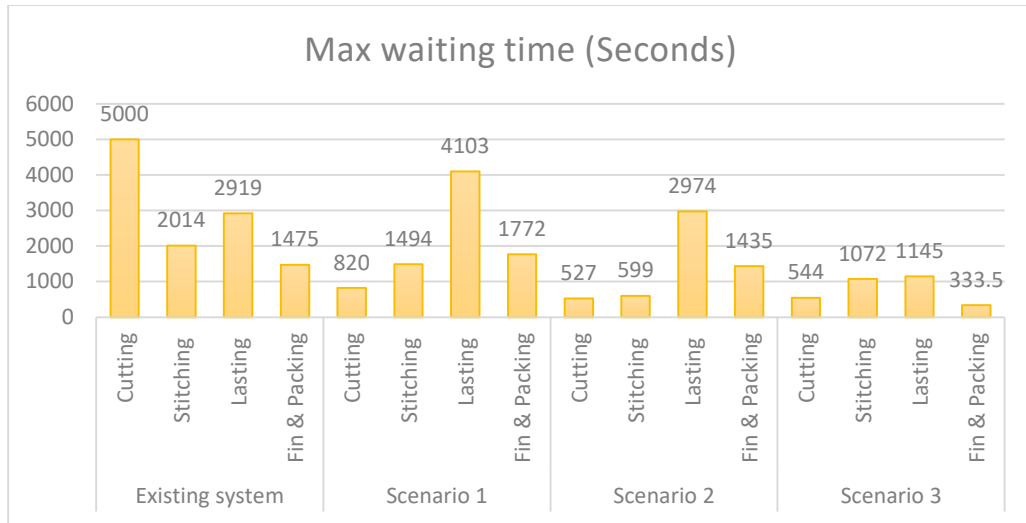


Figure 5-4: Maximum waiting time comparison

The fourth performance criteria were the maximum no of waiting shoes in the workstations. Figure 5-5 showed that additional resources have decreased the maximum no of waiting shoes. It has reduced from 97.25 pairs to 49.9 pairs, from 195 pairs to 120 pairs, from 119 pairs to 58.42 pairs, from 160 pairs to 35.7 pairs in cutting, stitching, lasting, and finishing production sections respectively.

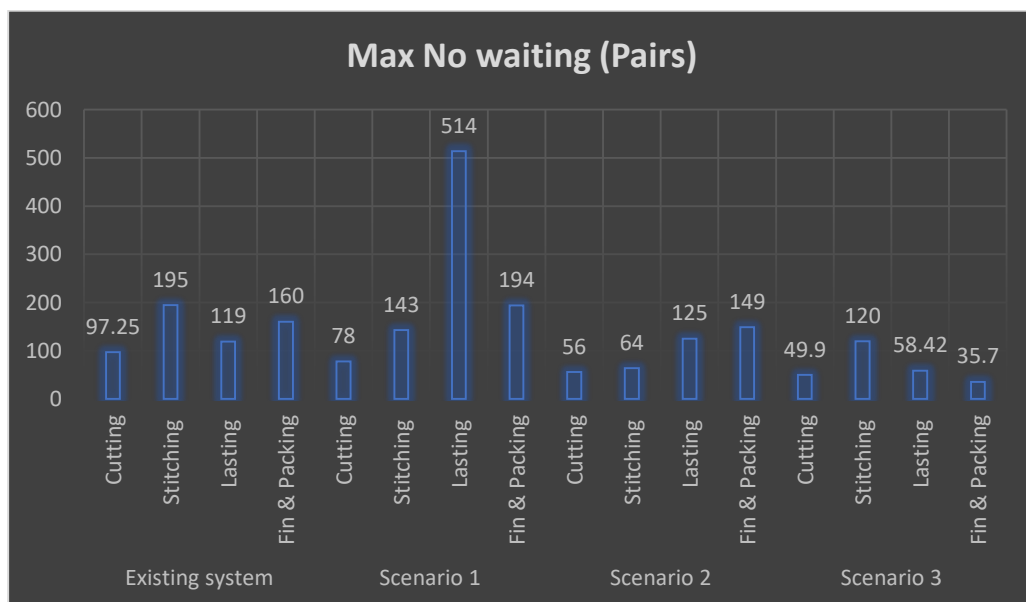


Figure 5-5: Maximum waiting number comparison

The last performance criteria were the analysis of sectional capacity utilization. Figure 5-6 showed the application of different scenarios to improve the capacity utilization of cutting, stitching, lasting, finishing, and packing production sections. Scenario 1 improves the production capacity utilization of the cutting section by 9.12 %, scenario 2 improves by 0.5%, and scenario 3 improves by 12.1 %. Similarly, scenario 1 improves the production capacity utilization of the stitching section from 55.47% to 57.52%, scenario 2 improves to 56.42% and scenario 3 improves to 64.6 %. Scenario 1 improves lasting production section capacity utilization by 7.4 %, scenario 2 improves by 2.5% and scenario 3 improves by 19.55%. Finishing and packing production section capacity utilization are improved by 4.7%, 2.9%, and 13.24 % by using scenario 1, scenario 2, and scenario 3 respectively.

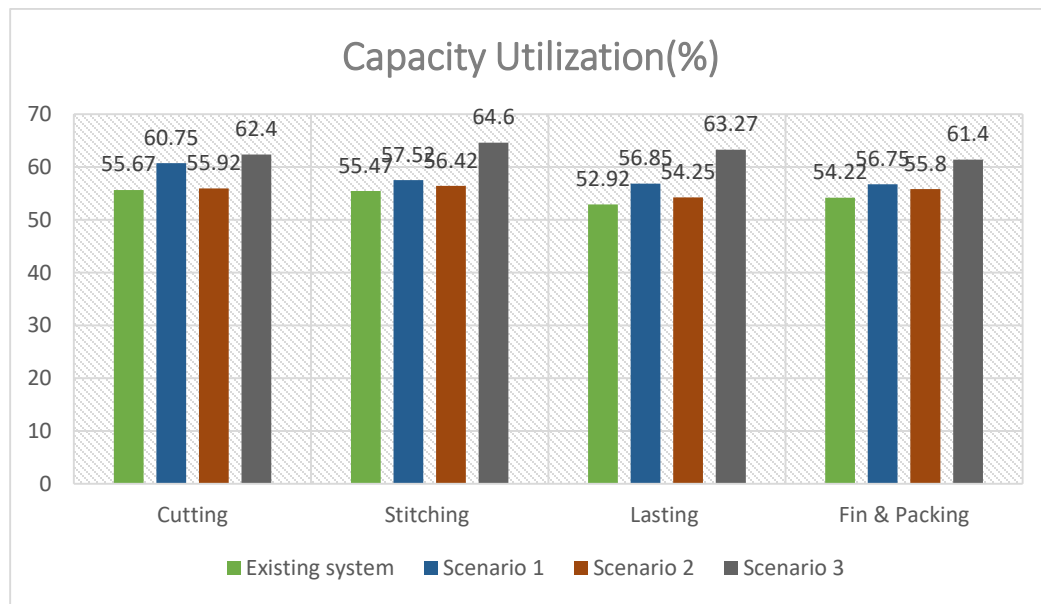


Figure 5-6: Capacity utilization comparison

Discussion from all simulations shows that there was an improvement in the production output, cycle time, WIP, queue number, and queue time between them. The objectives of this study were already obtained which were to improve the performance and capacity utilization of the production lines. Moreover, if the improved suggestion were applied in the manufacturing process, there will be some changes in improving the results.

5.2. Cost-Benefit Analysis

The cost-benefit analysis is used to determine which scenario is the best among the three alternatives for additional profit-making. The average annual working days were taken as 300 days and machinery lifetime was assumed to be 10 years. Costs related to additional operators were calculated based on monthly salary for regular working days only. Details for additional machinery and human resource costs are shown in Appendix 8 and 9. The gross profit of the proposed model is calculated based on the minimum company's margin. Therefore, from the three scenarios, the first scenario could generate an additional annual minimum gross profit of 921,120 Birr, the second scenario could generate an additional annual minimum gross profit of 546,320 Birr, and the third scenario could generate an additional annual minimum gross profit of 1,918,160 Birr.

Table 5-15: Cost-benefit analysis

Scenarios	Annual production Per 300 days	Proposed production per 300 days	Production difference	Total profit (30.4 Birr/pair) before tax	Annual additional cost M/C	Annual additional cost O/P	Total cost (OP +MC)	Annual minimum profit (Birr)
Scenario 1	650,700	681,000	30,300	921,120				921,120
Scenario 2	650,700	669,000	18,300	556,320	10,000		10,000	546,320
Scenario 3	650,700	737,100	86,400	2,626,560	250,000	458,400	708,400	1,918,160

Generally, the addition of one hydraulic cutting machine and three operators to the cutting section quality inspection workstation; two operators in arranging and tying workstation to the stitching section; one side part lasting machine with an operator, one heat setting machine with an operator, two roughing machines with two operators to the lasting section; and five operators to finishing section manual overflow cutting workstation gives better production performance and profit for the organization. Therefore, it is recommended that the company take into consideration the addition of resources to bottleneck workstations.

