



Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering (SMIE)

**Optimizing Production System Flow and Simulation for
Production Effectiveness: A Case of Lucy Garment Industry**

A Thesis Submitted to School of Graduate Studies of Addis Ababa Institute of
Technology, Addis Ababa University in Partial Fulfilment of the Degree of
Masters of Science in Industrial Engineering

By: Bezawork Alemayehu

Advisor: Dr. Gezagen T. (PHD)

Co-Advisor: Dr. Temesgen G. (PHD)

Addis Ababa, Ethiopia

October, 2023



Addis Ababa University
Addis Ababa Institute of Technology
School of Graduate Studies
School of Mechanical and Industrial Engineering
Optimizing Production System Flow and Simulation for Production
Effectiveness: A Case of Lucy Garment Industry
By: Bezawork Alemayehu

Approved by Board of Examiners:

<u>Dr. Gezahegn Tesfaye</u> Advisor	 Signature	06/12/23 Date
<u>Dr. Kassa Jilcha</u> Internal Examiner	 Signature	Dec 06/23 Date
<u>Dr. Shimelis Tilahun</u> External Examiner	 Signature	06/12/23 Date
<u>Dr. Araya Abera</u> School Dean	 Signature	06/12/23 Date
<u>Dr. Sosina Mengistu</u> Associated Director for PG Program	_____ Signature	_____ Date



ii | Page

DECLARATION

I hereby declare that the work which is being presented in this thesis entitled “Optimizing Production System Flow and Simulation for Production Effectiveness:A Case of Lucy Garment Industry” is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.



Bezawork Alemayehu

(Candidate)

06/12/23

Date

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



Dr. Gezabegn Tesfaye (Advisor)

06/12/23

Date

ACKNOWLEDGMEN

Prior to everything, glory to God who gives everything for nothing for making me start and finish my work. Then my family whose love and give special supports. In addition, of all my family, to my Mom and Dad that wanted to see me be in bigger places.

Then I would like to express my deepest gratitude to my advisor Dr. Gezahegn Tesfaye and Co-advisor Dr. Temesgen Getachew, for their unreserved support with takes time and encouragement throughout the thesis work. He gives a supportive idea and shows the ways of success of the thesis work through spent more of his time, so I would like to thank him for all his contributions.

I would also like to express my gratitude thanks to individuals who support me in data collection in case company for over three months. I would like to show my gratitude to case company Lucy Garments industry as a company and all groups, teams, individuals. I want to thank all you in all your motivation, appreciation and support you did for me during the time. specially Mr.Tarekegn Girma, Mr. kassaw Dilamo, and Mrs. Fentanesh and others from human capital management, all line supervisors who were support me in data collection, production manager, trainers, facility manager, ergonomics and human safety manager, ware house manager, finished goods manager, and all others I have great respect for you and thanks a lot.

Finally to my friends who are with me during this paper work and encouraging me, I need them and for supplying materials that I need and supporting me in editing my work. Thank you all very much.

ABSTRACT

Textile and Apparel industry is one of the priority sectors of Ethiopian manufacturing sector having a substantial contribution in GDP of the economy. Most of the apparel factories of Ethiopia are export oriented earning highly demanded foreign exchange. However, the productivity of Ethiopian garment industries is currently low, failing to meet the existing demand and supply of their products. This study focuses on the case of Lucy Garment Industry, which produces shirts and faces a significant discrepancy between expected and actual outputs. Despite high market demand, the industry struggles to achieve its target output. The objective of this research is to identify and address the factors that contribute to low productivity in the garment industry. The identified factors include unwanted movement, unbalanced operation processes, ineffective time management, low labor motivation, product loss and low output per labor. The research methodology involves the use of Arena simulation software to analyze data and propose alternatives. Additionally, Flexsim2021 employed to optimize the production arrangement flow and reduce the distance movement of workers. Excel 2010 and QM for Windows V5 utilized to implement the proposed results and present data through graphs and charts. The findings of this study indicate that by addressing the identified factors, overall productivity in Lucy Garment Industry can improved. The proposed improvements result in an increase in daily output to 474 pieces, with an efficiency rate of 79%. Moreover, the output per labor per day enhanced to 15 pieces, while unwanted movement reduced to 67.6m. The study also reveals reductions in loss (21,600 ETB per year) and ineffective time (2,175 minutes per year). Additionally, labor requirements reduced by two, and the number of IRN and SNL machines also decreased. In conclusion, this research highlights the importance of management's role in facilitating productivity improvements in the garment industry. By implementing the proposed interventions and creating favorable working conditions, companies can enhance productivity, meet customer demands, and contribute to the economic growth of the country.

Keywords: Garment industry, Productivity, Line balancing, simulation modeling

Table of Contents

ACKNOWLEDGMEN	i
ABSTRACT.....	ii
LIST OF TABLE	iv
LIST OF FIGURE.....	v
LIST OF ABBREVIATIONS.....	vi
CHAPTER ONE	1
1. INTRODUCTION AND PROBLEM JUSTIFICATION.....	1
1.1 Introduction of the study	1
1.2 Background and Justification of the study	3
1.3 Problem Statement	5
1.4 Research Questions	6
1.5 Research Objectives	6
1.5.1 General objective	6
1.5.2 Specific Objectives	6
1.6 Scope of the study	7
1.7 Significance of the Study	7
1.8 Organization of the paper.....	8
CHAPTER TWO 2. LITERATURE REVIEW	9
2.1 Introduction	9
2.2. Overview of garment manufacturing industries and challenges faced in productivity...9	
2.3 Manufacturing Productivity	11
2.4 Productivity Improvement on Garment Manufacturing.....	12
2.5 Relationship between Effectiveness and productivity	14
2.6 Major factors affect productivity of the garment industry	16
2.7 Assembly line balancing frameworks	16
2.8 Types of Assembly Line Balancing Model.....	18
2.9 Terminology Used in assembly line balancing	19
2.10 Assembly Line balancing in Garment.....	23
2.11 Modeling and Simulation in Line Balancing	25
2.12 Arena Simulation Software	27
2.13 Assembly line balancing using simulation modelling with operator skill matrix.....	28
2.14 Literature summary	30
CHAPTER THREE 3. RESEARCH METHODOLOGY AND MATERIALS.....	33
3.1 Description of the study area.....	33

3.2 Research approach.....	33
3.3 Data source and collection	34
3.3.1 Primary data.....	34
3.3.2 Secondary data.....	34
3.4 Sampling strategy	35
3.5 Tools Selection.....	37
3.6 System Modeling and Simulation	37
3.6.1 Model’s Verification.....	38
3.6.2 Model Validation	38
3.6.3 Number of Replications	38
3.7 Ethical consideration	39
3.8 Result and Discussion	39
3.9 Research Framework.....	39
CHAPTER FOUR.....	41
4. DATA PRESENTATION AND ANALYSIS	41
4.1 Data collection for Cycle time analysis.....	41
4.2 Actual SMV and target outputs	43
4.3 Data collection for distance movement analysis	45
4.4 Flow process of each operations	46
4.5 Data collection for Identification of Workers skill matrix	47
4.6 Determining number of replication	47
4.7 Model Verification and Validation	49
4.7.1 Model Verification	49
4.7.2 Model Validation	50
4.8 Data collection for bundling section	51
CHAPTER FIVE	54
5. RESULT AND DISCUSSION	54
5.1 Simulation Model Formulation	54
5.1.1 Assumptions during modeling and running.....	55
5.2 Arena Input Analyzer based analysis	57
5.3 Simulation Model Output Analysis.....	60
5.3.1 Existing System Analysis Based on Model Results	60
5.3.2 Identification of Bottleneck operations in the existing system.....	61
5.3.3 Resource utilization for existing system.....	61

5.3.4 Identification of Bottleneck Operations Based on Different Processing Status of the Existing System	65
5.4 Alternative Model Development Based on Different Scenarios	66
5.5 Development of the proposed model	73
5.6 Comparison of Existing System and Proposed System	77
5.7 New discovery from previous studied.....	79
5.8 Kanban lean tools in the bundling section for the effectiveness of the overall production process.....	80
CHAPTER SIX.....	82
6. CONCLUSION AND RECOMMENDATION.....	82
6.1 Conclusion.....	82
6.2 Recommendations	83
6.3 Future Work	84
REFERENCE.....	90
ANNEX A: I. RATING DATA FOR OPERATORS SKILL.....	95
II. WORKERS SKILL MATRIX RATING FOR ALL OPERATIONS IN (%).....	96
ANNEX B: SEWING MACHINES USED IN CASE COMPANY AND THEIR APPLICATION AREA	97
ANNEX C: DISTANCE MOVEMENT OF OPERATIONS	98
ANNEX D: STATITISTICAL OUTPUT REPORT FOR EXISTING SYSTEM ON SIMULATION MODELING	99
ANNEX E: REPORT FROM SIMULATION OUTPUT OF IMPROVED SYSTEM.....	103

LIST OF TABLE

<i>Table no.</i>	<i>Description</i>	<i>page no.</i>
<i>Table 2.1.</i>	<i>Types of allowances Summary</i>	<i>23</i>
<i>Table 2.2.</i>	<i>Literature summery</i>	<i>30</i>
<i>Table 3.1.</i>	<i>Preliminary sample for operation</i>	<i>35</i>
<i>Table 4.1</i>	<i>Operations and Cycle time of each process</i>	<i>42</i>
<i>Table 4.2.</i>	<i>Actual SMV and target output per shift of each operation</i>	<i>43</i>
<i>Table 4.3.</i>	<i>Rating of workers skill matrix's</i>	<i>47</i>
<i>Table 4.4.</i>	<i>Sample data for determining number of replications</i>	<i>48</i>
<i>Table 4.5.</i>	<i>Sample data for validation test</i>	<i>50</i>
<i>Table 4.6.</i>	<i>Inputs that entered to assembly line 2</i>	<i>53</i>
<i>Table 5.1.</i>	<i>Probability distribution of operations summary table</i>	<i>58</i>
<i>Table 5.2.</i>	<i>Existing assembly line simulations model output report</i>	<i>60</i>
<i>Table 5.3</i>	<i>Highly utilized resources</i>	<i>63</i>
<i>Table 5.4</i>	<i>Lease than 30% utilized resource</i>	<i>63</i>
<i>Table 5.5.</i>	<i>Lease than 40% utilized resource</i>	<i>64</i>
<i>Table 5.6.</i>	<i>List of bottleneck operations and their average waiting time in second</i>	<i>66</i>
<i>Table 5.7.</i>	<i>List of no waiting time operations (0.0 waiting time)</i>	<i>66</i>
<i>Table 5.8.</i>	<i>Performance measurement of scenario 1</i>	<i>68</i>
<i>Table 5.9.</i>	<i>Performance measurement of scenario 2</i>	<i>70</i>
<i>Table 5.10.</i>	<i>Performance measurement of scenario 3</i>	<i>72</i>
<i>Table 5.11.</i>	<i>Comparison of all scenarios in terms of various performance measurement</i>	<i>72</i>
<i>Table 5.12.</i>	<i>Balanced operating time by sharing of operation</i>	<i>74</i>
<i>Table 5.13.</i>	<i>Balanced the operation and reduce distance movement</i>	<i>75</i>
<i>Table 5.14.</i>	<i>Comparison of the existing and proposed assembly line</i>	<i>77</i>
<i>Table 5.15:</i>	<i>Reduced machines and worker</i>	<i>79</i>

LIST OF FIGURE

Fig.no. no.	Description	page
	<i>Figure 3.1 Research frameworks.....</i>	<i>40</i>
	<i>Figure 4.1 Operators Distance movement with time consume bar chart.....</i>	<i>45</i>
	<i>Figure 4.2 : Flow process of each operations:.....</i>	<i>46</i>
	<i>Figure 5.1 Assembly line simulation model for existing production system.....</i>	<i>56</i>
	<i>Figure 5.2. Theoretical Distribution Summary for Notch sleeves.....</i>	<i>58</i>
	<i>Figure 5.3. Graphical expressions of entities entering to the system.....</i>	<i>61</i>
	<i>Figure 5.4. Resource utilization rate for existing assembly line system.....</i>	<i>62</i>
	<i>Figure 5.5. Graphical representation for resource utilization of existing system.....</i>	<i>64</i>
	<i>Figure 5.6. Bottleneck operations based on average waiting time for existing system.....</i>	<i>65</i>
	<i>Figure 5.7. Simulation number output result for scenario 1.....</i>	<i>68</i>
	<i>Figure 5.8. Simulation output report for resource usage of scenario 1.....</i>	<i>68</i>
	<i>Figure 5.9. Simulation number output result for scenario 2.....</i>	<i>69</i>
	<i>Figure 5.10. Simulation output report for resource usage of scenario 2.....</i>	<i>69</i>
	<i>Figure 5.11. Simulation number output result for scenario 3.....</i>	<i>71</i>
	<i>Figure 5.12. Simulation output report for resource usage of scenario 3.....</i>	<i>71</i>
	<i>Figure 5.13: improved and arranged process flow.....</i>	<i>76</i>
	<i>Figure 5.14: Comparison between exist system and improved system.....</i>	<i>78</i>

LIST OF ABBREVIATIONS

GDP: Gross Domestic Product

PASDEP: Plan for Accelerated and Sustained Development to End Poverty

GPS: Global Positioning System

AGOA: African Growth and Opportunity Act

COMESA: Common Market of Eastern and Southern Africa

ILO: International Labor Organization

WIP: work in progress

PLC: private limited company

ETB: Ethiopian birr

ERP: enterprise resource planning

VSM: value stream mapping

JIT: just in time

TPM: total productivity maintenance

KPIs: key performance indicators

PMTS: predetermined motion time systems

OT: observed time

NT: normal time

BT: basic time

ST: standard time

SMV: Standard Minute Value

SAM: standard allocated minute

SNLS: single needle lockstitch

IRN: ironing machine

DNLS: Double needle lockstitch

BH: buttonhole

SNCS: single needle chain stitch machine

LBH: label button hole

CHAPTER ONE

1. INTRODUCTION AND PROBLEM JUSTIFICATION

1.1 Introduction of the study

One of the top priority industries in Ethiopia's manufacturing sector is the textile and apparel industry, which significantly boosts the country's GDP. According to Shiferaw and Affairs (2017), the majority of Ethiopia's clothing factories are export-focused and generate in-demand foreign currency [1]. Export-driven and labor-intensive industrialization are indicators of Ethiopia's industrial growth plan. In its garment sector, the nation is quickly becoming the most significant investment destination. [3]. The Ethiopian government intends to diversify exports away from agricultural products and towards important industries like the clothing and the textile industry [7]. The government of Ethiopia is focusing on the growth of the textile and apparel industry in its second Growth and Transformation Plan II [11].

Apparel is a seasonal demand; to place order with garment factories international buyer needs short production lead-time in order to meet their customer demand [4]. The apparel industry must produce momentous quantities in shorter lead times. Apparel production needs high level of productivity; production lines should be balanced to get shorter possible time and effective way for each style as well as quantity. As cited by Mazharul et al., (2015), defines assembly line productivity as how well a production system uses its resources to achieve production goals at optimal costs. The focal constraint against the higher productivity is the variation in individual capacity, which is the cause of improper line balancing which can lead to bottleneck process including increase of labor cost, work in process (WIP), cycle time and poor throughput [53].

Many researchers have reported various productivity techniques and performance measures with the aim of increasing manufacturing productivity. Some of the major techniques and methods are technology-based, employee-based task-based, product based techniques, and material-based techniques. Line balancing-is one of the task-based techniques that can increase productivity, machine utilization, material and labor utilization in manufacturing industry [52].

Assembly lines are important flow-oriented production systems, which contain serially located workstations, where operations are continuously carried out. Line balancing is the one power full task for enhancing productivity and reducing production cost of manufacturing firms and service system as well [5]. Assembly line design and structure consists of grouping and assigning a given set of tasks to a number of workstations to reduce non-value added time, labor cost, and maximize the throughput as well as improve line efficiency without violating the number of precedence constraints of tasks [6]. Critical factors in the production process were identify by recording losses of production by each factor and frequencies of occurrence in consecutives of three months of production [7] [8].

Previous assembly line balancing studies shows that application of assembly line balancing studies finding can reduce the length of production lines up to 58 percent. Flexible model for assembly line balancing simulation solves problems of competitions and globalization that creates a dynamic, changeable and uncertain global market. Application of assembly line balancing used for greater flexibility and responsiveness that creates more smooth flows in production line [12].

To handle problem of complexity and non-flexible manufacturing system problems, there are a lot of operation research tools and mechanisms, out of this tools simulation modelling is one power full tool, which used to analyze the current system and improving the production system through different scenarios.

Since productivity is the ratio of outputs produced and inputs of the production system, in order to increase productivity outputs of the production system should be increase or inputs of the production should be reduce, as cost of production. Sewing machines, operators, cycle time, fabrics and threads are the most inputs of production for garment manufacturing industries. To maximize productivity of manufacturing companies in apparel industries, productivity should be enhance in reducing inputs of production. Reducing inputs in production time side, employee side, avoiding non-value-added activities, reducing workstations, increasing machine and raw material utilizations.

In current complex and highly integrated production system, it is difficult to examine the real production lines and very expensive. Manual examinations and analysis s difficult due to many

operations which done manually. The difficulty is the rate at which the whole operations and the processing time distribution is not deterministic, process takes place, the interaction between workers and the different transition times between works makes confusion and costly to observe the real garment manufacturing system closely. In order to overcome those difficulties and for better decision-making process, simulation modelling is an easier helpful way to build up models which can be representing real production system [17]. The model assists to identify production line bottlenecks, getting insight in terms of production output, queues (waiting time and number waiting in each process), resources utilization, and simple insight for entities movement and capacity of production prediction in the future time [20].

This research focuses on garment manufacturing productivity improvement through, identification of critical factors of production and line balancing to analyze the current production line bottlenecks and propose productivity improvement alternative models that are critical factors of losses and successes based comprehensive models by taking Tal garments manufacturing plc. As case company.

1.2 Background and Justification of the study

Lucy garment industry is a private limited company, which established in Addis Ababa saris industrial zone in September 29, 2003. At present, the company is equipped with the state of art technology and diligent management team. This team has proven record of managing the production of the modern dress shirt using arrange of different models and integrating its professionals with up to date garment technology. The products of the factory are ready-made at a daily capacity of 600 pieces completed dress shirt.