5.3. Discussion

The approach taken in improving the performance of the production lines was based on the results obtained from experimentation made on the simulation model. Emphasis was given on identifying bottlenecks, experiment with the validity of the approaches, increasing the production output, and increasing line utilization to improve the overall production performance.

Results from the analysis showed that the highest waiting times were 5000 seconds at the upper-quality inspection workstation, 4117 seconds at stitching rework workstation, 2919 seconds at side part lasting queue in the lasting section, and 1475 seconds at manual overflow cutting stations in the finishing section. High variation in capacity utilization of resources also has shown there was an uneven distribution of work within the production line. Underutilization of the resources in all sections and uneven distribution of work explains that some of the resources are busy with value-adding activities while others are not. For instance, resource 5 in the cutting section was 99.59 % utilized while resource 2 from the same section was utilized for only 19.01 %. Similarly, stitching machine 5 was utilized for 99.13 % in the stitching section while marking operator 2 was utilized for 27.44 %. Heat setting machine from the lasting section was utilized at 96.1% but manual glue pasting operators were utilized at 7 %. The utilization of resources was relatively better in the finishing section. It ranges from 57.78 % for resource 3 to 19.23% for resource 10 which is an indication of inefficient and unbalanced utilization of resources. This was probably because an area where most of the bottlenecks found and different scenarios were to be developed to solve the causes of the bottlenecks. Thus, attention was needed at these workstations to improve the performance of the lines.

Three scenarios i.e. changing the work method by merging or splitting workstations, layout rearrangement, and addition of resources to the bottleneck workstations were considered for experimentation. The application of these scenarios improved the performance and capacity utilization of the production lines. Performance parameters such as daily production output, WIP, maximum waiting time, maximum waiting number, and capacity utilization were used to compare the developed models within the existing production system. Scenario 1 could

increase the daily production output by 101 pairs, scenario 2 could improve the output by 63 pairs, and scenario 3 could improve the daily output by 288 pairs.

Scenario 1 increases the WIP of components in the lasting section from 420 to 685 and from 476 to 525 in the finishing section but it decreases in the cutting section from 170 to 138 and stitching section from 428 to 391. Scenario 2 increases the WIP of components from 170 to 398 in the cutting section and from 428 to 449 in the stitching section but it decreases from 420 to 387 in the lasting section and 476 to 423 in the finishing section. Scenario 3 could decrease the WIP in all production sections i.e from 170 to 78, from 428 to 257, 420 to 235, and 476 to 366 in cutting, stitching, lasting, and finishing sections respectively.

In the cutting, stitching, lasting, and finishing production sections, scenario 1 could increase the production line capacity utilization by 9.12 %, 3.69%, 7.42%, and 4.67%, scenario 2 could increase the production line capacity utilization by 0.45%, 1.71%, 2.5%, and 2.91%, and scenario 3 could increase the capacity utilization by 12.1%, 16.45%, 19.56%, and 13.24%.

Finally, a cost-benefit analysis was conducted to compare different scenarios and to select the best approach. The results of the analysis showed that the addition of resources costs 708,400 Birr and increases the annual production output by 86,400 pairs of shoes. Changing the arrangement of the layout costs 10, 000 Birr annually and increases the production output by 18,300 pairs. It is also possible to increase the annual production output by 30,300 pairs of shoes by changing the working method without any additional cost.

Although it incurs the highest machinery and operator cost, scenario 3 (the addition of resources to bottleneck stations) would provide the best production performance. However, the implementation of this scenario highly depends on the budget and human resource policy of the company to recruit new employees and to purchase new machinery.

On the other hand, the analysis has shown that it is possible to get the second-best result in terms of production performance by changing the working method without any additional expenses. This scenario might be considered if the company HR policy and budget do not allow to implement the first scenario.

Chapter Six

Conclusions & Recommendations

6.1. Conclusions

Performance improvement is an important concern in footwear manufacturing industries. Manufacturing firms nowadays are more focusing on improving production performance in terms of capacity utilization to survive in the competitive market. It can be achieved through the application of appropriate performance improvement methods and tools.

In this research manufacturing system modeling and performance analysis using simulation was done for Tikur Abbay shoe share company production lines. Simulation models were developed, verified, and validated. After verifying and validating the models, it is simulated for 7.5 hours of working time with 160 replications. Based on the analysis of the simulation runs, the bottleneck of production lines has been identified with high processing time, high work-in-process, high waiting times, high waiting numbers, low capacity utilization, and low line balancing efficiency. The identified bottleneck workstations have influenced the whole production system by slowing down the subsequent operations.

To improve the problems identified, three alternative models were proposed i.e. changing the working method to minimize the processing times, layout rearrangement to reduce the over traveling, and addition of machine and/or labor on bottleneck workstations to improve resource usage. After going through the simulation analysis, it has been proved that all proposed alternative scenarios achieve better production performance than the existing production system. From the comparison of the results, the addition of resources to bottleneck workstations is a better approach that could provide high production performance and additional earnings. Changing the work method scenario could generate the second-best performance and earnings while the layout rearrangement scenario could generate 546,320 Birr annual gross revenue.

Finally, this research has identified the possible internal bottleneck causes of capacity underutilization and proposes different approaches to improve the production performance and the capacity utilization of the production sections.

6.2. Recommendations

Based on the results of this research the following recommendations are proposed:

- Production performance is one of the major factors to win a competition in the global market. Therefore, the company should improve its production performance continuously and sustainably.
- To resolve performance-related issues significantly, then the addition of resources to the bottleneck workstations scenario is recommended.
- Simulation should be seriously considered as a very important tool for the company concerning future performance improvement and management decision making.
- The effect of external causes is not considered in this study, but, considering the contribution of external causes in analyzing production performance could be a source of significant improvements.

Reference

- Addis, S., Dvivedi, A., & Beshah, B. (2017). Identifying and prioritizing operational performance indicators of the Ethiopian leather industry. *International Journal of Productivity and Quality Management*, 22(3), 378–394.
- Agarwal, R., Bagul, D., Agey, C., & Ayare, P. (2019). Basic Study of Assembly Line Balancing. *International Research Journal of Engineering and Technology (IRJET)*, 06(04), 2627–2630.
- Ahmad, S. A., Ng, K. W., Airdzaman, S. H., Ang, M. C., & Suliano, B. (2018). Improving Queuing System with Limited Resources Using TRIZ and Arena Simulation. *International Journal of Innovative Technology and Exploring Engineering*, 1–17.
- Ahmed, H. (2018). Operational Performance and Profitability : an Empirical Study on the Bangladeshi Ceramic Companies. *International Journal of Entrepreneurship and Development Studies (IJEDS)*, 63-73.
- Anand P., Sanjay K., Kapil D., Abhishek S., (2017). Productivity, quality, and business performance : an empirical study. *International Journal of Productivity and Performance Management*, 66(1), 78-91.
- Andradóttir, S., Healy, K. J., Withers, D. H., Nelson, B. L., & Maria, A. (1997). Proceedings of the 1997 Winter Simulation Conference. 7–13.
- Araya, T.(2018). Efficiency Analysis and Performance Improvement of Bottling Production Line (Unpublished master's thesis). Addis Ababa University, Addis Ababa, Ethiopia.
- Aregawi yemane, Serajul haque, I. S. M. (2017). Bottleneck Identification Using Time Study and Simulation Modeling of Apparel Industries. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, 321–331.
- Begashaw, G. (2015). Drivers of Manufacturing Performance in Medium and Large Scale Firms in Ethiopia (Unpublished doctoral dissertation). University of South Africa, South Africa.
- Bodner, D. A., & Mcginnis, L. F. (2002). A Structured Approach to Simulation Modeling of Manufacturing Systems. *Proceedings of the 2002 Industrial Engineering Research*

Conference.