Sewing section is the largest section of the floor, which covers about 65% of the total floor. From the total area of sewing section, 80% is occupied by sewing machine lines and the other 20% occupied by other machines and free space the one sewing line but the machines are arranged in four lines including special machines are found. Fusing parts performed specially for collars, cuffs, and placket in sewing section not in the cutting section.

This process will create another additional task of bundle pieces and corresponding parts, and to that, exchanges of pieces may cause problems. Since the operation breakdown and the movement

of material from operation to operation is not appropriate and therefore, backtracking is occurring. The company's production system is a progressive bundle system and it has four lines, the fourth line is special machines such as fusing and adjustment machines.

The basic option to reduce cycle time, tact time and number of work station is through developing simulation model in flexible and comprehensive variable for current and future improvement strategies like technology adoption, style change overs, operator skill matrixes, sewing machine reliability variations. In general the for higher productivity and competition in garments industry needs to become the vital few causes of lower productivity and bottleneck operations in the assembly line section of the production system [16].

Line balancing are basic problems in apparel industry. Many techniques of line balancing algorithms have applied for many years in the garment industry. However, manual-operations oriented system of this sector makes it impossible to gain certain results with the algorithms currently used, and makes it difficult to predict upcoming events when the production system modified [41]. This paper examines and determines the application of computer simulation for the design of a manufacturing process for t-shirt production. Building up models that represent actual production systems made simpler and more effective by using simulation models [38]. The model will help to locate bottlenecks in the manufacturing line and provide information on production output, queues, resource utilisation [39].

Therefore, to develop a new system, good observation is necessary. However, observing the actual production system is expensive and sometimes tedious [8]. The speed at which the entire process takes place, the interactions between workers, and the varying transition times between workers make it increasingly difficult for humans to make accurate decisions about the speed at which each operator should work. To continue the process. While maintaining productivity and output at an acceptably high level [12].

The Lucy garment industry is one of the many industries in Ethiopia that contribute significantly to the country's economic growth. However, because of a number of problems, the industry's productivity is low. This study focuses on ways to increase the case study's productivity and suggests alternative solutions.

1.3 Problem Statement

The garment industry in Ethiopia. Ethiopia has long histories in garment and textile companies starting from 1939. Even though the country has faces a multitude of challenges, including fast fashion trends, the impact of the COVID-19 pandemic, supply chain complexities, and the need for transparency in global trade and tariffs [3]. It have good opportunities of low man power cost, low cost raw material cost and low energy cost as compared with other countries, efficiency level of the sector is still slow development of 40% to 45% [5]. In Ethiopia the garment sectors resource requirement is 40% of them available in and 60% of them are import from abroad. Though the country has these opportunities, the sector production times are 45 to 60 days longer as compared with other countries [6].

Lucy Garment Industry PLC, a leading private limited garment manufacturing company in Ethiopia, specifically faces challenges within its production flow, particularly in the cutting, bundling, and sewing departments. The company grapples with an unclear flow of production, high inventory levels in the bundling section, and an excessive amount of work in progress (WIP) in the sewing line. These issues hinder the company's ability to achieve optimal productivity and efficiency, leading to delays in order delivery and potential customer dissatisfaction.

The company's reports for the years 2020, 2021, and 2022 highlight a significant gap between the expected and actual daily output. For example, while the expected output for 2022 is set at 600 pieces per day, the company only manages to produce 349 pieces per day, resulting in an overall performance rate of 58.2% (Lucy Garment Industry PLC, 2022). This discrepancy indicates a substantial loss in productivity and raises concerns about the company's ability to meet customer demands. Furthermore, the output per labor per day stands at 11.6 pieces, indicating potential inefficiencies in the production process. The company also incurs an annual loss of 74,400 ETB, which can attributed to various factors such as material waste, rework, and operational inefficiencies (Lucy Garment Industry PLC, 2022).

Meeting order delivery times is a crucial challenge for Lucy Garment Industry, as delays can have adverse effects on buyers' ability to fulfill seasonal demand, impacting both pricing and delivery schedules. Additionally, the high level of work in progress (WIP) on the production. [5].

1.4 Research Questions

The research questions derived from the identified problems of Lucy Garment Industry are as follows:

- 1) What are the major causes that affect the productivity and contributing to production losses in the current production process of Lucy Garment Industry?
- 2) Which specific operations within the bundling and sewing departments act as bottlenecks, reducing overall productivity?
- 3) How the company's utilize resource at an optimum level?
- 4) What are the strategies to reduce inventory held on bundling section?

1.5 Research Objectives

1.5.1 General objective

The general objective of this research is to improve the production flow of Lucy Garment PLC by optimizing resource utilization and reducing inefficiencies, leading to enhanced productivity and customer satisfaction.

1.5.2 Specific Objectives

- 1) To investigate the major causes that affect the productivity contributing to production losses in the current production process of Lucy Garment Industry.
- 2) To determine specific operations within the bundling and sewing departments act as bottlenecks, reducing overall productivity.
- 3) To assess the level of resource utilization and identify opportunities for improvement in resource allocation and utilization by developing alternative simulation model based on operator skill matrix.
- 4) To indicate Kanban tools procedure to reduce inventories on bundling section in Lucy Garment Industry.

1.6 Scope of the study

There is different garment industries are there in Ethiopia, but for this study, it select Lucy garment industry as a case study. The study focuses on productivity and the overall production process of the industry, and identifies the causes that affect the company's productivity. Lucy Garment Share Company is the target company that intended to benefit from the results of this research. Productivity improvement in the garment industry helps to make competitive for the global market demand by responding to the questions on market demands of high production volume with short lead-time and flexibility in sustainable way.

1.6 Limitation of the study

The parameters of the study were limited in finding critical causes, identifying bottleneck operations, and developing alternative and more verified and validated simulations based on different scenarios helps to improve the section. Due to a given period, the study is focus only on the selected case study and on a ready-made shirts product which product has high demand on the market.

1.7 Significance of the Study

Lucy Garment industry is the target company that intended to benefit from the results of this research. Productivity improvement in the garment industry helps to make competitive for the global market demand by responding to the questions on market demands of high production volume with short lead-time and flexibility in sustainable way. From this study it have an expected outcomes as a company, Factors that influence production system of the process was identified, assembly line bottleneck operations was identified, resources used effectively, WIP inventories was reduced. It gained high daily overall productivity with labour productivity and high efficiency and customer satisfaction of the company through reduced factors affect their productivity of the company. At a country level, enhance job opportunity and reduce poverty by attaining the Ethiopian government goal on poverty reduction and transfer of knowledge.

1.8 Organization of the paper

The paper is organized in six chapters. The preceding chapter is an introductory part, which contains the statement of the problem, objectives, scope, and significance of the study. Chapter two is the literature review on productivity improvement on garment manufacturing, assembly line balancing, modeling and simulation also highlights review of studies on line balancing and gap of the literature. Chapter three focuses on the methodology tool and method of data analysis and data source discussed. The fourth chapter deals with data collection and analysis as well as simulation model formulation, verification and validation. Chapter five consists result and discussion mainly on simulation model result analysis and alternative model development. Finally, the conclusion and recommendation addressed.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

Garment manufacturing use lightweight machines that are easily moved during a line changeover. The practice is to rearrange the manufacturing line depending on the style required to produce. The same machine arrangement may prevail for several years for large order quantities or it may last for a few days for very low quantities and specialized fashion tailored styles. As the fashion change rapidly, today's trend of garment industry is to move towards fast change order and fashion quantities. Hence, manufacturing lines should react fast for rapid changeovers [11].

Garment industry is one of the most labor-intensive industries where the raw textile materials, by manipulating through workstations, are converted first to semi products and then to final products. By its nature, garment industry is very similar to other product assembly industries, for instance the automotive industry. However, garment industry has its own characteristics that make it different from other industries. The big variety of raw materials with different properties is one of the characteristics that distinguish garment industry from other industries. Consequently, a high level of skills is required by the workers in order to manipulate efficiently with the machines and materials used. Furthermore, mainly manual skills are required from the workers in garment industry in the process of machine and material manipulation [53].

2.2. Overview of garment manufacturing industries and challenges faced in productivity

The government of Ethiopia intends to shift its export base away from agricultural products and toward important industries like clothing and textile production. The first garment factory built in Ethiopia in 1939, marking the beginning of a lengthy textile history [55]. According to data for Ethiopia, the textile and apparel industries have developed at an average rate of 51% during the past 5 to 6 years, and more than 65 international textile investment projects have granted licenses for foreign investors during this time [3]. As stated before, the majority of Ethiopia's garment manufacturing sectors operate in various regions with lower productivity levels and lesser

income contributions to the GDP of the entire nation. Even the sector's utilisation, which ranges from 35% to 55%, is not encouraging [2] [5]. There are a variety of factors that contribute to the poor production rate and greater bottleneck in the clothing manufacturing industry. However, balancing sewing lines without taking into account the causes does not result in balanced and long-lasting solutions for eliminating operational waste. It is imperative to create an evolving model that helps businesses to be viable and appropriate while implementing various strategies for both present and future development [18] [41] [44].

The government of Ethiopia has chosen and given particular emphasis to the textile and apparel industries in each of the country's subsequent five-year plans, especially with the introduction of PASDEP in 2005 [2] [52]. The apparel industry has begun to consider the use of modernization, a variety of engineering tools, and techniques in the production of clothing in order to increase productivity and efficiency. It also needs to concentrate on time consumption, visual management, and work standards techniques in order to improve productivity and quality [23] [36]. Determine the issues that affect productivity and quality first, and then reduce them easily accomplish both quality and production in the sewing line [55]. The clothing industries are constantly working to increase production and garment quality in order to compete in the fiercely competitive market. The productivity of the clothing business determines its long-term viability and financial success [56].

Hundreds of workers and thousands of bundles of sub-assemblies produce many styles of clothing simultaneously during the sewing process in assembly lines, which consists of a collection of workstations where a certain activity performed in a predetermined order at each station. Bundles have different issues because assembly lines do not have a one-piece flow mechanism. Because of its vital necessity, this process needs to be properly design by adopting a one-piece flow system and minimising lead-time wastes. As a result, it is necessary to design a strong sewing line balance with limited inventories in order to boost output, productivity, and product quality [8] [40].

Therefore, the purpose of sewing line assembly line balancing is to give tasks to the workstations so that the machines of the workstation can complete the assigned task with a balanced loading with diverse labour skill levels and correct assignments in accordance with their skills and machine layout [21] [19] [51].

Global production tools are one of the most crucial elements in the inventive transformation of nations and regions for developing countries, according to [20].

Due to the global production network, which serves as a direct conduit for the transfer of knowledge and technical expertise from the global level to regional structures, regions that were once considered peripheral have quickly developed into cutting-edge, innovative regions that specialise in the production of high-tech goods and the generation of scientific knowledge for improved production systems[55]. By sharing costs and financial risk with other businesses, as well as utilising a crucial component of the new global system of production and computing, global corporations' global production networks can reduce their costs and financial risk [36]. Ethiopia is among the majority of developing nations that have started participating in GPSs more actively. The percentage of emerging nations in global trade has climbed from 20% to 30% within GPSs [21].

2.3 Manufacturing Productivity

Productivity refers to how effectively and efficiently organisational resources (inputs) are put to use in order to produce goods or services for the organisation (outputs) [23] [24]. In the ready-made clothing sector, output can be interpreted as the total quantity of goods produced, whereas inputs are the labour, equipment, and industrial resources needed to produce those goods within a specific period. Lean tools are the best mechanism for these utilisations since in an ideal circumstance, input should be managed and minimised while output is maximised [35].

Enhancements to productivity can be understood on other levels [51]. Individual productivity may be demonstrated by employment rates, income rates, employment stability, job satisfaction, or employability across occupations or industries [53] [57] [62].

One of the key factors enabling industrial organisations to compete in the global market is productivity. Utilising manufacturing resources efficiently and according to methods that will lead to increased competitiveness is one of the most crucial elements that contribute to a company's ability to compete [37]. Therefore, the use of machinery and materials offers the chance to boost production while minimising the loss of labour-related elements. The sewing room is a production area in garment businesses where the majority of labourers work and the size of apparel businesses is determined by their sewing capacity. A sewing room's efficiency

and productivity also taken into account when producing clothing. As a result, studies that used to boost sewing department productivity have a significant impact on business productivity [54].

$$\mathit{productivity} = \frac{\mathit{Output}}{\mathit{Input}}$$

Before attempting to improve the current system, the present process should measure as thoroughly as possible. This is one of the core concepts of productivity improvement. One of the many metrics used to assess an organization's effectiveness is productivity [34] [39].

Labour and machine productivity are lower in emerging countries for this incorrect reason. The fashion sector is quite volatile, so if orders not fulfilled on time, there is concern of losing customers and market share. The best method to make the production system flexible is to increase labour productivity [36] [38].

2.4 Productivity Improvement on Garment Manufacturing

Productivity is how effectively and efficiently organisational resources (inputs) put to use in order to produce goods or services (outputs). In the ready-to-wear sector, "output" can be interpreted as the quantity of products produced, while "input" refers to the labour, equipment, and industrial resources needed to produce those products within a specific period. In fact, the optimal scenario calls for controlling and minimising "input" while maximising "output" [34] [35].

Higher productivity brings higher profit margin in a business and increment in productivity level reduces garment-manufacturing cost. Hence, factory can make more profit through productivity improvement. Machine productivity as well as labor productivity increases when a factory produces more pieces by the existing resources such as labor, time and machinery. Sometimes-specific problems such as machine break down, machine set up time, imbalanced line, continuous feeding to the line, quality problems, performance level and absenteeism of workers may hamper the productivity in garment industries [25].

Many researchers have reported various improvement techniques and performance measures with the aim of increasing garment manufacturing productivity.

As described by Legesse, D. (2014) lean manufacturing is a productivity improvement methodology or approach that considers the expenditure of resources on non-value-added activities to be a waste. Value-added activities are activities that are necessary to create value for the end customer. Value is defined as any activity carried out during the course of producing a product/service that the customer would be willing to pay for. Lean manufacturing is therefore focused on the elimination of all activities that do not add value to the product [19].

Another approach for productivity improvements using lean manufacturing tools is propose by Mulugeta, L. (2021) and Kitila, L. aimed to use and apply lean tools as way of improving manufacturing systems that lead to reduction of wastes and standardization of cycle time.

On another research by Balaji Rathod *et al.* (2016), they showed to improve productivity through optimization of Cycle Time by Lean Manufacturing Techniques for reduction of non-value-added activity. Furthermore, Yemane and Malfanti, *et al.* (2017) showed the Role of Productivity Improvement Tools and Techniques in the Textile Sector during manufacturing, mainly focused on time and motion study.

Sudarshan, B. *et al.* (2014) showed to improve productivity through cellular manufacturing approach that is the application of the principles of group technology in manufacturing. Cellular manufacturing helps to create a concept known as single or one-piece flow. Equipment and the workstations are arranged in sequences to allow for a smooth flow of materials and components through the process. The cell is made up of workers and the equipment required performing the steps in creating the product. The layout of the equipment and the workstations is determined by the logical sequence of production [44]. By grouping similar products into families that can be processed on the same equipment in the same sequence, cellular manufacturing offers companies the flexibility to give customers the variety they require. Factories converted to cellular manufacturing benefit by the reduction of overproduction and waste, shorter lead-time, improved quality and productivity, improved teamwork and communication [29].

Mahmut Kayar *et al.* (2014) shows application of work-study to improve the productivity through the systematic analysis of existing operations, processes, work methods and resources.

Another approach to increase productivity is line balancing. Line balancing loss is waiting time, which is caused by unbalanced or inadequate balanced production line, expressed in no. of operators. That means, periods when the operator waits for further work that is coming from workstations in the production line that works in sequential steps. If the line is balanced well, the line balancing loss should be at a minimum [26]. Perfectly balanced lines with a line balancing loss of zero operators are unusual. To find the optimum or an appropriate line balancing loss is certainly an issue companies are focusing on. Planning tools in production line balancing attract notice of an increasing number of companies. To keep the production labor costs per produced piece as low as possible, companies try to increase efficiency in worker's assignment [47].

In addition, productivity improvement can also be achieved by various techniques and methods, which consists of technology-based techniques, employee-based techniques task-based techniques, product-based techniques, and material-based techniques. Line balancing-is one of the task-based techniques that can increase productivity, machine utilization, material utilization and labor utilization in a manufacturing industry [52]. Rupali *et al.* (2013) proposed effective productivity improvement model using multi skilled labor in apparel industries.

As discussed, productivity may improve with lean, cellular manufacturing, work-study and line balancing. This research will follow the line balancing approach to improve productivity on the case factory and propose possible solutions to improve productivity

2.5 Relationship between Effectiveness and productivity

Productivity and effectiveness are related concepts. They both play essential roles in the success of an organization, but they focus on different aspects of performance. Improved Effectiveness Leads to Increased Productivity. Using the right accountability framework can turn improved effectiveness into increased productivity. Simply put, while productivity is about getting things done, effectiveness is about getting the right things done. Effectiveness is about doing the right task, completing activities and achieving goals [13].

Productivity: Productivity measures the output or results achieved in relation to the input or resources used. It often expressed as a ratio of output to input. In the context of manufacturing, it can be the number of garments produced per hour or the amount of revenue generated per employee [58].

Effectiveness: Effectiveness, on the other hand, is about accomplishing objectives and goals. It evaluates how well an organization or individual achieves the intended outcomes. In the context of garment manufacturing, effectiveness might relate to meeting production targets, delivering high-quality garments, or satisfying customer demands [57] [58].

Productivity supports effectiveness: Productivity can be a means to achieve greater effectiveness. When an organization or individual becomes more productive, they can accomplish more with the same resources or achieve the same goals with fewer resources. This can lead to increased effectiveness by optimizing resource utilization [34].

Additionally, the terms efficiency and effectiveness sometimes used interchangeably with the word productivity. Efficiency and effectiveness are two different concepts, where efficiency refers to how effectively resources put to use to achieve a goal [37] [44]. Productivity refers to how effectively and efficiently organisational resources (inputs) put to use in order to produce goods or services (outputs). In the ready-to-wear sector, "output" interpreted as the quantity of products produced, while "input" refers to the labour, equipment, and industrial resources needed to produce those products within a specific period. In fact, the optimal scenario calls for controlling and minimising "input" while maximising "output" [30] [31].

While productivity and effectiveness are related, it is crucial to strike a balance between them. Simply focusing on productivity at the expense of effectiveness can lead to producing more goods or services that do not meet customer expectations [36].

In summary, productivity and effectiveness are interconnected but distinct concepts. Productivity relates to the efficiency of resource utilization, while effectiveness pertains to the achievement of objectives and goals. Striking a balance between these two factors is crucial for the long-term success of any organization. Garment productivity depends on various factors, from planning and technology to workforce management and quality control. A holistic approach that considers all these aspects and continuously seeks improvement is essential for achieving and maintaining high levels of effectiveness in garment productivity [43].

2.6 Major factors affect productivity of the garment industry

Productivity in the garment industry influenced by various factors, ranging from internal operational aspects to external market forces and global trends. The factors that significantly influence the efficiency and effectiveness of garment manufacturing. Here are some major factors that affect the productivity of the garment industry: [58]

According to Daniel K.'s research, Ethiopian apparel manufacturing companies need to perform better overall if they want to survive the market's persistently fierce competition. The hardest part of the Ethiopian clothing sector to export is its low productivity efficiency [15].

A company's efficiency and worker absence rates have a significant impact on productivity. It must increase the productivity of the clothing industry in order to remain competitive. To do this, it must identify potential productivity factors and choose intervention areas [61]. Minimum wage, working conditions, lower production efficiency, and lower motivation are some factors that have an impact on productivity. The presence of inadequate management and unsafe working conditions is the main factor affecting productivity, particularly in the Ethiopian garment sector [55] [62].

The apparel industry began considering how modernization, diverse technical tools, and procedures applied to the production of clothing to increase its productivity and efficiency. The industry needs to operate more competently and efficiently if it is to survive in this cutthroat environment [55]. Long-term economic growth and improved living standards ultimately driven by improving productivity growth [33].

2.7 Assembly line balancing frameworks

Industrial engineering departments frequently use line-balancing difficulties in their work, and the garment sector has been using various line balancing algorithms for a long time [62]. Production managers in the garment sector sometimes struggle with the problem of not being able to finish the orders by the deadline [55]. The lack of a Line Balancing mechanism that could take into account the stochastic nature of the sewing process, which reflected through things like variations in stitching timings, is one of the causes of this problem [43].

Assembly lines are production systems developed to meet the requirements of humankind, which continue to grow day by day. The demand for greater product variability and shorter life cycles has caused traditional production methods to be replaced with assembly lines. The aims of these systems are to manufacture products at higher production rates in the shortest time, in the most productive way, cheaply and with the quality required.

In 1913, Henry Ford completely changed the general concept of assembly by introducing Assembly Lines in automobile manufacturing for the first time. He was the first to introduce a moving belt in a factory, where the workers were able to build the famous Model-T cars, one piece at a time instead of one car at a time. Since then, the Assembly Lines concept revolutionized the way products were made while reducing the cost of production. Over the years, the design of efficient ALs received considerable attention from both companies and academicians. It had been found from ‘that a well-known assembly design problem is assembly line balancing (ALB), which deals with the allocation of the tasks among workstations so that a given objective function is optimized’. ALB has been a focus of interest to academics in operation management for the last decades.

Swapnil (2014) stated that the good assembly line is the line that has high value of line efficiency. Line efficiency can be defined as the percentage of good parts at the end of the line versus the theoretical number that the line should produce in a given time period. Time periods for averaging are determined by the goal of the production. To achieve 100%-line efficiency, one station must never be blocked or starved, and the station must always operate at its theoretical capability. The higher outputs of the line can be considered as the efficient line because the line can produce higher outputs in the specific production time [47].

Line balancing can be defined as the process of assigning tasks to workstations in such a way that the workstation has approximately equal time requirement. The tasks that assign to each workstation must fulfill the equal time requirement. In other words, the workloads at each workstation must be the same and the time consume during the assembly process is also equal at each workstation [49].

2.8 Types of Assembly Line Balancing Model

An assembly line can be classed into three categories based on numbers of models assembled on the line and according to the line step.

1. Single-model assembly lines

This model has used in single line or model production systems. There is large amount of the products in this type, which have the same physical design on the line and operators who work at a workstation execute the same amount of work when a sequence of products goes past them at a constant speed of operations [48].

2. Mixed-model assembly lines

This line models usually used to assemble two or more than two products simultaneously. The assembly line in which worker do in different models of a product in the same assembly line called mixed assembly line [49].

3. Multi-model assembly lines

In this model, the uniformity of the assembled products and the production method is not that much enough to accept the enabling of the product and the production levels in the system. To minimize resources or inputs this model is arranged in batches and this allows the short-term lot-sizing issues which made in groups of the models to batches and the result will be on the assembly levels [9] [16].

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

line balance, the setup times might be reduced considerably, which in turn allows for a formation of smaller lots with all associated advantages.

2.9 Terminology Used in assembly line balancing

Time Study in garment manufacturing

The garment industry, which also includes method study and work measurement, is able to apply work-study in both time study and motion study, just like other manufacturing industries. Time study is a method of measuring the amount of work done that involves timing a given operation or its components as they completed under predetermined conditions and then analysing the results to determine how much time is required for an operator [21]. The most popular techniques for measuring work include stopwatch time studies; historical time studies, predetermined motion time systems (PMTS), and work sampling. One of the most popular methods of job measurement in the system for particular activities is time study using a stopwatch. Time analysis results in the creation of work standards for improved working system management [45]. Calculating three times, such as observed time (OT), normal time (NT) or basic time (BT), and standard time (ST), is part of the time research process [43].

Cycle time

Alireza *et al.*, (2011) stated that the area within a workplace equipped with special operators and/or machines for accomplishing tasks is called workstation. Cycle time is the time between the completion times of two consecutive units/workstations. Cycle time also defined as how frequently a finished product comes out of production facility [33]. Cycle time shows how often the production line can produce the product with current resources and staffing. It is an accurate indicator to represent of how the line is currently set up to run.

According to Swapani (2014), Task time and cycle time are definitely not the same. Task time represents the maximum time allowed to meet the customer demand whereas cycle time is the actual time necessary for an operator to perform an activity or complete one cycle of his process. Both task time and cycle time are determined by customer demand.

To meet customer demand or monitor productivity the cycle time and takt time should be balanced in parallel. The higher cycle time than takt, time may result the late delivery and customer dissatisfaction whereas shorter cycle time than takt time may cause the excess inventory or excess use of resource [44].

Cycle time also known as observed time is defined as the time duration from starting point of a job to the starting point of the next job. This time is established from the observation data of an operator while working at a certain pace.

Workstation

A workstation is a physical area where a worker with tools, a worker with one or more machines, or an unattended machine performs particular sets of work together. Number of workstations working is the amount of work to be done at a work center expressed in number of workstations.

Minimum number of workstations is the least number of workstations that can provide the required production. Actual number of workstations is the total number of workstations required on the entire production line, calculated as next integer value of the number of workstations working [49].

Minimum number of workstations can be calculated by total task Duration time (the time it takes to make the product) divided by the cycle time. Fractions are rounded to the next higher whole number [45].

Tact time

According to Pekin (2006), manufacturing a product on assembly lines requires dividing the total work into a set of elementary operations. A task is the smallest, indivisible work element of the total work content. Task time or processing time is the necessary time to perform a task by any specific equipment. It shows also how fast the need to manufacture product in order to fill the customer orders. Same or different equipment might be required to produce the tasks. Producing faster than task time results in over-production that is a type of waste whereas producing slower than task time results in bottlenecks where the customer orders may not be filled in time [47].

Bottleneck

Bottleneck is a delayed time in the transmission of materials that slow down the production rate to much extent. It is the slowest or least efficient part of the process, preventing the system from operating at a higher capacity or speed. Bottleneck represents a constraint or limitation within a process, operation, or system that restricts its ability to handle a higher volume of work [20]. This constraint could be a machine, a worker, a resource, or any other element that determines the pace of the process. It directly affect the throughput or the rate at which products, services, or information can produced, delivered, or processed. The output of the entire system limited by the capacity of the bottleneck [56].

Lead Time

In apparel industry, lead time is the total amount of time required for completing a product beginning from the date of receiving the order to the shipment of the goods to customer. Time is a great issue in apparel trade as orders are based on weather, seasons and occasions. Lead time carries huge importance when delivering the products to the respective outlets is concerned [46].

According to Nahom (2011), manufacturing lead time (MLT) of a product is the total time required to process the product through the manufacturing plant. The total lead time (TLT) of a product is the total time elapsed from the instant at which raw materials are ordered until the instant the finished product is delivered. Total lead-time is made up of time devoted to processing orders, procuring and manufacturing items, and transporting items between the various stages of the supply chain [32].

Standard Minute Value (SMV)

SMV is the allotted amount of time for a worker (operator) to finish a task. The time value determined for a task known as SMV or occasionally as SAM (Standard Allocated Minute). Based on the typical output rate that skilled workers will normally reach without exerting themselves excessively. As long as they are motivated to put effort into their task, are aware of and follow the prescribed procedure [23].

Allowance

In garment production, "allowance" typically refers to the intentional addition of extra dimensions or measurements to a clothing pattern or garment during the design and cutting stages. These allowances are included to accommodate factors such as ease of movement, fit preferences, sewing margins, and shrinkage allowances. The specific types of allowances used in garment production can vary depending on the type of garment, its intended use, and the design considerations [32]

A worker cannot and does not work continuously throughout her full working hours in garment industry. Different action are there like bundle, tie it up, go to lavatory, take out bobbin case, replace a blunt needle, talk to the supervisor or line inspector, a small rest to recover from fatigue, etc. and it cannot avoid doing all these things, because they are beyond her control [34].

There are different types of allowances in industrial engineering, namely

a. Relaxation allowance:

It is the time allowed to an operator to attend to personal needs and to recover from fatigue. Fatigue is a mental or physical exhaustion developed in a worker due to continuous work. It assumed that a small rest or pause in work lessens fatigue and as a result, the person is re-energized.

b. Contingency allowance:

There are some factories, which encounter frequent minor interruptions. They cover them by a contingency allowance.

c. Machine Delay Allowance:

This is the time allowed for delay due to machine maintenance. Allowance time varies with the complexity of the machine. Some typical machine delay allowances shown below for reference

d. Style Change Allowance:

Allowance time permitted where frequent style changes occur.

e. Special allowance:

Sometimes, special time given as start time allowance, shut down allowance, cleaning allowance, etc. because time wasted at start time or change of work shift. These times covered by special allowance.

In the garment industry, this type of time allowed to operators for some unavoidable but non-performing task called allowance and the time ranges from 15-25 %, allowance time taken into account during setting up of Standard Time [35].

Table 2.1. Types of allowances Summary

Situation	Nature of allowance (avoidable or unavoidable)	Reasoning for avoidable or unavoidable allowance
personal and fatigue	Unavoidable	One has to attend such needs, and control them with improved working conditions and better methods
Machine breakdowns	Both	Machine breakdowns for new machine should be under avoidable allowance but for a factory with very old machines such as breakdown maybe considered as unavoidable allowance. Changing of broken needle should come under unavoidable allowance category but may controlled by using the correct needle to the correct material and an improving machine handling.
Contingency allowance	Avoidable	Situations such as writing recording the production figures, updating the supervisor, reporting the quality related matters or machine maintenance related issues with the concerned person, picking up and arranging the fallen bundles or trimmers, waiting for materials to be stitched from the previous work station, or waiting for the correct sewing trims are avoidable or significantly controllable. Situation that required contingency allowance might eliminated with an effective intervention on method improvement, workplace improvement, and effective real time monitoring, improved technology interface.

2.10 Assembly Line balancing in Garment

Garment manufacturing in its nature is complicated; it involves a number of machines, hundreds of employees and thousands of bundles of sub-assemblies producing different styles simultaneously. In the apparel industry, assembly lines are widely adopted for mass production. The design of the bundle assembly line is one important issue for efficient production. It consists of assigning and balancing tasks between workstations of an assembly line in order to minimize balance delay, labor force and ultimately minimizing the total production cost [40].

Different literatures have been reviewed to gain insight about line balancing in garment industries.

According to Wickramasekara, A *et al.* (2016), the fundamental line-balancing problem is how to assign a set of tasks to an ordered set of workstations, such that the precedence relations and some performance measures (minimizing the number of workstations, cycle time and idle time) are satisfied. Hence, Bongomin *et al.* (2020) provides two main goals while balancing an assembly line which are minimization of the number of workstations for a given cycle time and minimization of the cycle time for a given number of workstations.

Mulugeta, N. (2011), discussed specific example for sequential decision problem for real time optimal line balancing control in apparel industry. The change of operator efficiency during real time production is the main reason that causes production line imbalance and thus the adjustment of operator allocation is required.

Hanan, et al., (2019). the varying skill of operatives and stochastic task time were considered for assembly line balancing in the clothing industry. As a result, the actual time for the completion of each task varies between different operatives and such variations exist at the same task repeatedly performed by the same operative.

Rahman H *et al.*, (2014), in most apparel enterprises, the estimation of production time for each task is by reference to Standard Minute Value (SMV). The characteristic of SMV is deterministic in nature, derived from the method of work study. However, it cannot reflect the real production environment because many factors such as the properties of fabric and sub-materials, performance of machinery, working environment and quality level of the product may cause variations on the task time. Such variations on task time cause the assembly line balancing problem in the clothing industry to become more complicated. Time variation between each task becomes important for the assembly line balancing. In the apparel industry, it is essential to form a new production line for each order, and the number of workers is changed according to the complexity of the order, the number of operations, throughput [54].

Jadhav *et al.*, (2017). reported that, since sewing department involves tedious manual labor, the process often resulted in a high cycle time and low yields, sewing department contribute a lot of problem in garment manufacturing company. There are many different operations done manually

and sewing operations needs high skill as well as quality work, especially when handling the difficulty associated with repairing of products sewed with wrong specifications.

Different researches also noted that, line-balancing problems in sewing department is most popular operational issue in apparel or garment industry.

According to Islam, *et al.*, (2015) study line balancing in garment industry deals with allocating the resources such as workers and machinery to the assembly line so that the precedence relation is satisfied and the sum of task at any workstation does not exceed cycle time. Simulation has been a preferred tool to evaluate the performance of garment production line as it has the ability to model dynamic and stochastic nature of production systems. It enables the researcher to gain a critical insight into the performance of a manufacturing company.

In garment industries, to examine a real manufacturing system is very expensive and sometimes cumbersome. Therefore, a simulation model is an easier way to build up models to represent real life scenarios, to identify bottlenecks, to enhance system performance in terms of productivity, queues, resources utilization, and the like.

According to Yemane, *et al.* (2020), with recent advances in computing and software technology, simulation tools are now available to help meet the challenge of quickly designing and implementing complex manufacturing systems that are capable of meeting growing demands for quality, delivery, affordability and service.

Simulation and modeling allow management to study the dynamics of the business and to consider the effects of changes without risk. With simulation models, we can explore how an existing system might perform if altered, or how a new system might behave before the prototype is even completed, thus saving on costs [17].

2.11 Modeling and Simulation in Line Balancing

Process modeling and simulation are modeling techniques available to support companies in gaining a better understanding of their manufacturing system behaviors and processes and therefore helping them in decision-making. Process modeling provides management with a static structural approach to business improvement, providing a holistic perspective on how the business operates, and provides a means of documenting the business processes. It also allows

management to study the dynamics of the business and to consider the effects of changes without risk [38].

Tesfaye B. (2019) stated that simulation models allow to test potential changes in an existing system without disturbing it or to evaluate the design of a new system without building it. Simulation early in the design cycle is important, because the cost to repair mistakes increases dramatically the later in the product life cycle the error is detected. This methodology also allows comparing new concepts, equipment's or scenarios before purchasing. For some purpose, simulations are better than the analysis of real data. With real data, it is never possible to perfectly know the real-world process that caused a particular measured situation, because of the too complex interactions inherent in large systems.

Simulation is one of several alternative methods of analyzing systems. Another technique is the use of mathematical analysis. Analytical modeling involves building a system description using some formal, mathematical notation. Unfortunately, mathematical analysis is limited to a relatively small number of simple systems and the opportunity to represent manufacturing systems in this way is felt to be limited [54].

Based on state of the system simulation can be categorized as using either a continuous or discrete time representation. Systems may have discrete or continuous state. In some systems, the state changes all the time, not just at the time of some discrete events. To represent the changes in the system, it is only necessary to describe the actions or events that cause the status of the system to change. This is referred to as discrete event system modeling. Discrete event simulation has applications in a wide range of sectors including automotive, healthcare, defense, electronics, pharmaceuticals, food and beverages, packaging, construction, footwear manufacturing and logistics [39].

Manufacturing, industrial and service sectors have been the most common fields of simulation applications. Simulation in general is to pretend that one deals with a real thing while really working with an imitation. The imitation is a computer model of the simulated reality. It is very costly, dangerous and often impossible to make experiments with real systems. So that models

are very important to describe reality, experimenting with them can save money, suffering and even time. This is done by developing a simulation model of the system.

In general, simulation is a practical methodology for understanding the high-level dynamics of a complex manufacturing system. Simulation has several strengths including: (Alula, 2013)

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

Modern manufacturing is characterized by high levels of automation and integration, complex interactions among system elements, and high capital costs. While modeling and analysis are important to help ensure good system performance, the integration and complexity of systems often makes purely analytic tools difficult to use. Hence, simulation remains one of the most widely used tools to fill this need.

2.12 Arena Simulation Software

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

Arena allows the interactions with other computer tools such as Visual Basic and Excel while integrating very well with Windows environment [27].

Computer simulation modeling has been applied to manufacturing industry since the late 1960's when IBM introduced its General-Purpose Systems Simulator (GPSS) package. Simulation found to be a very useful means of analyzing the dynamics of materials flow through a manufacturing plant, for example, to:

- Identify current or potential bottlenecks and their impact on profitability.
- Examine effects of changing resource capacity (e.g. adding or subtracting operators or units of equipment, working additional shifts and purchasing extra machine)
- Analyze effects of different batch sizing policies on inventory levels, throughput and lead times.
- Examine effects of random equipment breakdowns and the potential impact of different maintenance strategies.
- Analyze the relative impact on material flow velocity of reducing process variability in alternative targeted areas.
- Check on the overall ability of the plant to respond to different assumed rates of demand increase, and identification of what resources will be the first to come under pressure [53].