- Boman, J., Currie, G., MacDonald, R., Miller-Young, J., Yeo, M., & Zettel, S. (2017). Overview of Decoding across the Disciplines. *New Directions for Teaching and Learning*, San Francisco: Jossey-Bass.
- Chaudhari, M. C. (2018). Concrete Mixture Assembly Line Improvement using ARENA Simulation - A Case Study. *International Journal of Trend in Scientific Research and Development (IJTSRD)*, 398–402.
- Chen, J. C., & Chen, J. (2014). Simulation Modeling and Analysis for Stitching Line of Footwear Industry. *International Conference on Industrial Engineering and Operations Management*, 1099–1106.
- Derbe, T. (2018). Productivity Analysis and Improvement in Ethiopian Metal Manufacturing Industries “ A Case of Yesu Metals Manufacturing” (Unpublished master's thesis). Addis Ababa University, Addis Ababa, Ethiopia.
- Dr. George Q. Sun, D. W. M. (2014). Manufacturing simulation - Improving Productivity and Reducing Manufacturing Cycle Time through Simulation Modelling. *Proceedings of the 2014 International Conference on Industrial Engineering and Operations Management (IEOM) Bristol, UK*.
- Elyazid, S. (2016). Performance Measurement : Quality, Cost, and Time Are New System : So-Called Strategic Cost Management. *Research Journal of Finance and Accounting*, 7(17), 1–12.
- Ericson, A. (2017). Bottleneck detection in manufacturing: A throughput case study at SCANIA. *Chalmer University of Technology (Unpublished master's thesis)*. Gothenburg, Sweden.
- Gashaw, T., Jilcha, K., & Berhan, E. (2014). Modeling and Simulation of Inventory Management System of Artistic Printing Enterprise. Addis Ababa University, Addis Ababa, Ethiopia.
- Ghiyasinasab, M., Lehoux, N., Ménard, S., & Cloutier, C. (2018). Using Lean Techniques and Simulation to Improve the Efficiency of Engineered Wood Production : A Case

- Study in a Small Factory. *Industrial Engineering & Management*, 7(4).
- Goshu, Y. Y., Matebu, A., & Kitaw, D. (2017). Development of Productivity Measurement and Analysis Framework for Manufacturing Companies. *Journal of Optimization in Industrial Engineering*, 10(22), 1–13.
- Groover, M. (2015). *Automation, Production Systems, and Computer-Integrated Manufacturing* (4th ed.). Pearson PLC, London, United Kingdom.
- Hazza, M., Elbishari, E., Ismail, Y., Adesta, E.(2018). Productivity improvement using discrete events simulation. *International Journal of Materials Science and Engineering*, 1-7.
- Hensley, R. L., & Utley, J. S. (2018). Assessing Multiple-Item Manufacturing Capability Measures: A Critical Review. *Archives of Business Research*, 6(10), 202–227.
- Herzegovina, B. (2012). Analysis Of Shoe Manufacturing Factory By Simulation Of Production Processes. *Southeast Europe Journal of Soft Computing*, 1(1), 120–127.
- Hon, K. K. B. (2005). Performance and evaluation of manufacturing systems. *CIRP Annals - Manufacturing Technology*, 54(2): 139–154.
- Iwao, S., & Marinov, M. (2018). Linking continuous improvement to manufacturing performance. *Benchmarking, An International Journal*, 25(5), 1319–1332.
- J. J. Cardiel-Ortega, R. Baeza-Serrato, and R. A. L.-M. (2017). Development of a system dynamics model based on Six Sigma methodology. *Ingeniería e Investigación*, 2017, 80–90.
- Jilcha, K., Berhan, E., & Sherif, H. (2015). Computer Science & Systems Biology Workers and Machine Performance Modeling in Manufacturing System Using Arena Simulation. *Journal of Computer Science & Systems Biology*, 8(4), 185–190.
- Kassaneh, T. C., & Workalemahu, R. N. (2018). Performance Measurement and Improvement Method for Leather Footwear Industries. *Journal of Engineering, Project, and Production Management*, 8(2), 97–104.
- Kelton, W. D. (2010). *Simulation with Arena, Sixth Edition* (6th ed.). McGraw-

Hill Education, 2 Penn Plaza, New York, NY.

- Kibira, D., Morris, K. C., & Kumaraguru, S. (2016). Methods and tools for performance assurance of smart manufacturing systems. *Journal of Research of the National Institute of Standards and Technology*, 121, 282–313.
- Kikolski, M. (2016). Identification of production bottlenecks with the use of Plant Simulation software. *Engineering Management in Production and Services*, vol. 8(4), pages 103-112.
- Kikolski, M. (2017). Study of Production Scenarios with the Use of Simulation Models. *Procedia Engineering*, 182, 321–328.
- Kłos, S., & Patalas-maliszewska, J. (2016). Improving Manufacturing Process. *Applied Computer Science*, 12(4), 7–17.
- Kommula, V. P. (2016). Productivity improvement using simulation modeling and lean tools: A case study. *International Journal of Engineering Sciences and Research Technology*, 5(1), 708-721.
- Lee, M. D. (2013). An Operations Research Approach for Maximizing Machinery Capacity Utilization for Sustainable Manufacturing Performance. *Journal of Manufacturing Operations Research and Sustainability*, 1(2), 21–30.
- Line, P., Naik, G. R., Raikar, V. A., & Naik, P. G. (2015). A Simulation Model for Overall Equipment Effectiveness of a Generic Production Line. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*.
- Mohamad, E., Ibrahim, M. A., Shibghatullah, A. S., & Rahman, M. A. A. (2016). A simulation-based approach for Lean Manufacturing tools implementation. *ARPJ Journal of Engineering and Applied Science*, 3400-3406.
- Nahom Mulugeta, T. G. (2014). Modeling and Performance Analysis of Manufacturing Systems in the Footwear Industry. *Science, Technology, and Arts Research Journal*, 7522(3), 132–141.
- Neeraj, R. R., Nithin, R. P., Niranjhan, P., Sumesh, A., & Thenarasu, M. (2018). Modeling

- and simulation of discrete manufacturing industry. *Materials Today: Proceedings*, 5(11), 24971–24983.
- Nguyen, N. (2015). *Simulation Modeling for Designing and Evaluating a New Flexible Manufacturing System Case Study: Cylinder Gas Industry* (Unpublished master's thesis). Aalto University, Helsinki, Finland.
- Gonçalo C., Giovanni O., José B., Sebastian S.(2016). Adapter for Self-Learning Production Systems. 3rd Doctoral Conference on Computing, Electrical and Industrial Systems (DoCEIS), Costa de Caparica, Portugal, 171-178.
- Ortikmirzaevich, T. B. (2017). Principles and Functions of Management. *International Journal of process management and New technologies* 5(4), 61–68.
- Othman, N. H. (2017). Improvement of Bottling Production Line Using Simulation Method. *Journal of Engineering and Technology*, 1(4), 76–88.
- Parvez, M., Amin, F., & Akter, F. (2017). Line Balancing Techniques To Improve Productivity Using Work Sharing Method. *IOSR Journal of Research & Method in Education (IOSR-JRME)*, 7(3), 7–14.
- R. Almour, S. C. (2018). Simulation-based Six Sigma value function for system-level performance assessment and improvement. *International Journal of Productivity and Performance Management*, 66–83.
- Rahman, C. M. L. (2015). Process Flow Improvement Proposal of A Batch Manufacturing System Using Arena. *Review of General Management*, 21(1), 63–77.
- Revolution, I., Whitney, E., States, U., Maudsley, H., Kingdom, U., Brunel, M. I., & Kingdom, U. (2003). Introduction to. In *Process Planning – The Design/Manufacture Interface*.
- Rogowska, P. (2018). The Case Study of Bottlenecks Identification for Practical Implementation to the Theory. *International Conference on Multidisciplinary Aspects of Production Engineering (MAPE2018)*, Zawiercie, Jurassic Highland, Poland.
- Romain, K. (2019). *The Effect of Manufacturing Capability on Firm Performance:*

- Empirical Evidence from Small and Medium Manufacturing Companies in Kigali-Rwanda. *The Pan-African Journal of Business Management*.
- Rooda, E. L., and J. E. (2015). Modeling and Analysis of Manufacturing Systems. *Journal of the Operational Research Society*, (June 1994).
- Roser, C, Lorentzen, K., & Deuse, J. (2014). Reliable Shop Floor Bottleneck Detection for Flow Lines through Process and Inventory Observations. *Procedia CIRP*, 63–68.
- Shahidul, M., S. T. Syed Shazali, Abdullah Y., C. H. Ting, A. H. Hishamuddin, M. S. M Azrin, and A. F. K. A. (2013). Measuring Machinery Capacity Utilization and Its Impact on Manufacturing Performance and Environment, 7–12.
- Shamuvel, P.(2016). Performance of manufacturing system improvement by arena 10 simulation software. *International Journal of Research in Advanced Engineering and Technology*. 2(5), 35–38.
- Silva P.S., Trigo A., Varajão J., Pinto T. (2010) Simulation – Concepts and Applications. In: Lytras M.D., Ordonez de Pablos P., Ziderman A., Roulstone A., Maurer H., Imber J.B. (eds) *Organizational, Business, and Technological Aspects of the Knowledge Society. WSKS 2010. Communications in Computer and Information Science*, vol 112. Springer, Berlin, Heidelberg.
- Skotnicka-zasadzień, B., & Gębalska A. (2018). Identification of bottlenecks and analysis of the state before applying lean management. 2nd International Conference On Economic and Business Management.
- Tamás, P., & Illés, B. (2017). Process Improvement Trends For Manufacturing Systems in Industry. *Academic Journal of Manufacturing Engineering*, 0-7.
- Tan Rimo, O. T. (2017). A simulation study of capacity utilization to predict future capacity for manufacturing system sustainability. *The International Conference on Eco Engineering Development*, 0-9.
- Thawani, S. (2016). Total Quality Management & Business Excellence Six Sigma Strategy for Organizational Excellence. *Journal Total Quality Management & Business Excellence* Volume 15, 606-614.