2.13 Assembly line balancing using simulation modelling with operator skill matrix.

Assembly line balance models should implement with complete identification of critical factors production and operations skills matrix. Most assembly line balancing problems have been resolved on how to assign operators to workstations to reduce operational bottlenecks and make the production system smooth and immediately [14]. According to the report of the industrial park, operator turnover and absenteeism are major. To develop simulation models of evolving assembly lines, an updatable operator skills matrix and identification of critical production factors is required modeling assignment [17].

A skills matrix is a visual framework that used to assess and map the skill and competency levels of employees. It offers a thorough grid that records information on the abilities needed for

efficient management, planning, and monitoring at various levels. As a result, team leads and line managers can make better decisions and allocate resources since they have a comprehensive understanding of the skill sets inside their teams [23].

You can use a skills matrix to better understand the skills on your team, assess how they will interact, and identify any gaps before the team meeting. This article will examine the value of skills matrices for organizations and provide a systematic tutorial for making your own as well as a ready-to-use template [21].

Project managers can determine whether their team has the essential abilities to finish a project by using a skills matrix. The matrix provides you with a fast overview of the abilities you have available and indicates whether you need to hire more people. Advantages of employing a skills matrix [23].

From some literatures gather the benefits of an operator skill matrix for had better understand tasks and requirements: With a skills matrix, company leaders and supervisors can easily understand exactly what skills and competencies needed to perform a certain activity [23].

- It records every operation; an operator has ever performed as well as their level of productivity in each one.
- Finding and choosing the most effective operators for an operation from the pull of operators takes engineers and line supervisors the least amount of time.
- Operators for line balancing can choose based on the nature of the operation. Engineers can choose an operator whose efficiency level is 50% of that operation, for instance, if the operation requires 50% less time than the pitch time.
- The skill matrix provides information on which operations should supplied to an operator when operation clubbing is necessary (for lower work content works).
- A supervisor can quickly replace an absent employee by selecting a qualified candidate from the skill matrix table [46].

The skills matrix can create as a spreadsheet. Real-time shop floor data tracking systems can also use to develop skills matrices. In the skills matrix, users can sort the performance of operators in

different activities and alternatively, in an activity, how many operators worked and how effective they were [21] [23] [53] [54].

2.14 Literature summary

To gain insights and examine the gaps in their productivity development strategies, many related literatures were analyzed the focus was mostly on line balancing in the clothing manufacturing industry. The most recent literature has evaluated from a variety of publications, articles, and thesis

Table 2.2. Literature summery

Author	Title	Methodology	Findings and solution
Yamane, <i>et al.</i> , (2020)	Productivity Improvement through Line Balancing by Using Simulation Modeling	gathering information about the number of operators, processing times for individual operations, and the order of jobs to be assigned to workstations using simulation	increasing the assembly line's productivity from 42% to 58.42% without increasing the cost of the machines and the workers
Mahmut Kayar <i>et al.</i> (2014)	A research on the effect of method study on production volume and assembly Line efficiency	Method study and assembly line balancing using Ranked Positional Weight	The effect of method study on production volume and assembly line efficiency analyzed. Author concludes that there isn't another method that are used within gaining higher productivity, reduction of costs by using present resources.
Tesfaye Bayeh (2019)	Productivity Improvement through Line Balancing: Case Study of Nazareth Garment SC	Time study data collected from the real system export production line. Data analysis accomplished with arena input analyzer to develop a simulation model	The total output of the preparatory line increased from 238 to 280 pcs per day and that of the assembly line increased from 253 to 275 pcs per day.
(Mengistu M., 2019)	Line Balancing Techniques for	Combination of large candidate and ranking	To reduce costs and increase productivity

	Productivity Improvement.	positional weight methods.	Cycle Time not comprised. Decrease in non-value-added activity.
Bongomin, <i>et al.</i> , (2020)	Improvement of garment assembly line efficiency using line balancing technique	Assembly line balancing techniques	Study its applicability in two-line balancing scenarios (while ignoring the operators' skill levels and important variables influencing the production system).
(Shumon, M. R. H., Arif-Uz-Zaman, K., Rahman, A., & Khulna, B., 2019)	Productivity Improvement through Line Balancing by Using Simulation Modelling	merging manual line balancing methods with computer simulation model	Increasing number of throughput per day labor output per day
Moktadir, <i>et al.</i> , (2017)	Productivity improvement by work study technique:	develop flexible and adjustable assembly line balance and mixed integer linear optimization	Designed a multi-objective optimization model to lower production costs.
Mazharul <i>et al.</i> (2015)	Line Balancing for Improving Apparel Production by Operator Skill Matrix	Operator Skill Matrix	Maximum utilization of manpower in labor intensive assembly lines, by delegating workers to various operations based on their skill. The study not focusing giving training and enhancing operator skills.
Islam, <i>et al.</i> , (2015)	Line Balancing for Improving Apparel Production by Operator Skill Matrix	Operator Skill Matrix: Sewing line operators may possess a variety of talents, thus employers must be aware of this information.	Maximizing the use of labor in assembly lines that need a lot of manual effort by assigning people to different tasks according to their abilities.
Wickramasekara, <i>et al.</i> , (2016)	An improved approach to line balancing for garment manufacturing	Processing time	The gap between target and achieved is reduced.

Reviewed literature gaps summarized as below:

- Most of reviewed studies were not analyzed Critical production factors, and the developed model does not fully consider operator skill matrix.
- Most of the reviewed literatures not considered productivity improvement by simultaneously improving the lead-time through line balancing.
- Most of the researches used arena simulation software focused on basic simple products like T shirts instead of complicated products. Complicated process, takes longer processing time, uses more number of resource and operations.
- On their improvement proposal the researches mainly focused on giving training as priority solution which may lead to additional cost to implement instead of finding possible alternatives first with the existing resource and skills.
- Examine its applicability under two-line balancing scenarios (without considering skill level of operators and critical factors affecting the production system).

The high-level dynamics of a complex manufacturing system may generally be understood using simulation, which is both a practical and theoretical tool [10]. Simulation offers several advantages, Researchers have worked to create computer-based algorithms for line balancing problem simplification and optimization throughout the years [14] [17]. Many manufacturing organizations have also used simulations of real production systems to design new systems, develop, implement, and assess problems with those systems [10]. Computer simulation, as defined, is the act of creating a model of a real system and running tests on it in order to learn how the system behaves and assess various operating system techniques [24] [37].

CHAPTER THREE

3. RESEARCH METHODOLOGY AND MATERIALS

It is important to identify and understand the research approaches to be undertaken because it influences the research instruments to be employed and the ultimate goal of the thesis. In addition, the selection should be based on the problem of interest, resources available, skills & training of the researcher, and the audience for the research. Integration of the following methods are used to achieve the objectives of this research.

3.1 Description of the study area

The study was focused on Lucy garment industry PLC is one of the leading private limited garment manufacturing companies in Ethiopia which began its operation in Addis Ababa, saris industrial zone in September 2011.

It is a specialized garment manufacturing company producing men's and women's formal dress shirt as well as occasional shirts with a view of satisfying both the international and local markets. This study is focus on the productivity of the Lucy garment business, which means that it will identify the case study's current productivity as well as the elements that influence the company's total productivity. Improve those elements to raise the company's daily output, labour productivity, and overall efficiency.

3.2 Research approach

With the aid of this research methodology, it is able to gather data and information about the real-world issues facing the current scenario, explain the fundamental ideas affecting productivity and the elements that affect it, and provide an alternative solution to the issue affecting the company's productivity.

The primary sources of the data used in this study were interview and observations and secondary sources included books, magazines, websites of companies, etc. In order to better understand the operational process, factors influencing productivity, and strategies for increasing productivity, the research used both quantitative and qualitative research approaches.

3.3 Data source and collection

For the sake of conducting this study, primary and secondary data collected. Direct observation and interview from the part of the primary data session and various literatures and documents surveyed from different sources such as the internet, books and the company profile documents as a part of secondary data and then the collected data are organized and analysed.

3.3.1 Primary data

Required data: critical factors of production and effects they have on actual output, skills each operator have in order to develop operator skill matrix, the number of sewing lines, number of operators, kinds of current layout, number of work station, processing time, activity precedence, production capacity and etc.

Methods:-

- Observation: while observing the sewing lines with unlimited WIP and unclear flow of the production.
- Interview: by interviewing some interviewees, like the line supervisors head and line supervisors about how to visualize the workflow and limit WIP in the sewing line

Tools used: Stop watch, camera, distance measuring instruments, different type of sheets for production and other information recording.

Data source: Case Company Statistical tools: Histograms, excel sheets, arena input analyser, cause and effect diagram using

Individuals participating in data collection and analysis: Researcher, line supervisors, production managers and others.

3.3.2 Secondary data

Literature survey: - A literature review is being to conduct, evaluate, develop, and identify gaps in the existing research on Ethiopia's arena simulation assembly line balance of the clothing manufacturing industries. To find the best tools, techniques, and methods for achieving the research's ultimate goals, surveys of the literature from reputable journal articles, company

reports from the same case companies, books, conference proceedings, dissertations, websites, and internet books conducted.

Required data: Production capacity, target output, line layout, general stitch data (GSD), number of shifts, production plans.

Strategies: Survey of Previous Company records, published articles, international standards, daily reports and other website references

Source of data: Different journals, report papers and case company

Statistical tools: Histograms, Excel sheets, Arena input analyser

Participant: researcher

3.4 Sampling strategy

For this paper, samples of different type taken to collect both primary and secondary data under the consideration of determining the proper number of samples for better decision-making process [50]. For this research available sampling technique was used to determine the number of observations (cycle time) required and to collect data. Some researchers like (Tesfaye Beyene, 2019), (Daniel and Ajit, 2014) used to determine the number of observations (cycle time) required for data collection five preliminary samples were considered. For operation iron, upper and lower sleeve placket was selected. Five preliminary sample observation was recorded using stopwatch.

Table 3.1. Preliminary sample for operation

Observations	Processing time in seconds (x)
1	22
2	24
3	29
4	30
5	26
Sample mean (\bar{X})	26.2
Sample std. dev (S)	3.34
Number of observations required (N)	10.304

Sample standard deviation calculated using below equations

$$S = \sqrt{\frac{\sum_{i=1}^n (X-x)^2}{n-1}} \dots \dots \dots equ(3.1)$$

$$N = \left(\frac{zS}{hx}\right)^2 \dots \dots \dots equ(3.2)$$

Where:

N = the number of observations or required for analysis

n = preliminary samples,

x = observations recorded with stopwatch in second

\bar{x} = mean of initial preliminary sample,

s = standard deviation

h = half the precision interval in percent,

z = normal standard deviations needed for desired confidence level.

In probability and statistics, the 97.5th percentile points of the standard normal distribution are a number commonly used for statistical calculations. The approximate value of this number is 1.96, meaning that 95% of the area under a normal curve lies within approximately 1.96 standard deviations of the mean. Because of the central, limit theorem, this number used in the construction of approximate 95% confidence intervals. Its ubiquity is due to the arbitrary but common convention of using confidence intervals with 95% probability in science and frequentist statistics are sometimes used [10] [24].

The use of this number in applied statistics can traced to the influence of Ronald Fisher's classic textbook, *Statistical Methods for Research Workers*, first published in 1925. "The value for which P = .05, or 1 in 20, is 1.96 or nearly 2, it is convenient to take this point as a limit in judging whether a deviation is to be considered significant or not." The commonly used approximate value of 1.96 is therefore accurate to better than one part in 50,000, which is more than adequate for applied work. Some people even use the value of two in the place of 1.96, reporting a 95.4% confidence interval as a 95% confidence interval [10].

The corresponding value of normal standard deviation and half the precision interval known to be 2.0 and 0.1 respectively. We can determine the number of observations required for the processing time distribution of each operation to be 10.304, which is approximately 10 observations.

3.5 Tools Selection

It becomes increasingly challenging a human to decide how quickly each operator should work in order to continue the process while maintaining high productivity and an acceptable level of throughput due to the rapid rate at which the entire process occurs, the interaction between workers, and the various transition times between workers. In light of this, creating simulation models is a simpler method to depict real-world scenarios, identify bottlenecks, and improve system performance in terms of productivity, queues, resources, cycle times, and lead times. High mix, low volume production systems can be flexible because of a re-configurable assembly line, helping them keep up with rising consumer demand.

For a sake of this paper Arena, simulation software selected as a primary tool. Arena simulation volume 14.0 used for examining the existing system performance of the case company and application of productivity improvement scenarios in different ways. In addition to this data analysis methods perceived in this research works was via on MS-Excel, cause and effect diagram and also show the result of the analyse data by different graphs with QM for Windows V5 for schedule and basic requirement activities in the implementation of the study and Kanban tools for control bundling inventory held in bundling section.

At the end interpret the result through graph and comparison their values and depend on identified result and the problems it was proposed possible solutions.

3.6 System Modeling and Simulation

It is appropriate to use simulation in order to simplify real life situations. Based on the data analysis of the existing system, simulation will be performed, and then different proposed models will be developed and measured for their performance by selecting and using suitable simulation tool. Finally, by considering different scenarios and alternative solutions will then be proposed.

It is reasonable to employ simulation to streamline operation procedures in the apparel industry. After performing a data analysis of the current system for the case company simulation, many proposed models created and their performance evaluated. Utilising simulation software Rockwell Arena® version 14.0, the simulation model created for processing and running with various scenarios.

3.6.1 Model's Verification

Verification is the process to make sure that the simulation model accurately and appropriately implemented in relation to the conceptual model. Practically verification entails sorting out the simulation model, which can accomplish using a variety of tools, such as animation by running the model. Further, verify the simulation model, trial runs were made under various settings of the input parameters, and will check the model output results for suitability. To verify simulation model trial runs prepared under different settings of the inputs by varying the arrival times. The animation of the processes observed to verify that each process path correct.

3.6.2 Model Validation

The validation process will proceed when the model verified. To demonstrate that the suggested model has an adequate level of confidence in the processing performances assumed, validation is required. The goal of validation is to show that the model accurately represents the real system.

The validation of a simulation model can divided into two categories. The model should at least superficially reflect reality, according to the first criteria, which is face validity. Statistics-based validity is the second. A quantitative comparison of the output performances of the real system and the model is necessary for statistical validity [24]. The model regarded as valid if there is no statistically significant difference between the data sets. If there is a statistically significant difference, on the other hand, the model is invalid and requires more work before additional analysis can do.

3.6.3 Number of Replications

Replication number is number of simulation runs that should achieved to analyze statistically the differences between the simulation model and the existing system to increase the output reliability. The output result becomes more accurate by doing more replication thereby we can

estimate the error we introduce in modeling the existing system. It has an integer value greater or equal to one [10]. The replication analysis process begins with selecting an initial number of replications. Summary statistics from this initial set of replication then used to calculate whether additional replication is required at a particular level of confidence. A common number of initial replications are ten. This provides a sufficient number of replications to have reasonable statistical confidence given that additional replications can always be subsequently added [10] [24].

3.7 Ethical consideration

Different population has different culture, custom, religion and others and it needs to respect during the study. Especially during the study processed and collecting data it needs consideration and respect the rule of the company.

Generally, after examining the existing system performance by experimentation arrangement of the process and simulation runs, alternative models were developed. At the end analysis conclusion, recommendation and future works were driven.

3.8 Result and Discussion

After experimentation and analysis done on the model, an improved model is developed. Finally, conclusions will draw from the analysis made and then recommendations based on those concluded points.

3.9 Research Framework

The initial step involves defining the goals of the study and determine what needs to be solved. The problem is further defined through objective observations of the process to be studied. Care should be taken to determine if simulation is the appropriate tool for the problem under investigation. Understanding how the actual system behaves and determining the basic requirements of the model are necessary in developing the right model. Creating a flow chart of how the system operates facilitates the understanding of what variables are involved and how these variables interact. After formulating the model, the type of data to collect is determined. New data is collected and/or existing data is gathered.