- Thomas Cherkos. (2011). Performance Analysis and Improvement of Ethiopian Leather Footwear Factories (Unpublished master's thesis). Addis Ababa University, Addis Ababa, Ethiopia.
- Thor, M. (2016). Bottleneck Analysis and Throughput Improvement Through Simulation-Based Multi-Objective Optimization. *International Journal of Production Research* 47:6929–6940.
- Tiago, J., & Covas, M. (2014). Production Line Balancing Simulation : A case study in the Footwear Industry (Unpublished master's thesis). University of Porto, Porto, Portugal.
- Tilahun, M. (2018). Enhancing Productivity of Mixed-Model Assembly Line in Tikur Abbay Shoe S. Co (Unpublished master's thesis). Addis Ababa University, Addis Ababa, Ethiopia.
- Velumani, S., & Tang, H. (2017). Operations status and bottleneck analysis and improvement of a batch process manufacturing line using discrete event simulation. *Procedia Manufacturing*, 10, 100–111.
- Wang, Y., Zhao, Q., & Zheng, D. (2016). Bottlenecks in Production Networks: an overview. *A Journal of Systems Science and Systems Engineering*, 0-18.
- White, K. P., Jr., and Ingalls, R. G. 2009. “Introduction to Simulation,” In Proceedings of the 2009 Winter Simulation Conference, edited by M. D. Rossetti, R. R. Hill, B. Johansson, A. Dunkin, and R. G. Ingalls, 12–23. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.
- Winston, W.L., & Goldberg, J.B. (2004). *Operations research: Applications and Algorithms*. Belmont, Calif.; London.
- Yemane, A., & Hailemicheal, M. (2020). Productivity Improvement through Line Balancing by Using Simulation (Case study Almeda Garment Factory). *Journal of Optimization in Industrial Engineering*, 153–165.
- Zahraee, S. M., Golroudbary, S. R., Hashemi, A., Afshar, J., & Haghghi, M. (2015). Simulation of manufacturing production line based on Arena. *Journal of Industrial Engineering and Management*, 487-504.

Zhu, L., Johnsson, C., Mevik, J., Varisco, M., & Schiraldi, M. (2018). Key performance indicators for manufacturing operations management in the process industry. In 2017 IEEE International Conference on Industrial Engineering and Engineering Management, 969-973.

Zupan, H., & Herakovic, N. (2015). Direct Production line balancing with discrete-event simulation : A case study. IFAC-Papers Online, 48(3), 2305–2311.

Appendix 1

No of Observation	Inter arrival time in minutes							
	Upper leather	Lining leather	Toe puff	Counter	Insole	Components to be stitched	Upper	Lasted shoe
1	29	45	16	16	14	0.17	110	30
2	30	45	16	14	15	0.17	115	30
3	31	44	15	15	14	0.17	116	31
4	30	45	15	15	14	0.17	10	31
5	30	46	15	15	15	0.16	100	30
6	31	45	15	14	15	0.17	113	31
7	31	45	14	15	14	0.17	98	30
8	30	44	15	15	15	0.17	110	30
9	31	45	15	15	15	0.18	114	30
10	30	45	15	15	14	0.16	117	29
11	29	45	15	14	15	0.16	110	30
12	30	45	15	15	15	0.17	112	30
13	31	44	15	16	14	0.17	111	30
14	30	46	15	15	14	0.17	100	29
15	30	45	15	15	15	0.17	113	29
Batch Size	40	40	40	40	40	1	180	100

Appendix 2

DEP	Operation	M/C or M/N	Machine Code	Qty	Number of Observations													Average	St. Deviation	
					1	2	3	4	5	6	7	8	9	10	11	12	13			
					14	15	16	17	18	19	20	21	22	23	24	25				
CUTTING	Upper Cutting	M/C		8	40	42	42	66	57	51	48	50	70	70	69	71	71	54	12	
					57	71	39	41	42	44	52	51	48	44	68	48				
	Lining Cutting	M/C		6	27	28	27	34	36	31	34	36	48	47	46	48	48	37	9	
					40	59	27	28	27	34	32	34	30	35	40	39				
	Toe puff Cutting	M/C		1	6	8	8	6	9	8	6	6	9	8	7	9	9	8	1	
					6	8	7	8	8	10	9	8	6	6	9	7				
	Counter Cutting	M/C		1	3	3	2	1	3	2	1	1	2	1	2	2	3	2	1	
					2	1	3	2	2	1	3	2	1	4	2	2				
	Insole Cutting	M/C		1	4	5	8	4	9	6	4	5	6	3	4	5	5	5	2	
					8	5	4	5	6	4	7	6	4	4	6	6				
	Soak Lining Cutting	M/C		1	6	13	5	13	6	8	23	8	5	14	6	16	8	9	4	
					10	11	6	13	5	10	11	8	9	8	4	18				
		Upper quality inspection	M/N		5	60	60	60	90	60	60	60	60	30	60	60	60	60	60	
						60	60	60	60	90	30	60	60	60	60	60	60			
	Lining quality inspection	M/N		5	40	50	50	50	50	60	40	50	50	50	60	50	50	50		
					50	50	50	50	40	50	50	50	50	50	50	60				

	Size labeling	M/N		3	2	3	3	3	3	5	2	3	3	3	2	5	5	3	
	Arranging component pair by pair	M/N		3	3	3	3	3	3	3	2	3	3	3	5	3		3	
PREPARATION & CLOSING	Marking	M/N		4	11	13	14	16	13	11	13	13	14	13	13	16	11	12	2
					12	12	10	11	14	12	12	13	11	11	10	14			
	Tongue to eyelet zigzag stitching	M/C	02-04-002, 02-04-004	2	9	13	14	13	16	16	14	11	13	12	14	14	16	12	2
					11	16	9	13	14	13	16	16	14	11	13	12			
	Counter zigzag stitching	M/C	02-04-003, 02-04-005	2	12	14	13	13	14	16	13	12	14	14	13	16	14	14	2
					16	12	12	11	16	13	16	13	17	11	12	13			
	Vamp to tongue stitching	M/C	02-05-034, 02-05-047, 02-05-038, 02-05-024	4	31	29	33	26	32	32	25	28	29	29	32	34	33	27	5
				27	27	21	18	19	20	24	21	23	25	27	21				
Counter stripe stitching	M/C	02-07-011, 02-07-019, 02-07-022, 02-07-026, 02-07-012	5	54	52	36	44	49	49	51	46	47	47	50	48	51	48	4	
				46	50	52	48	50	46	46	50	52	48	48	47				
Inner part folding	M/C	02-05-017, 02-	5	21	16	25	34	29	32	25	23	27	27	33	23	32	30	6	

stitching with upper		05-023, 02-05-029, 02-05-041		29	34	36	41	41	32	33	34	34	39	29	39			
Size labeling on the upper	M/N		5	32	43	33	25	57	39	41	41	34	47	46	32	41	41	7
				46	50	39	41	40	34	45	46	32	41	48	40			
Quarter to counter stitching	M/C	02-05-025, 02-05-040, 02-05-018, 02-05-035, 02-05-027, 02-05-044, 02-05-045	6	98	69	85	92	93	66	82	75	78	89	69	66	73	80	10
				80	71	89	93	64	73	75	85	82	82	92	77			
Eyelet trimming	M/C	03-11-002, 02-11-001, 02-11-004, 02-11-003	4	27	29	31	33	26	32	31	32	34	25	29	29	28	30	3
				25	34	34	25	31	33	23	31	31	34	27	27			
Eyeleting	M/C	02-10-013, 02-10-003	2	18	20	20	21	14	17	16	18	16	12	14	20	18	17	3
				13	16	19	14	18	13	17	19	16	18	20	16			
Vamp to quarter stitching	M/C	02-07-005, 02-07-006, 02-07-002, 02-07-017, 02-07-003	5	34	29	33	33	29	27	34	29	39	46	32	29	27	34	6
				32	29	39	46	32	29	31	31	36	46	32	29			

	Thread burning	M/N		5	28	31	27	27	33	34	46	32	25	31	29	27	27	33	6
					39	33	28	33	34	44	32	26	30	40	44	30			
	Quality inspection and trimming	M/N		3	9	20	17	13	18	11	11	16	21	13	16	21	23	17	5
					11	19	21	20	22	22	23	12	18	5	19	22			
	Piercing for rivet	M/C	02-10-008	1	9	9	9	9	10	10	10	11	9	10	10	9	9	9	1
					11	8	8	10	8	9	7	7	8	10	9	8			
	Rivet inserting	M/N		4	36	29	28	27	37	37	29	32	36	29	39	34	34	32	4
					39	28	28	28	30	34	32	32	36	29	30	28			
	Riveting	M/C		1	8	5	6	8	8	6	6	8	5	8	6	8	6	7	1
					8	8	8	7	7	8	6	8	6	8	8	8			
Lacing	M/N		6	29	32	50	60	41	39	41	43	43	46	33	37	41	42	6	
				46	52	41	41	40	42	46	40	40	41	38	38				
Arranging and tying with rope	M/N		4	42	36	17	28	65	51	23	29	39	36	36	28	44	37	11	
				50	29	51	22	35	39	36	42	28	44	38	50				
LASTING	Toepuff glue pasting & inserting	M/N		3	20	24	17	18	20	18	24	26	25	28	21	27	23	23	3
					23	20	24	22	22	26	28	27	24	20	18	25			
	Counter glue pasting & inserting	M/N		3	36	55	59	64	60	52	55	46	50	55	43	43	59	52	8
					62	46	38	40	50	62	48	60	61	44	49	56			
	Inner side glue pasting	M/N		2	50	43	47	37	29	39	34	43	46	47	33	36	50	39	6
					34	41	40	30	40	36	43	30	47	35	36	31			

Needle tacking	M/C	03-15-001	1	14	10	14	9	13	14	18	16	11	10	16	12	13	14	3
				11	10	15	10	17	17	18	15	16	17	13	9			
Insole glue pasting	M/N		2	25	20	24	23	27	27	21	24	20	25	23	23	27	24	2
				21	23	22	24	25	26	26	20	27	23	23	24			
Heat setting	M/C		3	93	95	96	96	94	97	91	94	86	89	95	92	89	92	3
				98	96	87	90	92	91	94	92	94	86	88	90			
Toe lasting	M/C	03-16-007	1	29	33	23	24	20	23	27	28	24	23	26	28	32	25	4
				23	20	28	23	23	25	28	32	23	20	26	29			
Side lasting	M/C	03-16-001	3	32	25	27	33	29	29	36	32	25	23	34	35	29	30	4
				28	33	27	27	30	29	29	36	35	29	22	34			
Nail removing	M/N		2	23	20	17	20	21	23	23	18	20	23	21	18	19	20	2
				19	21	20	22	24	17	20	20	22	19	18	17			
Bounding	M/C	03-09-001	1	11	13	13	13	9	10	10	13	14	11	10	8	9	12	2
				12	13	13	14	9	10	11	13	14	13	10	10			
Glue pasting	M/N		1	6	6	6	8	6	8	6	6	9	5	6	6	8	7	1
				5	8	5	7	6	8	6	8	6	6	9	8			
Back part lasting	M/C	03-17-004	1	18	25	27	19	17	14	17	14	20	23	20	19	24	19	4
				16	19	18	25	27	18	17	14	17	10	20	19			
Manual hammering	M/N		1	9	14	10	6	11	8	13	9	11	10	12	13	9	11	2
				8	13	12	14	10	14	11	9	13	9	10	10			
	M/C		1	6	10	9	9	10	11	8	6	9	8	11	9	10	9	1

	Roughing with sandpaper		03-18-004		10	8	7	8	10	11	9	10	10	8	9	10			
	Roughing with wire 1	M/C	03-18-005	1	13	14	18	20	18	16	17	16	16	18	17	19	18	17	2
					20	16	15	15	17	20	20	19	18	16	14	19			
	Roughing with wire 2	M/C	03-18-003	1	26	28	27	20	24	28	29	20	23	24	24	28	20	25	3
					23	21	26	26	22	23	24	24	28	20	23	28			
	De lasting	M/C	03-19-005	1	9	20	12	13	18	11	10	16	18	11	16	12	14	15	3
					18	17	19	16	14	15	15	20	11	11	12	16			
	Tightening pair by pair	M/N		3	18	19	23	17	25	18	23	20	18	25	23	23	20	20	3
					19	18	21	20	24	18	17	16	22	20	24	18			
FINISHING & PACKING	Volcanizing	M/C		24	156	157	140	154	159	151	138	143	156	154	147	139	161	150	8
					152	138	150	160	154	139	140	157	154	147	149	156			
	Trimming	M/C	04-11-010, 04-11-009, 04-24-008	6	26	28	29	24	25	27	23	24	24	27	26	27	27	25	3
					23	28	28	21	20	23	27	23	25	20	26	26			
	Manual overflow cutting	M/N		9	101	112	87	59	75	71	63	82	89	103	101	73	86	83	14
					78	93	66	68	100	94	67	75	77	94	89	70			
	Insole inserting	M/N		6	11	13	16	11	10	9	12	23	18	21	23	12	20	15	5
					16	11	11	13	16	11	10	9	12	23	18	11			
	Decoration	M/N		6	50	44	23	29	42	20	28	34	41	26	46	48	34	35	9
					40	35	48	44	24	29	42	20	28	34	41	26			

Spraying	M/C	03-24-001	1	4	5	4	4	5	5	3	3	4	4	4	3	5	4	1
				4	4	4	5	4	3	5	5	3	4	4	5			
Lacing	M/N		4	29	11	21	25	20	23	32	27	25	26	20	21	27	23	5
				24	21	29	15	21	20	20	23	32	26	25	26			
Quality inspection	M/N		4	25	29	17	13	13	17	19	21	16	23	27	28	25	21	5
				29	18	25	29	17	16	13	15	19	21	18	20			
Packing	M/N		4	25	24	27	26	23	25	23	27	25	26	32	28	26	25	3
				25	22	26	22	23	20	24	21	23	26	26	26			

Cutting Section Machine Failure

List of machines	Machine ID	Frequency	Uptime in hrs	Downtime in minutes	MTBF in hrs	MTTR in minutes
Cutting Machine 1	01-01-015	5	715	320	Expo (143)	Expo (64)
Cutting Machine 2	01-01-014	4	717	200	Expo (179)	Expo (50)
Cutting Machine 3	01-01-027	3	719	90	Expo (240)	Expo (50)
Cutting Machine 4	01-01-012	4	717	180	Expo (179)	Expo (45)
Cutting Machine 5	01-01-011	6	715	300	Expo (119)	Expo (50)
Cutting Machine 6	01-01-019	7	716	260	Expo (102)	Expo (37)
Cutting Machine 7	01-01-018	6	715	300	Expo (119)	Expo (50)
Cutting Machine 8	01-01-016	6	714	390	Expo (119)	Expo (65)
Lining Cutting MC 1	01-01-001	4	716	240	Expo (179)	Expo (60)
Lining Cutting MC 2	01-01-002	3	717	180	Expo (239)	Expo (60)
Lining Cutting MC 3	01-01-003	3	717.5	150	Expo (239)	Expo (50)
Lining Cutting MC 4	01-01-004	5	716	240	Expo (143)	Expo (48)
Lining Cutting MC 5	01-01-005	2	718	120	Expo (359)	Expo (60)
Lining Cutting MC 6	01-01-006	4	717	170	Expo (179)	Expo (43)
Travel Head Cutting MC 1	01-01-007	8	714	380	Expo (89)	Expo (47)
Travel Head Cutting MC 2	01-01-008	5	716	220	Expo (143)	Expo (44)
Travel Head Cutting MC 3	01-01-009	6	715	280	Expo (119)	Expo (47)
Travel Head Cutting MC 4	01-01-010	3	716	240	Expo (239)	Expo (80)

Stitching Section Machine Failure

List of machines	Machine ID	Frequency	Uptime in hrs	Downtime in minutes	MTBF in hrs	MTTR in minutes
Zigzag Stitching Machine 1_2	04-02-002	7	716	230	Expo (102)	Expo (33)
Zigzag Stitching Machine 2_2	02-04-003	8	716	270	Expo (89)	Expo (34)
Zigzag Stitching Machine C 1_3	02-04-004	6	716	240	Expo (119)	Expo (40)
Zigzag Stitching Machine C 2_3	02-04-005	6	715	320	Expo (119)	Expo (53)

Stitching Machine V_T 1_4	02-05-034	6	711	540	Expo (119)	Expo (90)
Stitching Machine V_T 2_4	02-05-047	3	717	180	Expo (239)	Expo (60)
Stitching Machine V_T 3_4	02-05-038	5	716	220	Expo (143)	Expo (44)
Stitching Machine V_T 4_4	02-05-024	5	716.5	210	Expo (143)	Expo (42)
Stitching Machine C_S 1_5	02-07-011	4	717.5	150	Expo (179)	Expo (37.5)
Stitching Machine C_S 2_5	02-07-019	15	717	180	Expo (48)	Expo (12)
Stitching Machine C_S 3_5	02-07-022	17	707.5	750	Expo (42)	Expo (44)
Stitching Machine C_S 4_5	02-07-026	14	712.5	450	Expo (51)	Expo (32)
Stitching Machine C_S 5_5	02-07-012	6	717	180	Expo (119.5)	Expo (30)
Folding Machine I_S 1_6	02-05-017	7	716.5	210	Expo (102)	Expo (30)
Folding Machine I_S 2_6	02-05-023	4	717.5	150	Expo (179)	Expo (37.5)
Folding Machine I_S 3_6	02-05-029	5	717	190	Expo (143)	Expo (38)
Folding Machine I_S 4_6	02-05-041	4	718	120	Expo (180)	Expo (30)
Folding Machine I_S 5_6	02-05-023	6	717	190	Expo (119)	Expo (32)
Stitching Machine Q_C 1_8	02-05-025	5	717	160	Expo (144)	Expo (32)
Stitching Machine Q_C 2_8	02-05-040	3	718.5	90	Expo (239.5)	Expo (30)
Stitching Machine Q_C 3_8	02-05-018	6	717.5	150	Expo (120)	Expo (25)
Stitching Machine Q_C 4_8	02-05-035	5	716	220	Expo (143)	Expo (44)
Stitching Machine Q_C 5_8	02-05-027	5	716	220	Expo (143)	Expo (44)
Stitching Machine Q_C 6_8	02-05-044	5	717	180	Expo (143.4)	Expo (36)
Trimming Machine 1_9	03-11-002	3	718	100	Expo (239)	Expo (33)
Trimming Machine 2_9	02-11-001	3	718	120	Expo (239)	Expo (40)
Trimming Machine 3_9	02-11-004	7	716	235	Expo (102)	Expo (34)
Trimming Machine 4_9	02-11-003	6	716	240	Expo (119)	Expo (40)
Eyeletting Machine 1_10	02-10-013	9	713	430	Expo (79)	Expo (48)
Eyeletting Machine 2_10	02-10-003	11	710.5	570	Expo (65)	Expo (52)
Stitching Machine V_Q 1_11	02-07-005	6	715.5	270	Expo (119)	Expo (45)
Stitching Machine V_Q 2_11	02-07-006	5	716.5	210	Expo (143)	Expo (42)
Stitching Machine V_Q 3_11	02-07-002	7	715.5	270	Expo (102)	Expo (39)