Verification is the process of ensuring that the model behaves as intended, usually by debugging or through animation. Validation can be achieved through statistical analysis. Additionally, face validity may be obtained by having the model reviewed and supported by an expert. Documentation consists of the written report and/or presentation. The results and implications of the study are discussed. The best course of action is identified, recommended, and justified.-

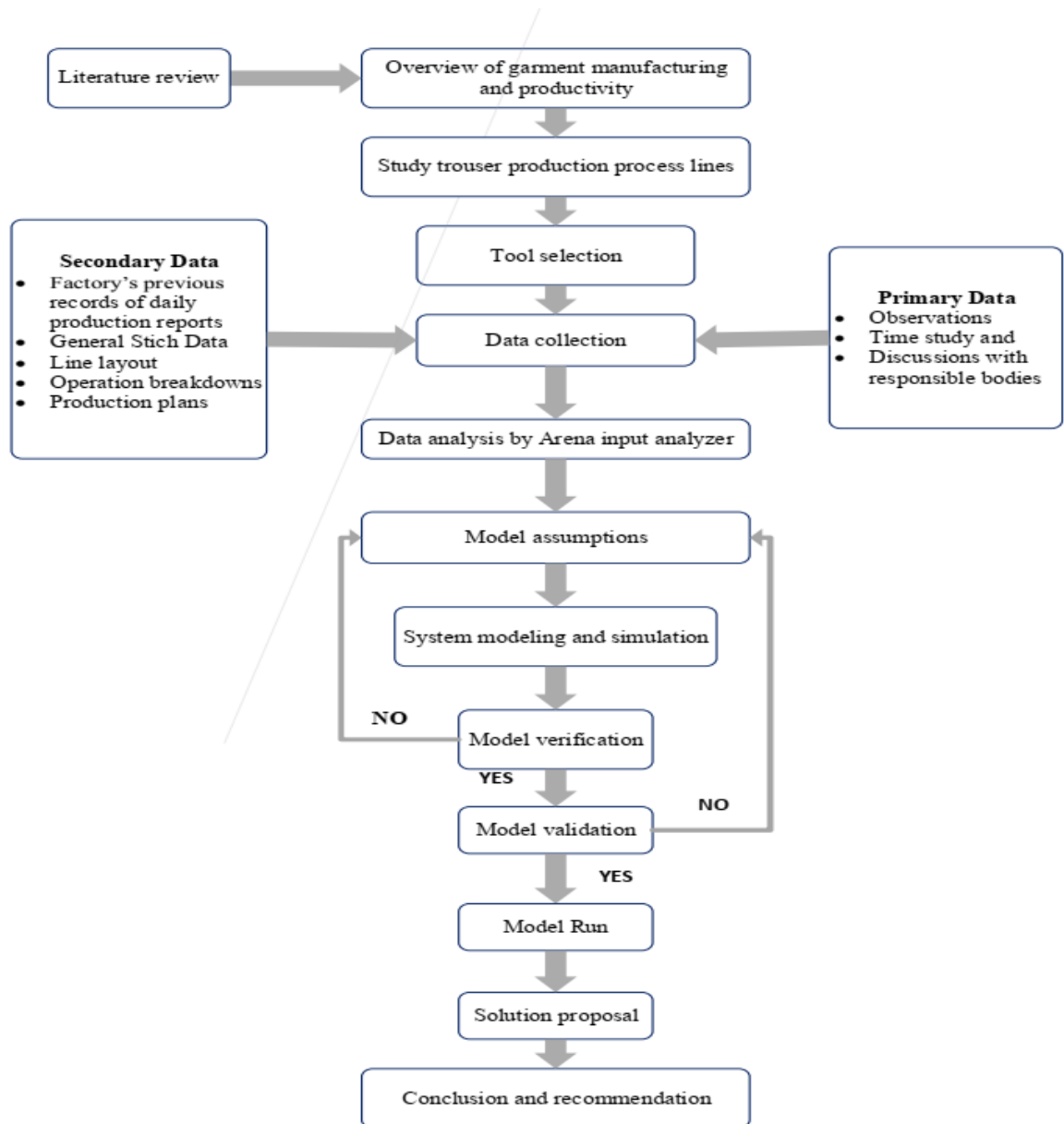


Figure 3.1 Research frameworks

CHAPTER FOUR

4. DATA PRESENTATION AND ANALYSIS

Lucy garment industry has been an existing operation item long sleeve slim shirts with in four sewing lines in each line performing by thirty-three operations for production of different styles of shirts for local and global markets. It is not expected that operators and machines would work all working hours of the shift without some interruptions. Therefore, allowances allocated i.e., machine allowances and personal allowances like fatigue and delay allowances. Here under this research paper 25% of allowances are included [24].

Data collection and analysis for developing simulation model is important as all output depends on the accuracy of the data in order to balance the sewing line. Initially, data collection begins from identifying and observing the different operations done on assembly line. Based on this, the number of tasks on each assembly lines are determined, the processing time for each operation was measured in second, and 10 measurements for each task recorded using stopwatch. In addition to make more accurate/validate the collected data, production reports and operation breakdowns and production plans considered.

4.1 Data collection for Cycle time analysis

Data collection and analysis for developing a simulation model is important as all output depends on the accuracy of the data in order to balance the sewing line. Initially, data collection begins from identifying and observing the different operations done on preparatory and assembly line. After observing all operations or tasks, which done on the lines, then defining the individual Work elements to each workstation follows. Individual work element is a minimum rational Work element having a specific limited objective. Based on this, the number of tasks on each Assembly lines are determined, the processing time for each operation measured in Second and 10 measurements for each task recorded using stopwatch.

The cycle time required to complete a task in each workstation depends on many factors such As the task by itself, operator skill, properties of fabric, design and style of shirts and sub b

Materials, working environment, sewing machine status, quality level of product, hours of the Day and psychology of the operator [50].

In general, the following data collected for model building, analysis of the existing production and building the best model based on different scenarios:

- Production output of the company per day
- Total no of operations performed under each part of shirt production
- Processing time for each operation and the number of machine and operator required for each operation
- Working hours per shift
- Skill level operators

Table 4.1 Operations and Cycle time of each process

Operation number	Operation name	Lbr	M/c	Cycle time									
				1	2	3	4	5	6	7	8	9	10
Collar section													
1.	collar run stitch	1	SNL	41	41	44	40	47	42	43	45	48	45
2.	collar turn and iron	1	IRN	24	25	24	24	27	25	25	26	27	25
3.	collar top stitch	1	SNLS	30	34	33	32	35	33	34	35	35	35
4.	collar band hem	1	DNL	32	34	33	33	37	33	34	36	37	35
5.	collar attach to band	1	SNL	44	47	45	44	40	45	46	49	51	47
6.	collar trimming marking and notching	1		35	38	37	36	41	37	38	40	41	39
7.	collar band centre stitch	1	SNL	31	33	32	31	35	32	32	34	35	33
Cuff section													
8.	run stitch cuff	1	SNL	44	47	45	44	50	45	46	49	51	47
9.	turn cuff	1		25	26	25	25	28	25	26	27	28	26
10.	iron cuff	1	IRN	29	31	30	29	33	30	30	32	33	31
11.	top stitch cuff	1	SNL	45	48	46	46	42	47	48	51	53	49
Front section													
12.	form button hole placket	1	JUKI BH	37	40	38	38	43	39	39	42	43	40
13.	crease button hole placket	1		44	47	45	44	50	45	46	49	51	47
14.	top stitch button hole placket	1	DNLS	25	26	25	25	28	25	26	27	28	26
15.	sew button placket	1	SNLS	29	31	30	29	33	30	30	32	33	31
16.	attach placket	1	SNLS	59	64	61	60	69	61	62	67	69	64

17.	sew label at placket	1	Juki DNLS	21	22	21	21	23	21	21	22	23	22
Back section													
18.	attach back yoke with back panel	1	SNLS	30	31	30	30	33	30	31	33	34	31
19.	back yoke topstitch	1	SNLS	40	43	41	40	46	41	42	44	46	43
Sleeve section													
20.	notch sleeves	1	DNLS	31	33	32	32	36	32	33	35	36	34
21.	iron upper and lower sleeves placket	1	IRN	32	34	39	40	36	33	33	35	36	34
22.	under placket attaching and tacking	1	SNL	48	51	49	46	55	50	54	54	56	52
23.	close lower placket	1	SNCS	46	50	43	49	57	48	49	52	54	50
24.	close upper placket and make	1	SNCS	65	69	71	65	75	67	68	73	76	70
Assembly section													
25.	Collar close and insert label	1	SNLSM	43	46	52	43	49	44	45	48	50	46
26.	side seam	1	DNCS	45	43	47	46	52	54	48	51	53	49
27.	Set front and back and mark neck for collar	1	SNL	37	34	38	37	42	45	39	41	43	39
28.	shoulder attach	1	SNLS	57	54	52	52	59	53	54	57	60	55
29.	Shoulder top stitch	1	DNL	34	36	34	34	38	35	32	37	39	36
30.	Top stitch armhole	1	DNCS	40	42	47	49	46	41	42	44	46	43
31.	Bottom hem	1	SNLSM	49	52	50	49	57	54	51	54	57	53
32.	BH front placket and caff	1	JUKI LBH	36	33	32	31	35	38	31	34	35	33
33.	Button attach	1	JUKI LBH	38	33	32	31	35	39	32	34	35	33

4.2 Actual SMV and target outputs

The detail exist information is recorded in table 4.2 to calculate Standard minute value (SMV) with target output per shift.

Table 4.2. Actual SMV and target output per shift of each operation

Operation no.	Operation	Ave(min)	Allowance	Actual SMV	Target/Hr	Target/Shift
1.	Collar run stitch	1.177	0.25	1.427	42	336
2.	Collar turn and iron	0.870	0.25	1.120	54	429
3.	Collar top stitch	1.010	0.25	1.260	48	381
4.	Collar band hem	1.023	0.25	1.273	47	377
5.	Collar attach to band	1.213	0.25	1.463	41	328

6.	Collar trimming marking and notching	1.087	0.25	1.337	45	359
7.	Collar band centre stitch	0.997	0.25	1.247	48	385
8.	Run stitch cuff	1.230	0.25	1.480	41	324
9.	Turn cuff	0.885	0.25	1.135	53	423
10.	Iron cuff	0.963	0.25	1.213	49	396
11.	Top stitch cuff	1.242	0.25	1.492	40	322
12.	Form button hole placket	1.115	0.25	1.365	44	352
13.	Crease button hole placket	1.230	0.25	1.480	41	324
14.	Top stitch button hole placket	0.885	0.25	1.135	53	423
15.	Sew button placket	0.963	0.25	1.213	49	396
16.	Attach placket	1.510	0.25	1.760	34	273
17.	Sew label at placket	0.812	0.25	1.062	57	452
18.	Attach back yoke with back panel	0.972	0.25	1.222	49	393
19.	Back yoke topstitch	1.160	0.25	1.410	43	340
20.	Notch sleeves	1.007	0.25	1.257	48	382
21.	Iron upper and lower sleeves placket	1.037	0.25	1.287	47	373
22.	Attach plackets	1.308	0.25	1.558	39	308
23.	Close lower placket	1.280	0.25	1.530	39	314
24.	Close upper placket and make	1.615	0.25	1.865	32	257
25.	Collar close and insert label	1.227	0.25	1.477	41	325
26.	Side seam	1.263	0.25	1.513	40	317
27.	Set front and back and mark neck for collar	1.108	0.25	1.358	44	353
28.	Shoulder attach	1.372	0.25	1.622	37	296
29.	Shoulder top stitch	1.042	0.25	1.292	46	372
30.	Top stitch armhole	1.183	0.25	1.433	42	335
31.	Bottom hem	1.327	0.25	1.577	38	304
32.	BH front placket and collar	1.013	0.25	1.263	47	380
33.	Button attach	1.020	0.25	1.270	47	378
	Total	45.40				

From table 4.2 total number of SMV is 45.40 minute with total number of 33workers and 8hr (480minute) per working day.

$$\text{Output per day} = [\text{total number of worker} * \text{available working time}] / \text{SMV} \dots\dots\dots \text{Eqn (4.1)}$$

$$= [33 * 480 \text{minute}] / 45.40 = \mathbf{349 \text{ output/day}}$$

$$\text{Labour output per day} = \text{total output per day} / \text{total worker} \dots\dots\dots \text{Eqn (4.2)}$$

$$= [349 \text{output/day}] / 33 = \mathbf{11 \text{ output/labour/day}}$$

The output plan of the company is 600 output per day, but the actual output is between 338 and 349 output/day.

$$\text{Max Overall efficiency} = [\text{actual output} / \text{output plan}] * 100 \dots\dots\dots \text{Eqn (4.3)}$$

$$= [349 / 600] * 100 = \mathbf{58.2\%}$$

4.3 Data collection for distance movement analysis

In each operation, there is distance movement which consume time and as factor in reduction of productivity of the company. In between some operation, there is unwanted movement and waste time, due to this reason there is waiting time to continue the next operations. The detail distance with their time consume is recorded in Annex C.

From Annex C overall operation of working time per day movement is 138.6m with 836sec (13.9minute) are there and because of this unwanted movement and waiting time the productivity of the company is less or cannot produce according to their plan. Figure below is showed distance movement with their time it takes in each operations.

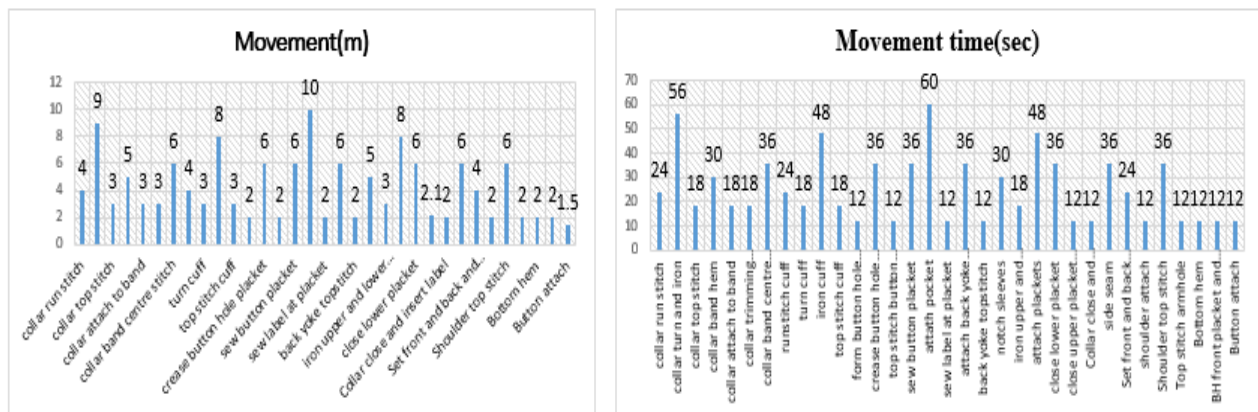


Figure 4.1 Operators Distance movement with time consume bar chart

4.4 Process Flow of Assembly Lines

In the figure 4.2, showed the arrangement flow process of operation.

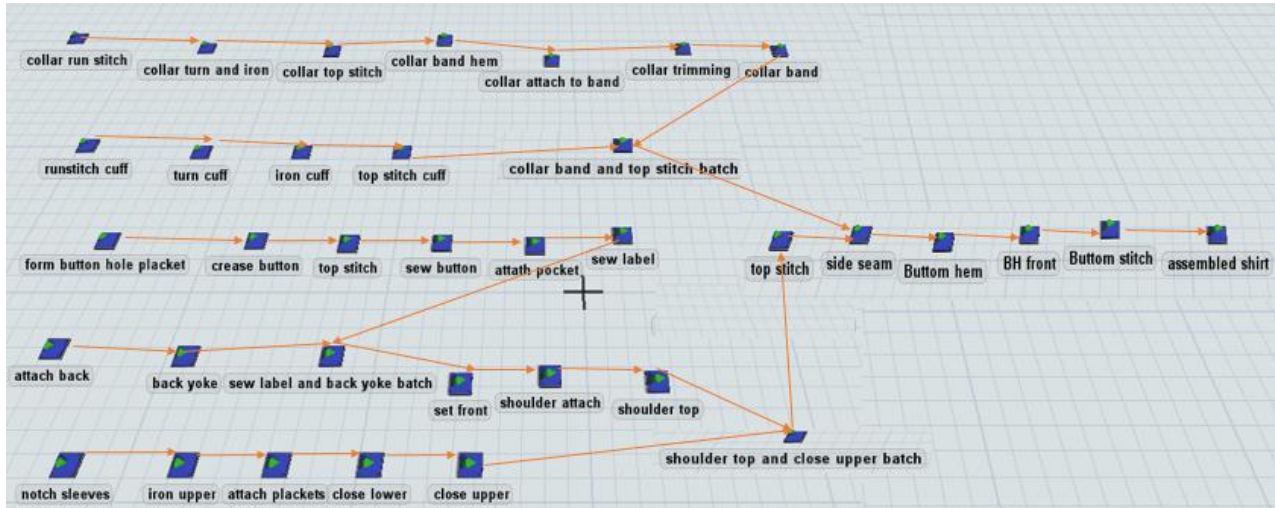


Figure 4.2 : Flow process of each operations:

From the distance movement table, total movement is 138.6m with a movement time of 836 s in each day of working time. From this, it needs to identify losses per day or year in both quantity and their loss in birr. In some operations, there is unwanted movement and ineffective time consumption, which affects the overall production process of the company. Production time in the year, according to the company plan, is 305 days, and calculating losses depends on the wasted time due to unwanted movement.

$$\text{Movement time/ day} = 836/60 = 13.9\text{minute}$$

$$\text{Movement time/year} = 13.9\text{minute} * 305 = 4239.5\text{minute}$$

Lose due to unwanted movement time/year = 4239.5/45.40= 93output per year.

$$\text{Loss in birr} = 93 * 800\text{birr} = 74400\text{birr/year.}$$

It means that there is a loss of 93 shirt with loss of 74400birr/year in the company due to of unwanted movement and it is a factor in affecting of the company productivity.

4.5 Data collection for Identification of Workers skill matrix

Designing an operator skill matrix is required to rotate before line-balancing operations begin, and operators are assigned to work stations based on their skill level. Excel sheets are used to build skill matrices for operators. Operators need to train to fill a skill gap caused by their design training level. Utilized an operator skill matrix to determine whether the assembly line balancing designer has enough workers with the necessary skills prior to allocating them to work stations or not.

In the workers skill matrix, it classifies their skill on a given operation and classifies and gives a 5 rating. Those workers who work all of the operations, some with the guidance of supervisors, and others are acts like helpers, as detailed in Annex A.

Table 4.3. Rating of workers skill matrix's

Skill level	Rating
Fully trained and can able to train others	4
Fully trained, can work without supervision of coach	3
Trained, can work with the supervision of coach	2
Started training	1
Training is required	0

4.6 Determining number of replication

In order to calculate the number of replications, first, the mean and standard deviation of the first ten replication calculated for assembly lines then standard error of the data calculated using Eqn.4.4 Multiple replications of simulation model are achieved by changing the random number streams that are used by the model and re- running the simulation[24]. The aim is to produce multiple samples in order to obtain a better estimate of mean performance.

$$\text{Standard error} = t_{(1-\alpha/2, n-1)} \frac{S}{\sqrt{n}} \dots\dots\dots \text{eqn. (4.4)}$$

Where,

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

n-1= degrees of freedom

s = standard deviation of the replication means

The standard error is essentially the amount of dispersion around the mean value that data may exhibit. The first term t comes from the t probability distribution table; the t value depends on two parameters, the level and the number of degrees of freedom. α level has to do with the level of confidence, for 95% confidence level the α level is 1 minus the confidence level 0.05.

$$S = \sqrt{\sum_1^n \frac{(X-x)^2}{n-1}} \dots\dots\dots \text{eqn. (4.5)}$$

Where,

s = standard deviation of sample

X = replication average output

x = mean of replication average output

Considering the first 10 replications, standard deviation and half width value shown on table 4.5

Table 4.4. Sample data for determining number of replications

Replication number	Arena simulation output report
1	338
2	340
3	344
4	353
5	335
6	339
7	327
8	340
9	351
10	355
Mean	342
Standard deviation	8.70
Half width	6.43

Mean of average replication result after ten replications is equal to 342 shirts assembled at 8 hour of production time. Standard deviation measures the amount of variability or dispersion of the replication results from the mean. The half width statistic used to help in determining the reliability of the results from the replication. In other word, half width is a sampling error introduced in taking sample [10] [24]. Therefore, the value of half width can be simply determined by using the standard error. Considering a 95% confidence level and $n-1=9$ samples the value of t can be read from t probability distribution table, hence t (at 95%, 9) = 2.262

$$\text{Half width of assembly model} = \frac{2.262 * 8.7}{\sqrt{10}} = \mathbf{6.2}$$

Set half width =h, solve for $n = t^2_{(1-\alpha/2, n-1)} \frac{s^2}{h^2}$ replace t by z, corresponding normal critical value

Where,

✓ n = number of observations in the sample = 10

✓ h = half width = 6.2

n_0 is the number of initial replications we had and h_0 is the half width. If error level from the initial sample of 10 replications is not quite satisfying, the initial half width can reduced thus greater precision level can be achieved. Assume half width for assembly line to be 3.1 and taking the value of Z at 95% confidence level to be 1.96 form z table then the number of replications for shirt line became: $\frac{1.96^2}{3.1^2} * 8.7^2 = 30.25$ approximately 30 number of replications are required for better decision making process.

4.7 Model Verification and Validation

4.7.1 Model Verification

The model was systematic coded and sorted. Each software path's accuracy checked using trace and animation techniques. We ran simulation trials with different input parameter settings and evaluated the model's output findings for suitability. The interval times of each entity measured every 5 seconds by repeatedly running the simulation model. It has repeatedly demonstrated that allowing for fewer inter arrivals has no impact on throughput and only slows down the simulation.

During test run model working smoothly without any faults or warnings under different settings of the inputs by altering the arrival times. It can said this model verified and represent the real system.

4.7.2 Model Validation

To validate the reliability of the model by comparing the output of the real system and the model output of the existing system, an experiment with 10 repetitions performed and the output value verified. The actual output of the system ranges from 327 to 355 parts/shift. The average output of the assembly department is 348 units. Testing the model with 10 iterations showed an output value of 342 parts for the assembly. Therefore, the output value according to the model is the actual value.

To illustrate that the proposed demonstrate has a satisfactory level of certainty within the preparing exhibitions accepted, approval is required. Approval too includes deciding whether the suggested demonstrate may be a genuine representation of the genuine framework. The demonstrate can approved in a number of ways. Theories tests with a throughput and a 95% certainty interim utilized to approve the show [10]. In order to test the validation of the model collected random sample data production on existing system and simulation system. Then calculate mean and variance of the data.

Table 4.5. Sample data for validation test

	Output for Existing system	Output sample for Arena modeling
1	340	338
2	352	340
3	338	344
4	366	353
5	349	335
6.	336	339
7.	342	327
8.	350	340
9.	352	351
10.	356	355
Mean	348	342
Variance	81.11	75.77

To evaluate whether there is a significant difference between the means of two groups and their relationships, a t-test is an inferential statistic that is used. In order to evaluate statistical

significance, the t-test, a test used for hypothesis testing in statistics, uses the t-statistic, the values of the t-distribution, and the degrees of freedom. For an equal variance t-test, the t-value and degrees of freedom are determined using the following formula: The hypotheses are:

H0: $\mu_{existing} = \mu_{Arena}$

H1: $\mu_{existing} \neq \mu_{Arena}$, the test is if $t_0 < t_{\alpha/2, n1+n2-2}$, we would accept the null hypothesis H0,

$$T\text{-value} = \frac{\text{mean 1} - \text{mean 2}}{\frac{(n1-1)*var1^2 + (n2-1)*var2^2}{n1+n2-2} \sqrt{\frac{1}{n1} + \frac{1}{n2}}} \dots \dots \dots \text{Equ. 4.6}$$

$n1$ and $n2$ the number of existing samples and runs of the model, respectively. The average throughput of five items of data ($n1 = 10$) collected from the existing system was $\mu_{existing} = 348$ unit with variance $S = 81.11$ and that for the ARENA model was $\mu_{model} = 342$ with variance $S2 = 75.77$ after running the model for five times ($n2=10$). Hence, $t_0 = 0.31$ and from 't' table (95% C.I.) $t_{\alpha/2, n1+n2-2} = t_{0.05, 8} = 2.306$ Since, $t_0 < t_{\alpha/2, n1+n2-2}$ it implies that there is no significant difference between the means; therefore the simulation model is valid.

4.8 Data from cutting department

Data collected from the customer order specifically for line two out of the three assembly lines and on the bundling section of Lucy Company and the line was producing men's dress shirt.

As for the study to done; I collected data from the cutting department the cutting order, which is handled by the bundling section and then it, will be edited to be shared with the catalog for the whole crew for making the men's dress shirt with the style of slim fit. The tables below are the data gained from the bundling section, which ordered by the customer named Sefa that is assigned for the line three supervised by the line supervisor.

For order 1: -

➤ Style- slim fit men's dress shirt

Order 1

Lucy Garment Industry PLC ሉሲ ጋርመንት ኢንዱስትሪ ኃ/የ ተ/የ ግ/ማበር	OF/MS/01	R-0
Cutting Order Domestic	Page 1 of 1	

Date order: -14/02/23

Production order code: - 001

Customer name: -

NO_	Code	Slim fit								NO_ of plies	Remark
		Size									
		S	M	L	XL	2XL	3XL	Total	Total Mts		
1		156	155					311			
2		366	371					737			
Total		522	526					1048			

Prepared by: - Marketing dep.

Received by: -

The next order received and assigned to this same line supervised by supervisor came up three days ago on 17 February 2023 with the same form and size and of course with the same style known as Slim fit. The summary of the order shown below on the table.

For order 2: -

Customer name: -

NO_	Code	Slim fit								NO_ of plies	Remark
		Size									
		S	M	L	XL	2XL	3XL	Total	Total Mts		
1		186	193					379			
2		351	354					705			
Total								1084			

Prepared by: - Marketing dep.

Received by: -

These orders will produced in sequence. As the flow of the cutting order continues, the first order will cut, and it will be bundled and put on the shelf. However, literally, before the first order has fully produced in the line, the second-round order will cut. This goes into the unnecessary inventory in the bundling section and the unlimited WIP in the sewing line, so far known as Line 3, supervised by the supervisor.

Notice that the orders are coming from the customers assigned to the three companies' lines in the round. For instance, if a customer order has been coming out, it will assigned to one of the lines, the other order to the next line, and the third order to the third line, and the cycle will continue in this manner unless special cases happen.

After the assignment of the order, the so-called supervisor will come to the bundling section and take her orders in order to bring them to the sewing line for production. Notice that she was only taking the catalogs to follow up on the production. There is no format to follow her up with.

- ✓ What her crew (the sewing line) is going to do
- ✓ What her crew is doing
- ✓ what her crew has done

The production head will supervise line 3 by observing what her crew is doing. Since the company has three assembly lines and one preparation sewing line, It may not be easy to control what they are doing with one production head. Therefore, this study will try to visualize what is going on in the production flow using the Kanban technique. The table below shows the inputs that entered into line 2 of the assembly line within one week.

Table 4.6. Inputs that entered to assembly line 2

Date	Code	Size		Total	Grand total
		S	M		
02/02/2023	402	393	398	791	791
04/02/2023	502	156	155	311	1048
		366	371	737	
06/02/2023		258	262	520	1062
		117	118	235	
		132	133	265	
		21	21	42	

There is actually an initial WIP in the assembly line 2, which is 450. The second table shows the output that line two produced within that week that the line supervisor received to know the WIP by subtracting the output from the input.

CHAPTER FIVE

5. RESULT AND DISCUSSION

5.1 Simulation Model Formulation

The model's building period based on the production process flow diagram for an existing shirt line that identified during observation. Sewing machines are arranged in groups based on the flow of the manufacturing process, but the line-balancing algorithm determines the number of machines used for each task. Each worker employs a straight-line production system with just one device. Creating or developing a model's goal is to ascertain which components of the system should be incorporated, and the model's direction of flow should mimic the actual system. The declaration of the entity launched the model's development. The placement of the workstations, the resources and producing path network, and the declaration of programming for arrival and processing. The simulation model entity's behaviour along its journey is described by logic flow. When developing the model, it was easy to see the path the entity takes.

The Arena's animation component was particularly useful in ensuring the assembly line system used to make men's long-sleeve shirts shown in the model below. The majority of the models in earlier studies using the Arena simulation program were created independently because the Arena 14.0 software was a student edition and only authorized for training purposes.

The student version of Arena 14.0 is confined to only 150 entities, and the number of modules and other features is similarly limited. With the use of various assembly modules, including processing modules, batch modules, match modules, and others, we can model the assembly section.

5.1.1 Assumptions during modeling and running

- The assembly line never starved; there is a continuous supply of material from the cutting section. There is no fabric loss since all cut panel bundles will be ready in advance before production starts.
- The product stays the same during the whole production process. The product model and style remain unchanged.
- Set-up times and machine cleaning times not taken into consideration. Because in a real system, the setup process in garment manufacturing usually accomplished at the beginning of trial production.
- All process times for sewing operations and manual operations include insignificant breakdowns like the detachment of sewing thread.
- Allowance time for both operators and machines is not included. Workers operate without any delay or interruption; the operator's performance and skill stay constant throughout the entire process.
- Operation time is eight hours per shift; it does not include lunch or break time.
- Machines are ready as per their uptime percentage within eight hours of working, and electric power and other utilities are available at all times.
- The shirt main assembly line and the component production lines (preparatory section) considered one system.
- Operations in the cutting room and during the finishing process are not included.
- Processed parts that are decided to be reworked by quality checkers in line inspections are processed by other operators and machines that are out of the basic work stations (i.e., preparatory and assembly sections).

The following figure shows the arena simulation model of the existing system for the case company, and from the arena simulation output, the existing output of the product is 338 per day.

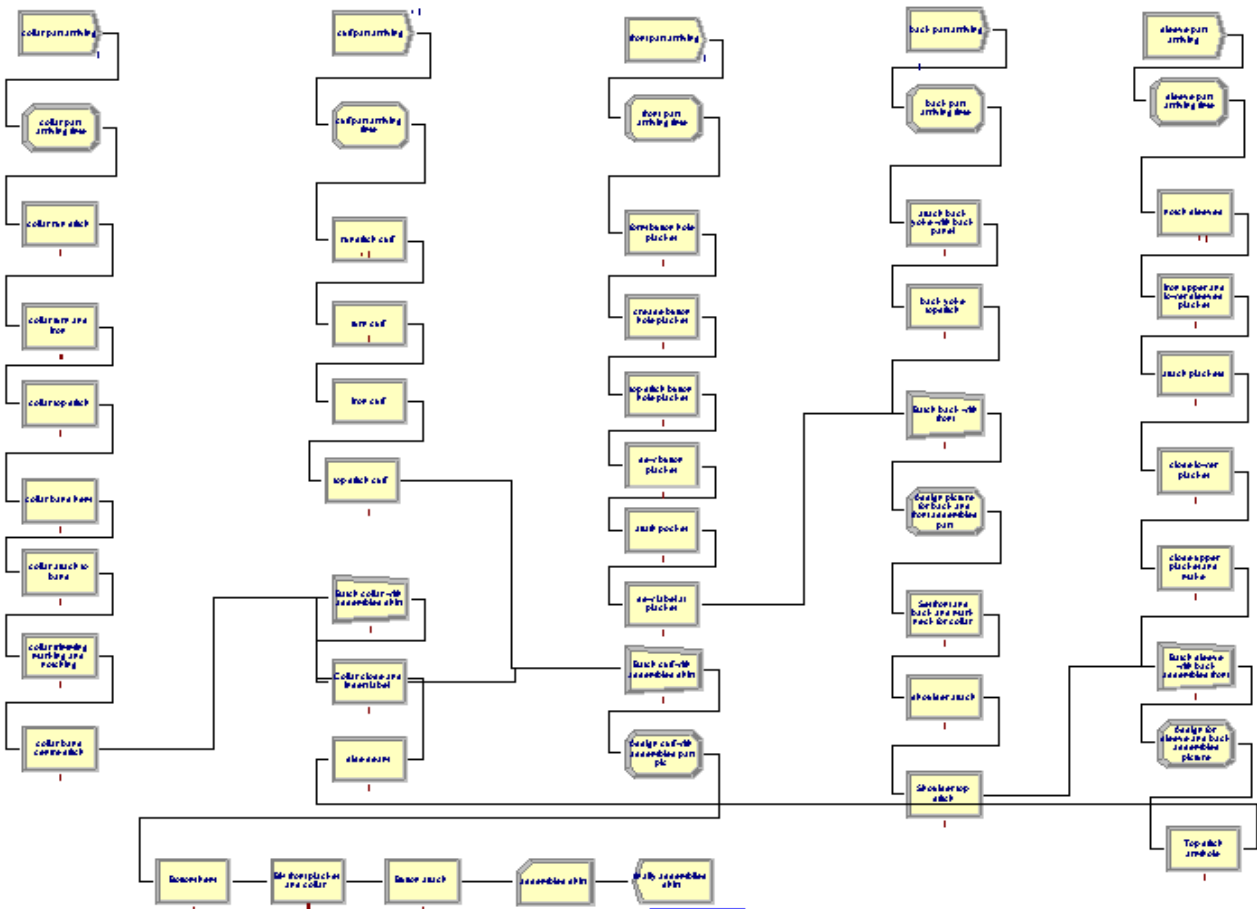


Figure 5.1 Assembly line simulation model for existing production system

Figure 5.1 shows the average production out of the existing simulation per 8 hours processing time for 30 replication in the given or selected sewing line. From the simulation modelling report and as per the objectives of this research the researcher generated the following basic reports for analysis of the existing system performance, identification of bottleneck operations and balancing the production system. Under this report the researcher find out basic performance metrix of the company with in a given production time. Here we have number out of the company for single sewing line, number out for each part, waiting time and other related informations are attached on the Annex D.

5.2 Arena Input Analyzer based analysis

The Input Analyser provided as a standard component of the Arena environment. This versatile tool can be used to determine the quality of fit of probability distribution functions to input data for building simulation model. It may be used to fit specific distribution functions to a data file to allow you to compare distribution functions or to display the effects of changes in parameters for the same distribution.

In order to determine the underlying best theoretical distribution for a set of probabilistic data, usually it involves to calculate goodness of fit test. These tests based on some sort of comparison between the observed data distribution or processing time observed before and a corresponding theoretical distribution. If the difference between the observed data distribution and the corresponding theoretical distribution is small, then it may be stated with some level of certainty that the input data could have come from a set of data or populations with the same parameters as the theoretical distribution [18]. There are four different methods for conducting this

comparison: Graphic approach, Chi-square test, Kolmogorov– Smirnov test and square error. The arena input Analyser has different packages to calculate chi-square, Kolmogorov–Smirnov (KS), and square error tests. In addition to these, it is capable of determining the quality of fitness of probability distribution functions to input data and generate high quality data plots [10] [24].

Therefore, the collected data processed in the Input Analyser tool built in Arena, and the results used to set the type of probability distribution function and its value to use in simulation model. Determining the best distributions for the probabilistic processing time is the critical phase for building comprehensive and more realistic simulation model for assembly lines. In deciding which distribution to present, it tried to choose those that are simple to describe, implement and are reasonably efficient as well [50].

Figure 5.2 shows distribution for Attach Notch sleeve operation from sleeve section of the shirt production process.

Probability distributions are mathematical functions that describe the likelihood of various outcomes in a random experiment. There are several types of probability distributions, each with its unique characteristics and applications.

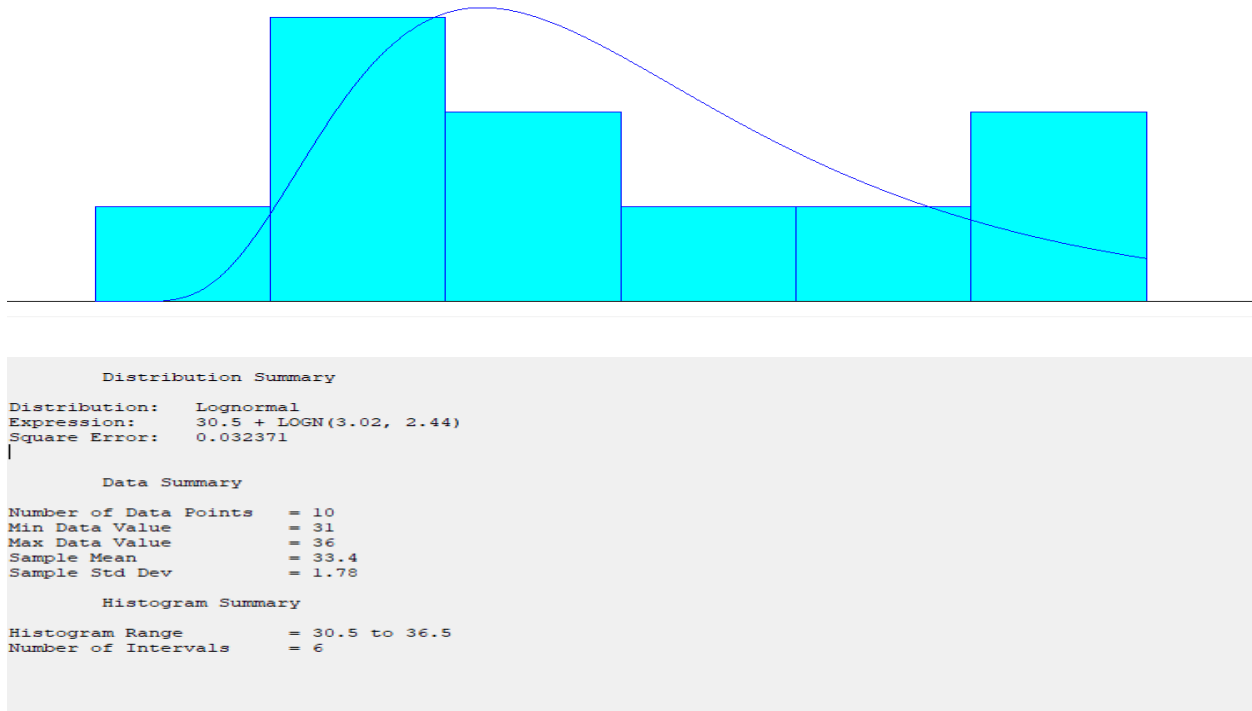


Figure 5.2. Theoretical Distribution Summary for Notch sleeves

The lognormal distribution describes data that follows a normal distribution when the natural logarithm of the data is taken. It is used for data that cannot be negative and has a right-skewed appearance.