Stitching Machine V_Q 4_11	02-07-017	9	715	310	Expo (80)	Expo (34)
Stitching Machine V_Q 5_11	02-07-003	12	712.5	450	Expo (59)	Expo (37)
Piercing Machine_14	02-10-007	6	718	120	Expo (120)	Expo (20)
Riveting Machine_16	02-10-008	4	718.25	105	Expo (180)	Expo (26)

Lasting Section Machine Failure

List of machines	Machine ID	Frequency	Uptime in hrs	Downtime in minutes	MTBF in hrs	MTTR in minutes
Tacking MC 1_4	03-15-001	5	716	240	Expo (143)	Expo (48)
Heat Setting MC 1_6	03-17-002	7	717	160	Expo (101)	Expo (22.8)
Heat Setting MC 2_6	03-17-003	6	716	240	Expo (118)	Expo (40)
Toe Lasting MC_7	03-16-007	5	710	600	Expo (142)	Expo (120)
Pounding MC_10	03-09-001	8	715.5	270	Expo (89)	Expo (34)
Back Part Lasting MC_12	03-17-002	4	710	600	Expo (177)	Expo (150)
Heel Setting MC 1_24	03-17-001	3	718.5	90	Expo (239.5)	Expo (30)
Heel Setting MC 2_24	03-17-004	6	718	120	Expo (120)	Expo (20)
Heel Setting MC 3_24	03-17-008	4	719	80	Expo (180)	Expo (20)
Heel Setting MC 4_24	03-17-0021	4	719	84	Expo (180)	Expo (31)
T Lasting MC 1_25	03-16-009	7	709	690	Expo (101)	Expo (99)
Side Las MC 1_26	03-11-014	3	718	130	Expo (239)	Expo (43)
Bonding MC 2_28	03-19-002	2	719	80	Expo (359)	Expo (40)
H Set MC2_30	03-19-005	6	718	120	Expo (120)	Expo (20)

Finishing and Packing Section Machine Failure

List of machines	Machine ID	Frequency	Uptime in hrs	Downtime in minutes	MTBF in hrs	MTTR in minutes
Volcanizing MC 1_1	04-11-008	3	718	120	Expo (239)	Expo (40)
Volcanizing MC 2_1	04-22-002	2	714	340	Expo (357)	Expo (170)
Volcanizing MC 3_1	04-22-005	4	716	240	Expo (179)	Expo (60)

Volcanizing MC 4_1	04-22-008	10	708	700	Expo (71)	Expo (70)
Volcanizing MC 5_1	04-22-009	6	717	200	Expo (120)	Expo (33)
Volcanizing MC 6_1	04-22-014	5	717.5	150	Expo (144)	Expo (30)
Volcanizing MC 7_1	04-22-015	12	712.5	450	Expo (59)	Expo (37.5)
Volcanizing MC 8_1	04-22-016	3	717.8	130	Expo (239)	Expo (43)
Volcanizing MC 9_1	04-22-019	9	704.5	930	Expo (78)	Expo (103)
Volcanizing MC 10_1	04-22-021	5	716.7	200	Expo (143)	Expo (40)
Volcanizing MC 11_1	04-22-022	4	716.9	186	Expo (179)	Expo (46.5)
Volcanizing MC 12_1	04-22-024	11	710.8	550	Expo (64)	Expo (50)
Volcanizing MC 13_1	04-22-025	3	717	180	Expo (239)	Expo (60)
Volcanizing MC 14_1	04-22-027	3	717	180	Expo (239)	Expo (60)
Volcanizing MC 15_1	04-22-028	6	717	180	Expo (119)	Expo (30)
Volcanizing MC 16_1	04-22-029	6	716.5	210	Expo (119)	Expo (35)
Volcanizing MC 17_1	04-22-030	12	708	740	Expo (59)	Expo (62)
Volcanizing MC 18_1	04-22-031	4	717	160	Expo (179)	Expo (40)
Volcanizing MC 19_1	04-22-033	2	710	600	Expo (355)	Expo (300)
Volcanizing MC 20_1	04-22-034	15	706	840	Expo (47)	Expo (56)
Volcanizing MC 21_1	04-22-035	5	712.5	450	Expo (142.5)	Expo (90)
Volcanizing MC 22_1	04-22-040	6	714	360	Expo (119)	Expo (60)
Volcanizing MC 23_1	04-22-041	4	718	120	Expo (179.5)	Expo (30)
Volcanizing MC 24_1	04-22-042	2	719	43	Expo (360)	Expo (21.5)
Trimming MC 1_2	04-11-010	11	716	253	Expo (65)	Expo (23)
Trimming MC 2_2	04-11-009	10	717	190	Expo (72)	Expo (19)
Trimming MC 3_2	04-24-008	24	714	384	Expo (30)	Expo (16)
Trimming MC 4_2	04-24-007	18	713	396	Expo (40)	Expo (22)
Trimming MC 5_2	04-24-006	22	712	484	Expo (32)	Expo (22)
Trimming MC 6_2	04-24-005	16	713	448	Expo (45)	Expo (28)
Spraying MC_6	03-24-001	7	715	315	Expo (102)	Expo (45)

Appendix 4

11:06:39AM

Category Overview

July 18, 2020

Values Across All Replications

Cutting Department Production

Replications: 160 Time Units: Seconds

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cutting Machine 1	0.5546	< 0.01	0.2961	0.6318	0.00	0.9091
Cutting Machine 2	0.6147	< 0.00	0.4920	0.6943	0.00	1.0000
Cutting Machine 3	0.5135	< 0.00	0.3753	0.5787	0.00	0.8333
Cutting Machine 4	0.5349	< 0.00	0.3887	0.6000	0.00	0.8696
Cutting Machine 5	0.6160	< 0.00	0.4348	0.6955	0.00	1.0000
Cutting Machine 6	0.4912	< 0.00	0.3289	0.5608	0.00	0.8000
Cutting Machine 7	0.5508	< 0.00	0.4982	0.6219	0.00	0.8929
Cutting Machine 8	0.5607	< 0.01	0.07088043	0.6089	0.00	0.9259
L Cutting MC 1	0.5215	< 0.00	0.3472	0.5583	0.00	1.0000
L Cutting MC 2	0.4759	< 0.00	0.3409	0.5128	0.00	0.9091
L Cutting MC 3	0.4382	< 0.00	0.4056	0.4676	0.00	0.8333
L Cutting MC 4	0.5010	< 0.00	0.4723	0.5370	0.00	0.9524
L Cutting MC 5	0.4570	< 0.00	0.3789	0.4877	0.00	0.8696
L Cutting MC 6	0.4382	< 0.00	0.3942	0.4680	0.00	0.8333
Resource 1	0.7158	< 0.00	0.4764	0.7282	0.00	1.0000
Resource 2	0.1901	< 0.00	0.1544	0.1960	0.00	1.0000
Resource 3	0.4927	< 0.00	0.4302	0.5062	0.00	1.0000
Resource 4	0.3143	< 0.00	0.2400	0.3267	0.00	1.0000
Resource 5	0.9959	< 0.00	0.9952	0.9963	0.00	1.0000
Resource 6	0.8529	< 0.00	0.8481	0.8629	0.00	1.0000
Resource 7	0.5983	< 0.00	0.5645	0.6045	0.00	1.0000
Resource 8	0.5981	< 0.00	0.5655	0.6034	0.00	1.0000