Assembly line operations data distribution function summarized as table 5.1.

Table 5.1. Probability distribution of operations summary table

S/N	Operation	Distributions	Probability
1.	collar run stitch	Uniform	UNIF(30.5, 37.5)
2.	collar turn and iron	Lognormal	13.5 + LOGN(1.74, 1.44)
3.	collar top stitch	Erlanger	21.5 + ERLA(1.15, 2)
4.	collar band hem	Lognormal	21.5 + LOGN(3.02, 2.44)
5.	collar attach to band	Beta	33.5 + 8 * BETA(0.917, 1.23)

6.	collar trimming marking and notching	Weibull	25.5 + WEIB(3.11, 1.55)
7.	collar band centre stitch	Erlanger	20.5 + ERLA(1.15, 2)
8.	Run stitch cuff	Beta	33.5 + 8 * BETA(0.917, 1.23)
9.	turn cuff	Exponential	15 + EXPO(1.1)
10.	iron cuff	Erlanger	18.5 + ERLA(1.15, 2)
11.	top stitch cuff	Gamma	34.5 + GAMM(2.06, 1.94)
12.	form button hole placket	Gamma	48.5 + GAMM(3.02, 1.69)
13.	crease button hole placket	Beta	10.5 + 3 * BETA(0.897, 1.02)
14.	top stitch button hole placket	Uniform	UNIF(14.5, 18.5)
15.	sew button placket	Exponential	19.5 + EXPO(1.8)
16.	attach pocket	Beta	37.5 + 9 * BETA(0.897, 1.02)
17.	sew label at placket	Triangular	TRIA(29.5, 30, 36.5)
18.	attach back yoke with back panel	Normal	NORM(9.2, 0.6)
19.	back yoke topstitch	Erlanger	19.5 + ERLA(1.15, 2)
20.	notch sleeves	Lognormal	20.5 + LOGN(3.02, 2.44)
21.	iron upper and lower sleeves placket	Erlanger	21.5 + ERLA(1.85, 2)
22.	attach plackets	Beta	35.5 + 11 * BETA(1.2, 1.04)
23.	close lower placket	Triangular	TRIA(32.5, 39.4, 47.5)
24.	close upper placket and make	Beta	54.5 + 12 * BETA(1.2, 1.04)
25.	Collar close and insert label	Beta	32.5 + 10 * BETA(0.648, 0.932)
26.	side seam	Erlanger	32.5 + ERLA(3.15, 2)
27.	Set front and back and mark neck for collar	Weibull	20.5 + WEIB(4.78, 1.55)
28.	shoulder attach	Normal	NORM(44.4, 3.58)
29.	Shoulder top stitch	Beta	36.5 + 14 * BETA(1.2, 1.04)
30.	Top stitch armhole	Uniform	UNIF(29.5, 39.5)
31.	Bottom hem	Weibull	38.5 + WEIB(4.56, 1.35)
32.	BH front placket and collar	Exponential	20.5 + EXPO(4.3)
33.	Button attach	Erlanger	20.5 + ERLA(1.85, 2)

5.3 Simulation Model Output Analysis

Simulation output analysis is the analysis of data generated a simulation run in order to analysing system performance or compare performance of two or more system scenarios. The simulation model developed in previous chapter generated different outputs of the system by running for 480 minutes of replication lengths and 30 replications for more precise output generation. Output analysis also used for understanding the initial performance of system and identifications problems, obstacles, wastes, resources utilizations, bottleneck operations etc. 95% of confidence interval is set for the output reports generated by simulation model developed.

The basic objective of this thesis is to enhancing the productivity of the garment production lines through line balancing, the output of the simulation model for the existing assembly line is analysed to propose different scenarios for productivity improvement through line balancing. Scenarios of different integrations proposed for better productivity in terms resource utilization, reducing wastes of processing time for each entity and other optimum utilization.

5.3.1 Existing System Analysis Based on Model Results

Based on the output of simulation model report with 30 replications the output, WIP values, resource utilization, productivity per operator, productivity per machine, lead time, waiting time in queue, tact time and line efficiency discussed in table 13 below.

Table 5.2. Existing assembly line simulations model output report

Section of long sleeve shirt	Number in	Number Out	WIP existing
Back	1075.43	838.77	142.56
Collar	878.20	675.80	116.02
Cuff	778.27	666.27	58.7390
Front	630	373.67	119.86
Sleeve	864.57	556.23	168.06
Overall output	349		

As it is observed from table 5.2 preparatory sections have different productivity levels, the final assembled shirt product depends on the minimum number of result as we observe from table 5.2

front section has minimum value i.e. 373 front sections per shift. The maximum product as overall efficiency become less than 373 shirts per shift i.e. 349 shirts per shift because of the preparatory section is an input for the assembly section.

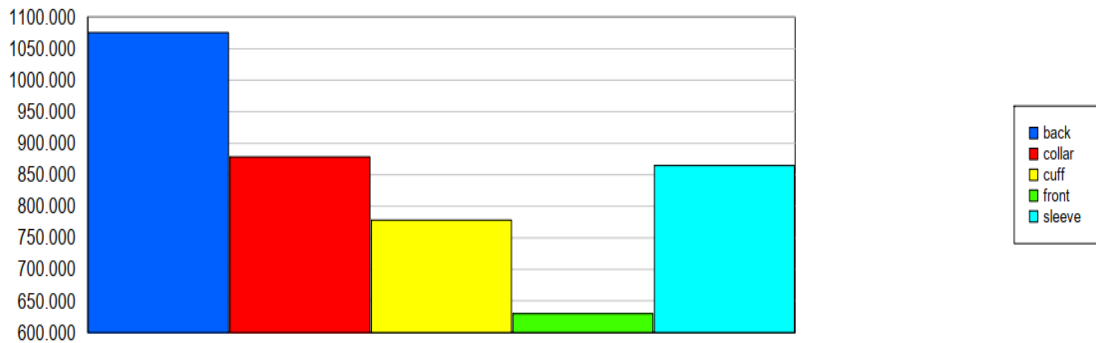


Figure 5.3. Graphical expressions of entities entering to the system

5.3.2 Identification of Bottleneck operations in the existing system

The next step will be identification of bottleneck processes or operations and resource utilization for the existing production system. In garments industry bottleneck means the lowest capacity in products processed, higher waiting time and high number WIP waiting for being processed. The above production status results in lowest production and ultimately lowest profit. Therefore, identifying bottleneck operations and removing them is a very significant

task to get the highest capacity production.

5.3.3 Resource utilization for existing system

Under this existing model, the resource means coded as sewing machines of different type operators assigned in each machine. For productivity improvement utilization of resources at possible maximum point is the first criteria since they are inputs the processing company.

A simulation model is an easier way to build up models to represent real life scenarios, to identify bottlenecks, to enhance system performance in terms of productivity, queues, resource utilization, and cycle times and lead-time.

Unnamed Project

Replications: 30 Time Units: Seconds

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
BH for forming button hole placket	1.0000	0.00	1.0000	1.0000	0.00	1.0000
close lower placket machine	0.7736	0.00	0.7682	0.7797	0.00	1.0000
close upper placket and make machine	0.9956	0.00	0.9951	0.9959	0.00	1.0000
DNL for collar band hem	0.3401	0.00	0.3380	0.3433	0.00	1.0000
DNL for top stitch button hole placket	0.3073	0.00	0.3040	0.3107	0.00	1.0000
helper for collar trimming	0.3933	0.00	0.3910	0.3960	0.00	1.0000
helper for creasebutton hole placket	0.2220	0.00	0.2202	0.2247	0.00	1.0000
helper for turn cuff	0.2013	0.00	0.1998	0.2028	0.00	1.0000
helper with IRN for collar turn	0.2115	0.00	0.2097	0.2130	0.00	1.0000
IRN for cuff	0.2603	0.00	0.2578	0.2623	0.00	1.0000
iron upper and lower sleeves placket machine	0.4906	0.00	0.4862	0.4946	0.00	1.0000
JUKI LBH	0.5747	0.00	0.5668	0.5858	0.00	1.0000
label attaching machine	0.5940	0.00	0.5877	0.6002	0.00	1.0000
notching sleeve machine	0.4578	0.00	0.4543	0.4613	0.00	1.0000
pocket attaching machine	0.7760	0.00	0.7675	0.7836	0.00	1.0000
Resource 11	0.3846	0.00	0.3811	0.3883	0.00	1.0000
Resource 12	0.6886	0.00	0.6831	0.6933	0.00	1.0000
Resource 13	0.6807	0.00	0.6706	0.6885	0.00	1.0000
Resource 14	0.5490	0.00	0.5446	0.5522	0.00	1.0000
Resource 15	0.6160	0.00	0.6099	0.6241	0.00	1.0000
SNL auto	0.4812	0.00	0.4777	0.4847	0.00	1.0000
SNL for collar band centre	0.3166	0.00	0.3141	0.3195	0.00	1.0000
SNL for collar run stitch	0.4721	0.00	0.4692	0.4756	0.00	1.0000
SNL for placket attaching	0.8046	0.00	0.8002	0.8103	0.00	1.0000
SNL for runstitch cuff	0.4619	0.00	0.4593	0.4646	0.00	1.0000
SNL for sew button placket	0.3964	0.00	0.3922	0.3995	0.00	1.0000
SNL VT for collar attch to band	0.5125	0.00	0.5096	0.5159	0.00	1.0000
SNLS for attaching back yoke	0.1148	0.00	0.1141	0.1155	0.00	1.0000
SNLS for back yoke top stitch	0.2724	0.00	0.2704	0.2763	0.00	1.0000
SNLS for top stitch	0.3309	0.00	0.3287	0.3328	0.00	1.0000
SNLSM	0.9937	0.00	0.9935	0.9941	0.00	1.0000

Figure 5.4. Resource utilization rate for existing assembly line system

Based on the above figure resource utilization report the maximum utilized resource is button hole forming machine that used for forming button holes on placket utilized 100% and the least utilization 11.48% for Single needle lock stitch machine for attaching back yoke. From figure 5.4 existing system resource utilization report, we can identify the highly utilized resources, Lease than 30% utilized resource and Lease than 40% utilized resource. Table 5.3 showed that highly utilized resources.

From figure 5.4 existing system resources utilization report, we can identify the Lease than 30% utilized resource Table 5.4 showed that those resources are not used fully efficient. It has ideal resources.

Table 5.3 Highly utilized resources

S.N	Resource	Utilization in %
12	BH for forming button hole	100
22	close upper placket and make machine	99.56
33	SNLSM button attaching	99.37
16	SNL for placket attaching	80.46
24	placket attaching machine	77.60
23	close lower placket machine	77.36

From figure 5.4 existing system resource utilization report, we can identify Lease than 40% utilized resource. as shown in table 5.4.

Table 5.4 Lease than 30% utilized resource

Operation no.	Resource	Utilization in %
18	SNLS for attaching back yoke	11.48
7	helper for turn cuff	20.13
2	helper with IRN for collar turn	21.15
13	helper for crease button hole	22.20
8	IRN for cuff	26.03
19	SNLS for back yoke top stitch	27.24

Table 5.5 showed that those resources are not used fully efficient. It has ideal resources.

Table 5.5. Lease than 40% utilized resource

Operation no.	Resource	Utilization in %
14	DNL for top stitch button hole placket	30.73
5	SNL for collar band centre	31.66
1	SNLS for top stitch	33.09
2	DNL for collar band hem	34.01
4	helper for collar trimming	39.33
15	SNL for sew button placket	39.64

As it is possible to observe from the resource utilization, histogram shape the utilization level has highly dispersed from each other. Higher deviation in utilization shows that there is balancing problem in sewing section of the garment industry. For maximum and optimum utilization of resources, the workstations should properly assigned. Assignments of operators to work station for balancing line based on the operator skill matrix data. In order to redesigning the process flow line and the simulation model, it needs that to identify process which have maximum number of WIP and maximum waiting time in addition to their resource utilization capacity mentioned in table 5.2.

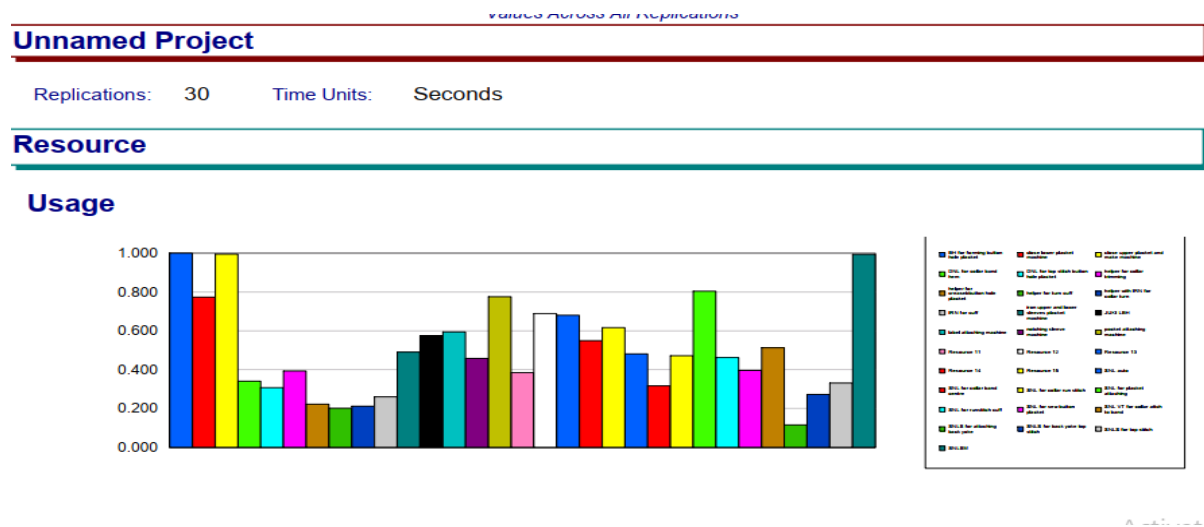


Figure 5.5. Graphical representation for resource utilization of existing system

From figure 5.5 for assembly lines we can see clearly how the capacity utilization of different resources of lines is varied. This shows that the work content of lines is not distributed uniformly among stations. In other word the lines are not balanced.

5.3.4 Identification of Bottleneck Operations Based on Different Processing Status of the Existing System

Resource Capacity utilization in the existing manufacturing system, the number waiting of assembly section summarized.

Replications: 30 Time Units: Seconds

Queue						
Other						
Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel.Queue	2.5275	0.00	2.5113	2.5420	0.00	44.0000
attach plackets.Queue	10.7779	0.05	10.4857	11.0084	0.00	29.0000
attath pocket.Queue	0.00036964	0.00	0.00002900	0.00089855	0.00	1.0000
back yoke topstitch.Queue	3.4690	0.01	3.4261	3.5579	0.00	28.0000
Batch back with front.Queue	0.4996	0.00	0.4923	0.5042	0.00	2.0000
Batch collar with assembled shirt.Queue	0.4971	0.00	0.4848	0.5118	0.00	2.0000
Batch cuff with assembled shirt.Queue	0.4969	0.00	0.4813	0.5152	0.00	2.0000
Batch sleeve with back assembled front.Queue	0.4960	0.00	0.4849	0.5085	0.00	2.0000
BH front placket and collar.Queue	0.00804361	0.00	0.00529823	0.01175134	0.00	1.0000
Bottom hem.Queue	22.6221	0.16	21.5860	23.5072	0.00	47.0000
Button attach.Queue	0.00061978	0.00	0.00	0.00344192	0.00	1.0000
close lower placket.Queue	0.06843976	0.01	0.04151400	0.1054	0.00	2.0000
close upper placket and make.Queue	49.7529	0.30	48.4373	50.9786	0.00	101.00
collar attach to band.Queue	1.0109	0.02	0.8936	1.1203	0.00	6.0000
collar band centre stitch.Queue	0.00000830	0.00	0.00	0.00018383	0.00	1.0000
collar band hem.Queue	0.00098416	0.00	0.00013856	0.00244121	0.00	1.0000
Collar close and insert label.Queue	26.5267	0.19	25.2236	27.5640	0.00	54.0000
collar run stitch.Queue	11.5692	0.02	11.5006	11.6514	0.00	49.0000
collar top stitch.Queue	0.00007598	0.00	0.00	0.00032383	0.00	1.0000
collar trimming marking and notching.Queue	0.00003514	0.00	0.00	0.00022400	0.00	1.0000
collar turn and iron.Queue	0.00	0.00	0.00	0.00	0.00	0.00
crease button hole placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
form button hole placket.Queue	45.7560	0.38	44.0023	47.9865	0.00	96.0000
iron cuff.Queue	0.00	0.00	0.00	0.00	0.00	0.00
iron upper and lower sleeves placket.Queue	1.1754	0.04	0.8945	1.3637	0.00	8.0000
notch sleeves.Queue	15.7976	0.03	15.6999	15.9792	0.00	69.0000
runstitch cuff.Queue	10.1608	0.01	10.0765	10.2323	0.00	44.0000
Set front and back and mark neck for collar.Queue	0.01033264	0.00	0.00834912	0.01248362	0.00	1.0000
sew button placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
sew label at placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00

Figure 5.6. Bottleneck operations based on average waiting time for existing system

In the existing system, some operations show higher number of waiting time as shown in table 5.6

Table 5.6. List of bottleneck operations and their average waiting time in second

Operation no.	Operation description	Waiting time in second	Number waiting
24	Close upper placket and make	2557.07	49.7529
12	Form button hole placket	2301.91	45.7560
25	Collar close and insert label	1772.8	26.5267
31	Bottom hem	1735.63	22.6221
1	Collar run stitch	830.90	11.5692
20	Notch sleeves.	811.00	15.7976
8	Run stitch cuff.	810.62	10.1608

From table 5.6 close upper placket operation, Form buttonhole placket and Collar close and insert label operations have maximum average waiting time and most of the assembly line production system depends on those operations. These operations will stop the whole production process and yields wastes and higher lead-time in production system.