Appendix 5

3:01:11AM

Category Overview

July 20, 2020

Values Across All Replications

Stitching Line Production

Replications: 160 Time Units: Seconds

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Burning Operator 1	0.6334	< 0.00	0.4741	0.6527	0.00	1.0000
Burning Operator 2	0.5183	< 0.00	0.3963	0.5319	0.00	0.8197
Burning Operator 3	0.5057	< 0.00	0.3848	0.5215	0.00	0.8000
Burning Operator 4	0.5266	< 0.00	0.3906	0.5432	0.00	0.8333
Burning Operator 5	0.6326	< 0.00	0.4842	0.6568	0.00	1.0000
Eyeletting Machine 1	0.8438	< 0.01	0.3112	0.9636	0.00	1.0000
Eyeletting Machine 2	0.8485	< 0.01	0.6075	0.9710	0.00	1.0000
Folding Machine I_S 1	0.6206	< 0.00	0.4782	0.6792	0.00	1.0000
Folding Machine I_S 2	0.4772	< 0.00	0.3061	0.5177	0.00	0.7692
Folding Machine I_S 3	0.5386	< 0.00	0.4462	0.5876	0.00	0.8696
Folding Machine I_S 4	0.6197	< 0.00	0.4459	0.6797	0.00	1.0000
Folding Machine I_S 5	0.6191	< 0.00	0.4746	0.6765	0.00	1.0000
Labeling Operator 1	0.8276	< 0.00	0.7226	0.8531	0.00	1.0000
Labeling Operator 2	0.6358	< 0.00	0.5566	0.6511	0.00	0.7692
Labeling Operator 3	0.7187	< 0.00	0.6328	0.7352	0.00	0.8696
Labeling Operator 4	0.8261	< 0.00	0.7258	0.8507	0.00	1.0000
Labeling Operator 5	0.8255	< 0.00	0.7191	0.8437	0.00	1.0000
Lacing Operator 1	0.6641	< 0.00	0.4989	0.6893	0.00	1.0000
Lacing Operator 2	0.6629	< 0.00	0.4944	0.6898	0.00	1.0000
Lacing Operator 3	0.6626	< 0.00	0.4890	0.6831	0.00	1.0000
Lacing Operator 4	0.5263	< 0.00	0.3893	0.5440	0.00	0.7937
Lacing Operator 5	0.5523	< 0.00	0.4092	0.5712	0.00	0.8333
Lacing Operator 6	0.5097	< 0.00	0.3851	0.5263	0.00	0.7692
Marking ooperator 1	0.3193	< 0.00	0.3156	0.3230	0.00	0.9091
Marking ooperator 2	0.2744	< 0.00	0.2716	0.2779	0.00	0.7813
Marking ooperator 3	0.3511	< 0.00	0.3473	0.3557	0.00	1.0000
Marking ooperator 4	0.3509	< 0.00	0.3462	0.3574	0.00	1.0000

Piercing Machine	0.8763	< 0.00	0.6554	0.8953	0.00	1.0000
Quality Inspector 1	0.5782	< 0.00	0.4435	0.5975	0.00	1.0000
Quality Inspector 2	0.5785	< 0.00	0.4298	0.5953	0.00	1.0000
Quality Inspector 3	0.5783	< 0.00	0.4452	0.6024	0.00	1.0000
Rework Operator 1	0.9402	< 0.01	0.6406	0.9840	0.00	1.0000
Rework Operator 2	0.7690	< 0.01	0.5359	0.8178	0.00	0.8333
Rework Operator 3	0.9046	< 0.01	0.6045	0.9760	0.00	1.0000
Rework Operator 4	0.7696	< 0.01	0.4916	0.8405	0.00	0.8696
Rework Operator 5	0.8695	< 0.01	0.5222	0.9651	0.00	1.0000
Rivet Inserting Opr 1	0.7758	< 0.00	0.5781	0.7965	0.00	1.0000

Model Filename: D:\Final project\Modell\Unit 1\Stitching Model\Modell1

Page 9 of 38

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
	Rivet Inserting Opr 2	0.7749	< 0.00	0.5789	0.7957	0.00
Rivet Inserting Opr 3	0.7750	< 0.00	0.5817	0.7955	0.00	1.0000
Rivet Inserting Opr 4	0.7746	< 0.00	0.5765	0.7972	0.00	1.0000
Riveting Machine	0.6817	< 0.00	0.5092	0.6994	0.00	1.0000
Stitching Machine C_S 1	0.8427	< 0.00	0.7533	0.8457	0.00	0.8478
Stitching Machine C_S 2	0.8272	< 0.00	0.7289	0.8313	0.00	0.8333
Stitching Machine C_S 3	0.9812	< 0.01	0.3478	0.9973	0.00	1.0000
Stitching Machine C_S 4	0.7856	< 0.01	0.4503	0.7976	0.00	0.8000
Stitching Machine C_S 5	0.9913	< 0.00	0.8229	0.9966	0.00	1.0000
Stitching Machine Q_C 1	0.6578	< 0.00	0.5166	0.6625	0.00	0.6667
Stitching Machine Q_C 2	0.8226	< 0.00	0.6678	0.8276	0.00	0.8333
Stitching Machine Q_C 3	0.7583	< 0.00	0.4722	0.7638	0.00	0.7692
Stitching Machine Q_C 4	0.8206	< 0.00	0.7180	0.8271	0.00	0.8333
Stitching Machine Q_C 5	0.8954	< 0.00	0.7485	0.9023	0.00	0.9091
Stitching Machine Q_C 6	0.9876	< 0.00	0.8753	0.9913	0.00	1.0000

Stitching Machine V_Q 1	0.6525	< 0.00	0.4682	0.7032	0.00	1.0000
Stitching Machine V_Q 2	0.5037	< 0.00	0.3800	0.5387	0.00	0.7692
Stitching Machine V_Q 3	0.5534	< 0.00	0.4161	0.5908	0.00	0.8475
Stitching Machine V_Q 4	0.6522	< 0.00	0.4922	0.7114	0.00	1.0000
Stitching Machine V_Q 5	0.6464	< 0.01	0.4744	0.6912	0.00	1.0000
Stitching Machine V_T 1	0.7340	< 0.01	0.3318	0.9007	0.00	1.0000
Stitching Machine V_T 2	0.7044	< 0.01	0.2278	0.8304	0.00	0.9524
Stitching Machine V_T 3	0.6461	< 0.00	0.4743	0.7859	0.00	0.8695
Stitching Machine V_T 4	0.7431	< 0.01	0.5199	0.9073	0.00	1.0000
Trimming Machine 1	0.5830	< 0.00	0.4676	0.6508	0.00	0.8000
Trimming Machine 2	0.7271	< 0.00	0.4905	0.7902	0.00	1.0000
Trimming Machine 3	0.7260	< 0.00	0.6141	0.8158	0.00	1.0000
Trimming Machine 4	0.7263	< 0.00	0.4957	0.8193	0.00	1.0000
Tying Operator 1	0.9751	< 0.00	0.7866	0.9829	0.00	1.0000
Tying Operator 2	0.7797	< 0.00	0.6228	0.7857	0.00	0.8000
Tying Operator 3	0.9106	< 0.00	0.7347	0.9175	0.00	0.9345
Tying Operator 4	0.9738	< 0.00	0.7835	0.9812	0.00	1.0000
Zigzag Stitching Machine 1_2	0.5961	< 0.00	0.5376	0.6826	0.00	0.8475
Zigzag Stitching Machine 2_2	0.6970	< 0.00	0.5962	0.7612	0.00	1.0000
Zigzag Stitching Machine C 1	0.6911	< 0.00	0.5529	0.7901	0.00	0.9091
Zigzag Stitching Machine C 2	0.6083	< 0.00	0.4668	0.6903	0.00	0.8000

Appendix 6

Values Across All Replications

Lasting Production Line

Replications: 160 Time Units: Seconds

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Back Part Lasting MC	0.9070	< 0.02	0.2463	0.9849	0.00	1.0000
Bonding MC2	0.3690	< 0.00	0.1445	0.3784	0.00	1.0000
Bounding MC	0.5745	< 0.01	0.2135	0.6164	0.00	1.0000
Counter glue pasting op 1	0.4980	< 0.00	0.4582	0.5368	0.00	1.0000
Counter Glue Pasting Op 2	0.4969	< 0.00	0.4541	0.5352	0.00	1.0000
Counter Glue Pasting Op 3	0.6524	< 0.00	0.6159	0.6858	0.00	1.0000
De Las Op	0.2340	< 0.00	0.0913	0.2434	0.00	1.0000
De Lasting Op	0.7103	< 0.02	0.1959	0.7788	0.00	1.0000
G Pasting Op 1	0.3281	< 0.00	0.1223	0.3547	0.00	1.0000
Glu Pas In Op 1	0.6475	< 0.00	0.5990	0.6820	0.00	1.0000
Glu Pas In Op 2	0.6464	< 0.00	0.5970	0.6854	0.00	1.0000
Glue Pasting I_N Op1	0.6304	< 0.00	0.5731	0.6894	0.00	1.0000
Glue Pasting I_N Op2	0.7397	< 0.00	0.6979	0.7840	0.00	1.0000
Glue Pasting Ins 1	0.6030	< 0.00	0.3622	0.6534	0.00	1.0000
Glue Pasting Ins 2	0.6028	< 0.00	0.3634	0.6532	0.00	1.0000
Glue pasting operator_1	0.1993	< 0.00	0.1824	0.2162	0.00	1.0000

HSetting MC 1	0.9596	< 0.00	0.7591	0.9653	0.00	1.0000
HSetting MC 2	0.9612	< 0.00	0.8947	0.9650	0.00	1.0000
HSetting MC 3	0.9601	< 0.00	0.8213	0.9643	0.00	1.0000
HSetting MC 4	0.9604	< 0.00	0.8740	0.9632	0.00	1.0000
Man Ham Op	0.3349	< 0.00	0.1305	0.3477	0.00	1.0000
Manual Ham Op	0.5085	< 0.01	0.1381	0.5604	0.00	1.0000
MN glue Pas Op 1	0.07018866	< 0.00	0.02721706	0.07291176	0.00	1.0000
MN glue Pas Op 2	0.07004835	< 0.00	0.02674584	0.07289256	0.00	1.0000
MN glue Pas Op 3	0.07006498	< 0.00	0.02748037	0.07328279	0.00	1.0000
N Rem Op	0.6492	< 0.01	0.2526	0.6685	0.00	1.0000
Nail Remover Op 1	0.5059	< 0.01	0.1896	0.5435	0.00	1.0000
Nail Remover Op 2	0.5059	< 0.01	0.1879	0.5426	0.00	1.0000
Needle Tac Op 1	0.2459	< 0.00	0.2306	0.2597	0.00	1.0000
Needle Tac Op 2	0.2462	< 0.00	0.2276	0.2621	0.00	1.0000
Needle Tac Op 3	0.2456	< 0.00	0.2274	0.2628	0.00	1.0000

Model Filename: D:\Final project\Model\Unit 1\Lasting Model\Model1

Page 9 of 36

Instantaneous Utilization						
	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Pair Tying Op	0.6128	< 0.01	0.2403	0.6290	0.00	1.0000
Rou Operator	0.7592	< 0.01	0.3007	0.7812	0.00	1.0000
Roughing Op 1	0.4287	< 0.01	0.1184	0.4696	0.00	1.0000
Roughing Op 2	0.7816	< 0.02	0.2151	0.8559	0.00	1.0000
Roughing Op 3	0.3839	< 0.01	0.1043	0.4205	0.00	1.0000
Roughing Op 4	0.3836	< 0.01	0.1035	0.4200	0.00	1.0000
Roughing Op 5	0.3835	< 0.01	0.1038	0.4214	0.00	1.0000
Side Las MC	0.9477	< 0.01	0.3661	0.9594	0.00	1.0000
Side Lasting 1	0.4920	< 0.01	0.1822	0.5435	0.00	1.0000
Side Lasting 2	0.4922	< 0.01	0.1840	0.5404	0.00	1.0000
Side Lasting 3	0.4914	< 0.01	0.1812	0.5422	0.00	1.0000
T Lasting MC	0.5247	< 0.01	0.1571	0.5420	0.00	1.0000
T_C Inserting Op 1	0.9467	< 0.00	0.8835	0.9956	0.00	1.0000
T_C Inserting Op 2	0.9460	< 0.00	0.8856	0.9951	0.00	1.0000
T_C Inserting Op 3	0.9457	< 0.00	0.8792	0.9951	0.00	1.0000
T_C Pasting Op	0.4164	< 0.00	0.3884	0.4499	0.00	1.0000
Tacking MC 1	0.6870	< 0.00	0.4130	0.7436	0.00	1.0000
Toe Lasting MC	0.4230	< 0.01	0.1574	0.4527	0.00	1.0000
TyING Op 1	0.3105	< 0.01	0.08531900	0.3401	0.00	1.0000
TyING Op 2	0.3102	< 0.01	0.08444797	0.3387	0.00	1.0000
TyING Op 3	0.3098	< 0.01	0.08536037	0.3395	0.00	1.0000
U_L Glu Pas Op	0.7151	< 0.00	0.6659	0.7491	0.00	1.0000

Appendix 7

Finishing and Packing Line

Replications: 160 Time Units: Seconds

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Resource 10	0.1923	< 0.00	0.1428	0.2284	0.00	1.0000
Resource 3	0.5778	< 0.00	0.4800	0.6483	0.00	1.0000
Resource 4	0.2025	< 0.00	0.1684	0.2265	0.00	1.0000
Resource 5	0.4755	< 0.00	0.4008	0.5352	0.00	1.0000
Resource 6	0.3231	< 0.00	0.2698	0.3626	0.00	1.0000
Resource 7	0.4632	< 0.00	0.3931	0.5188	0.00	1.0000
Resource 8	0.4045	< 0.00	0.3443	0.4554	0.00	1.0000
Resource 9	0.4830	< 0.00	0.4112	0.5369	0.00	1.0000
Trimming MC 1	0.3577	< 0.00	0.3115	0.4087	0.00	1.0000
Trimming MC 2	0.3570	< 0.00	0.2637	0.4026	0.00	1.0000
Trimming MC 3	0.3555	< 0.00	0.2895	0.4072	0.00	1.0000
Trimming MC 4	0.3571	< 0.00	0.2885	0.4092	0.00	1.0000
Trimming MC 5	0.3543	< 0.00	0.2708	0.4102	0.00	1.0000
Trimming MC 6	0.3557	< 0.00	0.2952	0.4104	0.00	1.0000
Volcanizing MC 1	0.5459	< 0.00	0.4619	0.6344	0.00	1.0000
Volcanizing MC 10	0.5414	< 0.01	0.3911	0.6348	0.00	1.0000
Volcanizing MC 11	0.5441	< 0.01	0.3714	0.6423	0.00	1.0000
Volcanizing MC 12	0.5350	< 0.01	0.4176	0.6461	0.00	1.0000
Volcanizing MC 13	0.5382	< 0.01	0.2221	0.6118	0.00	1.0000
Volcanizing MC 14	0.5422	< 0.00	0.4452	0.6566	0.00	1.0000
Volcanizing MC 15	0.5418	< 0.00	0.4528	0.6421	0.00	1.0000
Volcanizing MC 16	0.5428	< 0.00	0.4533	0.6291	0.00	1.0000
Volcanizing MC 17	0.5319	< 0.01	0.2976	0.6163	0.00	1.0000
Volcanizing MC 18	0.5436	< 0.00	0.4552	0.6200	0.00	1.0000
Volcanizing MC 19	0.5430	< 0.00	0.4507	0.6160	0.00	1.0000
Volcanizing MC 2	0.5464	< 0.01	0.3213	0.6494	0.00	1.0000
Volcanizing MC 20	0.5343	< 0.01	0.3634	0.6193	0.00	1.0000
Volcanizing MC 21	0.5381	< 0.01	0.2926	0.6102	0.00	1.0000
Volcanizing MC 22	0.5403	< 0.01	0.4094	0.6196	0.00	1.0000
Volcanizing MC 23	0.5417	< 0.00	0.4591	0.6328	0.00	1.0000
Volcanizing MC 24	0.5427	< 0.00	0.4552	0.6227	0.00	1.0000
Volcanizing MC 3	0.5449	< 0.00	0.4701	0.6367	0.00	1.0000
Volcanizing MC 4	0.5407	< 0.01	0.3395	0.6319	0.00	1.0000
Volcanizing MC 5	0.5447	< 0.00	0.4586	0.6169	0.00	1.0000
Volcanizing MC 6	0.5441	< 0.00	0.4431	0.6244	0.00	1.0000
Volcanizing MC 7	0.5433	< 0.00	0.4163	0.6153	0.00	1.0000
Volcanizing MC 8	0.5455	< 0.00	0.4647	0.6222	0.00	1.0000

Model Filename: D:\Final project\Model\Unit 1\Finishing and Packing\Model1

Page 5 of 28

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Volcanizing MC 9	0.5384	< 0.01	0.3434	0.6245	0.00	1.0000

Appendix 8

Machine	Qty	Price in Birr	Total cost in Birr	Machinery Cost per year	Total Transportation cost	Transportation cost per year	Total cost per year (Birr)
Heat activation machine	2	50,000	100,000	10,000	20,627	2,063	12,063
Hydraulic cutting machine	1	122,500	122,500	12,250	25,268	2,527	14,777
Side part lasting machine	1	1,500,000	1,500,000	150,000	309,409	30,941	180,941
Heat setting machine	1	245,000	245,000	24,500	50,537	5,054	29,554
Roughing machine	2	52,500	105,000	10,500	21,659	2,166	12,666
Total				207,250	427,500	42,750	250,000

Appendix 9

Production Section	Operator	Qty	Average monthly salary (Birr)	Salary per year (Birr)
Cutting	Clicking operator	1	3,500.00	42,000.00
	Quality inspectors	3	2,500.00	90,000.00
Stitching	Arranging and tying operator	2	2,100.00	50,400.00
Lasting	Side lasting operator	1	3,000.00	36,000.00
	Heat setting operator	1	2,500.00	30,000.00
	Roughing operator	2	2,500.00	60,000.00
Fin & Packing	Overflow cutting operators	5	2,500.00	150,000.00
Total				458,400.00