Table 5.7. List of no waiting time operations (0.0 waiting time)

In the existing system, some operations show no number of waiting time as shown in table 5.7

Operation no.	Operation description	Resource
15	sew button placket	SNLS
17	sew label at placket	JUKI DNLS
2	collar turn and iron	Helper with IRN
13	crease button hole placket	Helper
3	collar top stitch	SNLS
6	collar trimming marking and notch	Helper
5	collar band centre stitch	SNLS
4	collar band hem	DNLS
32	BH front placket and collar	BH JUKI
33	Button attach	BH JUKI

5.4 Alternative Model Development Based on Different Scenarios

Depending on their skill level and the machine type that can utilized for two or more activities with the same machine type, operators rotated through scenarios of many options. The previous simulation modelling of assembly lines does not include an operator skill matrix. But in this study, an operator skill matrix is created and used as a source of data for assigning operators to

various work stations in order to minimize cycle times of operations, lower the amount of WIP, and increase productivity of the assembly lines without affecting activity precedence.

Based on the operator skill matrix provided the following scenarios are prepared for the ultimate goal of increasing productivity of the case company.

Scenario 1: merging two or more operations based on the skill matrix and machine type.

After completion of the validation procedure, various design or reconfiguration possibilities for the assembly line assessed. To reduce the assembly line bottleneck, skilled operators added for the appropriate operations. Additionally observed queue length in line and how each resource being used.

It is crucial in this scenario first to understand the skill levels of each operator and to monitor performances. To achieve the ideal mix of different grades of operators for each line in each factory and to provide incentives and possibilities for growth to performers. The management's commitment to the ethical application of the policies and practices outlined in the worker management process is one of the most crucial elements in the construction of an effective skill matrix.

In order to determine bottlenecks and idle operations in the existing simulation layout model a number of the existing system machine utilization, waiting time of operation, average number out, number busy, number waiting and desired cycle time were taken into account. It observed that operation number 24, 12, 25, 31, 1, 20, 8 are busy process and operation number 15, 17, 2, 13, 3, 4, 5, 2, 32, 33 are idle.

As it is observed from skill matrix operation sew button placket (operation no. 15) and sew label at placket (operation no. 17) can be merged together in order to be done with the same resource and the operators have skill to accomplish the task without any guidance. Skill matrix tells information that operators has skill to operate operations (see Annex A). This means that, operator of sewing button placket can operate sew label at placket operation without supervision of coach without affecting precedence of operation since the two operations are in parallel lines. The nature of both tasks is front part of the shirt and done by helpers in the assembly lines.

assembly simulation model by Bezawork A.

Replications: 30 Time Units: Seconds

Key Performance Indicators

System Average
Number Out 338

Figure 5.7. Simulation number output result for scenario 1

From figure 5.8 for both assembly lines, we can see clearly how the capacity utilization of different resources of lines is varied. This shows that the work content of lines is not distributed uniformly among stations. In other word the lines are not balanced.

Assembly line simulation by Bezawork A.

Replications: 30 Time Units: Seconds

Resource

Usage

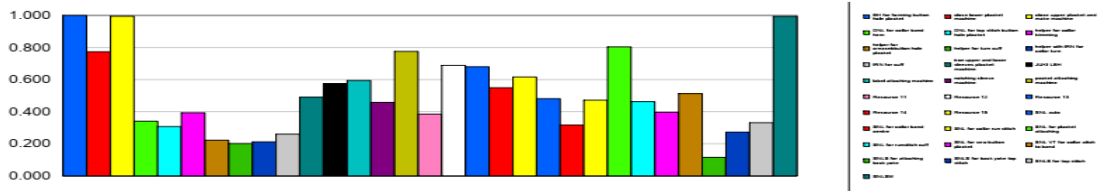


Figure 5.8. Simulation output report for resource usage of scenario 1

The result of this alternative obtained by running the simulation model the following table summarizes results based on scenario 1,

Table 5.8. Performance measurement of scenario 1

S.N	Performance measures	Value
1.	Average output/ day	338 shirts
2.	Average Resource utilization	0.5056
3.	Total number of machines required in line	33
4.	Total number of operators requires in the line	33
5.	Standard minute value (SMV)	46.86 minute
6.	Labor output/ day	10 shirts

Scenario 2: merging no queue or 0:0 waiting time operations based on resources and adding machines

Taking in to account all the conditions of the existing system model, we have developed the second scenario by merging of no queue or 0:0 waiting time operations based on resource and by adding machine in order to solve the processes problems.

Other possible alternative for merging operations is, merging collar band hem (op. 4) and collar trimming (op. 6) of the shirt. As it observed from waiting time table both have no waiting time. It have low work in progress and they are done in collar section for band hem used DNLS machine and for trimming used a helpers so the helper done those activities without interrupting the second operations with the supervision of coach skill level.

When two extra machines with their operators added to the busy operations in the existing model. Adding of 2 SNLS for helping operation of Close upper placket and make, Collar close and insert label and collar run stitch. The result of this scenario obtained by running the simulation model.

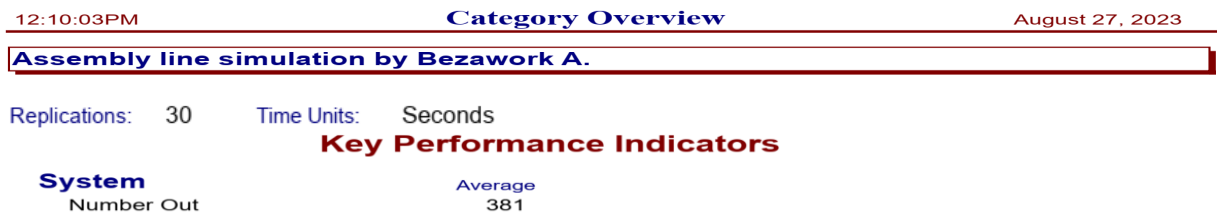


Figure 5.9. Simulation number output result for scenario 2

From figure 5.10 for assembly lines, we can see clearly how the capacity utilization of different resources of lines is varied.

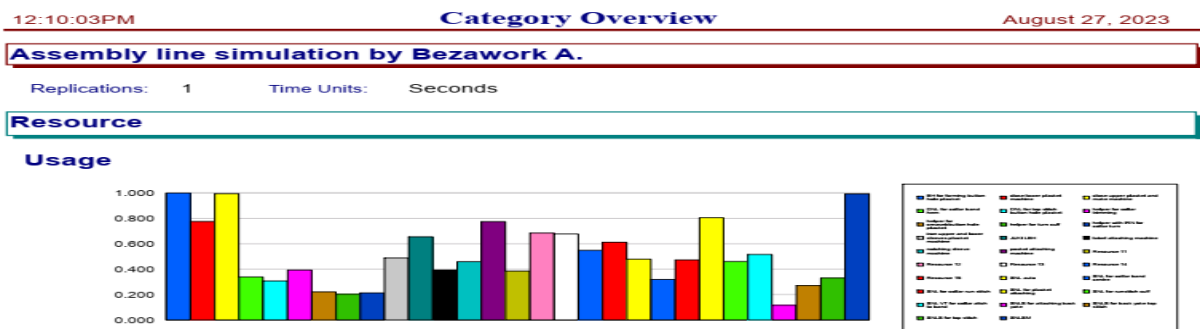


Figure 5.10. Simulation output report for resource usage of scenario 2

Table 5.9. Performance measurement of scenario 2

S.N	Performance measures	Value
1.	Average output/ day	381
2.	Average Resource utilization	0.5313
3.	Total number of machines required in line	35
4.	Total number of operators requires in the line	34
5.	Number of newly added machines	2
6.	Number of newly added operators	2
7.	Standard minute value (SMV)	44.09 minute
8.	Labor output/ day	11 shirts

Scenario 3: select ideal resources and merging operations based on operator skill matrix

Taking in to account all the conditions of the existing model, we have developed the third alternative by sharing of operational time between idle and busy operations as well as merging of idle operations in order to overcome the processes problem.

Possible alternative for merging operations with more idle resource is, merging operation collar turn and iron with cuff ironing of the shirt operations required the same machine, turning and ironing machine. From resource utilization table both resources are idle 21% and 26% of the processing time the simulation model runs. Skill matrix shows that both operators can operate operation without any the supervision of coach. In addition to nature of operations, the precedence rule of operation is not disturbed because of the processes are parallel and operations of different shirt pars (collar and caff part) respectively.

Under those scenarios operator number 5, 10 and 17 are ideal in addition to reducing number of operator 1 SNLS and one IRN machines are ideal. As it observed from waiting table operation number 24, 12, 25, 31, 20 and 8 have high amount of number waiting in queue (WIP) therefore these workstations need additional resources. From skill matrix, operator number 5 can rotated to work station 25 operator 10 to work station 12 and operator 17 to work station 24.

We have developed the third alternative by combining sharing of operational time between idle and busy Operations, merging of idle operations and merging of no waiting time operations. The result of this alternative obtained by running the simulation model.



Figure 5.11. Simulation number output result for scenario 3

Figure 5.12 showed that instantaneous resource utilization after developing scenario 3.

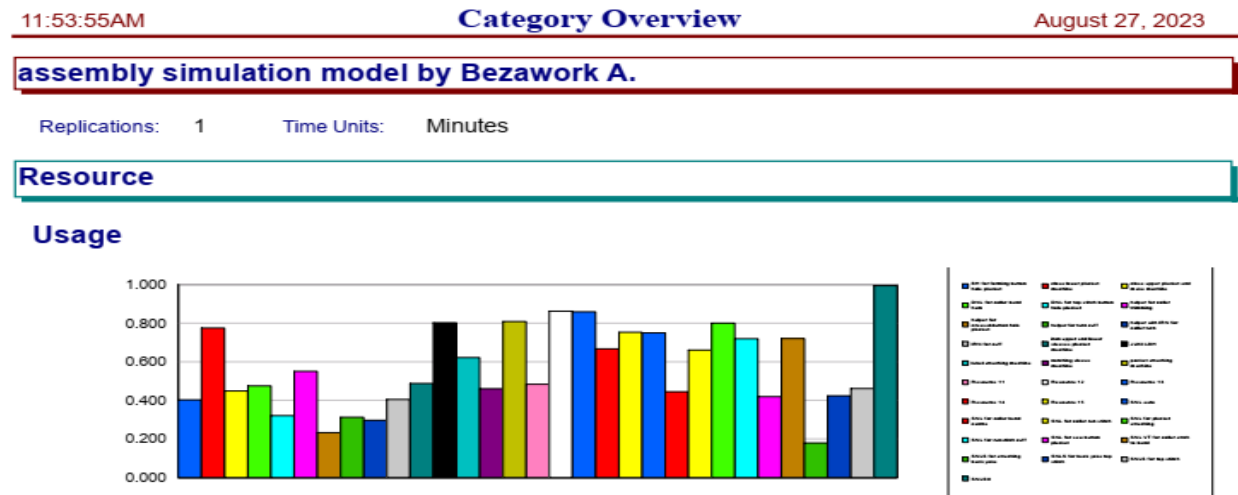


Figure 5.12. Simulation output report for resource usage of scenario 3

Having seen the performance measurements of the three line balancing scenarios, we can select the one, which is best and which can functional in the sewing line of the existing section. Before the selection process, we must identify the performance measures that can clearly tell us how much a line is balanced.

Table 5.10. Performance measurement of scenario 3

S.N	Performance measures	Value
1.	Average output/ day	474
2.	Average Resource utilization	0.6041
3.	Total number of machines required in line	31
4.	Total number of operators requires in the line	31
5.	Standard minute value (SMV)	34.41 minute
6.	Labor output/ day	15 shirts

A well-balanced line characterized by a balanced distribution of operations across the assembly line, efficient resource utilization and higher number out. Therefore, the performance measures of the three alternatives are summarize in the comparison in Table 5.11.

Table 5.11. Comparison of all scenarios in terms of various performance measurement

S.N	Performance measurements	Scenario 1	Scenario 2	Scenario 3
1	number output/day (8 hrs)	338 shirt	381 shirt	474 shirt
2	Average Resource utilization	0.5056	0.5313	0.6041
3	Standard minute value (SMV)	46.86 min	44.09 min	34.41min
4	Labor output/ day	10 shirts	11 shirts	15

5.5 Development of the proposed model

The Proposed model developed after the analysis of existing model's performance. During the analysis, the bottlenecks and idle stations known. The bottlenecks identified based on waiting time and number waiting in queues. Whereas the idle operations identified based on resource utilization. In the development of the proposed model, the first thing to done is balance the line manually using the time study at hand and then interpret it to simulation model. To balance a line manually there are various techniques we use sharing of operational time between idle and busy

Resources	Average Instantaneous Utilization		
	Existing	Scenario 1	Scenario 2 & 3
BH for forming button hole placket	1.0000	1.0000	0.4022
Close lower placket machine	0.7736	0.7760	0.7745
Close upper placket and make machine	0.9956	0.9955	0.4489
DNL for collar band hem	0.3401	0.3389	0.4747
DNL for top stitch button hole placket	0.3073	0.3070	0.3210
Helper for collar trimming	0.3933	0.3927	0.5507
Helper for crease button hole placket	0.2220	0.2214	0.2326
Helper for turn cuff	0.2013	0.2022	0.4047
Helper with iron for collar turn	0.2115	0.2126	0.2961
Iron upper and lower sleeves placket machine	0.4906	0.4888	0.4047
JUKI LBH	0.5747	0.6557	0.8020
Label attaching machine	0.5940	0.3934	0.6220
Notching sleeve machine	0.4578	0.4595	0.4603
Placket attaching machine	0.7760	0.7749	0.8086
SNL auto	0.4812		0.7501
SNL for collar band center	0.3166	0.4793	0.4439
SNL for collar run stitch	0.4721	0.3182	0.6609
SNL for placket attaching	0.8046	0.4732	0.8005
SNL for run stitch cuff	0.4619	0.8055	0.7189
SNL for sew button placket	0.3964	0.4598	0.4189
SNL VT for collar attach to band	0.5125	0.5154	0.7206
SNLS for attaching back yoke	0.1148	0.1150	0.4830
SNLS for back yoke top stitch	0.2724	0.2705	0.4235
SNLS for top stitch	0.3309	0.3297	0.4612
SNLSM	0.9937	0.9935	0.6672

1. Operational time-sharing between idle and busy operations

The following table summarizes the line balancing of operations done by sharing of SMV between idle and busy operations.

Table 5.12. Balanced operating time by sharing of operation

R.no;	Idle operations			Bottleneck operations		
	operation code	SMV	Balanced time	operation code	SMV	Balanced time
1	5	1.01	0.77	25	1.47	0.77
Remark: operation #5 can work 1.01 min and share work with operation #25 for the last 0.46 min						
2	10	0.612	1.23	12	1.865	1.23
Remark: operation #15 work 0.612 min & share work with operation #17 for the last 1.253 min						
3	17	0.763	1.06	24	1.365	1.06
Remark: operation #19 can work 0.763 min & share work with operation #20 for the last 0.602 min						

2. Merging of operations;

Sew button placket (operation no. 15) and sew label at placket (operation no. 17) can be merged together in order to be done with the same resource (SNLS) with 0.76 and 0.61 min SMV respectively, but they are idle since the cycle time is 1.42min/piece. Therefore, we can merge these operations to be done by one operator and one machine by removing operator 15 along with SNLS.

Merging collar band hem (op. 4) and collar trimming (op. 6) of the shirt. It has low work in progress and they are done in collar section for band hem used DNLS machine and for trimming used a helper with 0.78 and 0.61 min SMV respectively the cycle time is 1.42min/piece. Therefore, the helper can do those activities without interrupting the second operations with the supervision of coach skill level.

Merging operation collar turn and iron (op. 2) with cuff ironing (op. 9) of the shirt operations required the same machine, helper and ironing machine with 0.67 and 0.68 min SMV respectively the cycle time is 1.42min/piece. Therefore, we can merge these operations to be done by one operator and one machine by removing operator 9 along with IRN.

Now we will be developing computer simulation model for the purpose of experimentation with the system. It will developed based on the findings of the manual line balancing which carried out in the above sections.

3. Balanced the operation and reduce distance movement

On the below table showed that there is different movement distance between each operation and it needs to reduce and merge operation those have related and have excess number of labour with machine. When unwanted movement reduced, also SMV value is changed or (reduced).

Table 5.13. Balanced the operation and reduce distance movement

S/N	Operation	Move's (m)	Time(sec)	SMV	Remark
1.	Collar run stitch	2	12	0.71	
2.	Collar turn and iron Cuff turn and iron	2	12	0.25	Merge and reduce distance
3.	Collar top stitch	3	18	1.26	
4.	Collar band hem	2	12	0.51	reduce distance
5.	Collar attach to band	3	18	1.46	Merge and reduce distance
6.	Collar trimming marking and notching				
7.	Collar band centre stitch	2	12	0.42	reduce distance
8.	Run stitch cuff	2	12	0.74	reduce distance
9.	Turn cuff	3	18	1.14	
10.	Top stitch cuff	3	18	1.49	
11.	Form button hole placket	2	12	1.37	
12.	Crease button hole placket	2	12	0.49	reduce distance
13.	Top stitch button hole placket	2	12	1.14	
14.					
15.	Sew button placket Sew label at placket	2	12	0.40	Merge and reduce distance
16.	Attaching big placket	2	12	1.06	
17.	Attach back yoke with back panel	2	12	0.41	reduce distance
18.	Back yoke topstitch	2	12	1.41	
19.	Notch sleeves	2	12	0.70	

20.	Iron upper and lower sleeves placket	3	18	1.29	
21.	Close lower placket	2	12	0.51	
22.	Close upper placket and make	2.1	12	1.87	
23.	Collar close and insert label	2	12	1.48	
24.	Side seam	2	12	1.00	reduce distance
25.	Set front and back and mark neck for collar	2	12	0.68	
26.	Shoulder attach	2	12	1.62	
27.	Shoulder top stitch	2	12	0.43	
28.	Top stitch armhole	2	12	1.43	reduce distance
29.	Bottom hem	2	12	1.88	
30.	BH front placket and collar	2	12	1.26	
31.	Button attach	1.5	10	1.27	
	Total	67.6m	406sec	31.36	
			6.77min		

Depend up on table 5.13, merge the operation, reduce distance movement, worker and materials (machine and table) through considering above terms, like Exist space between operation, Related operation (consecutive operation, Workers physical movement, Standard operation process, Quality of product and Machine or manual operation (table).

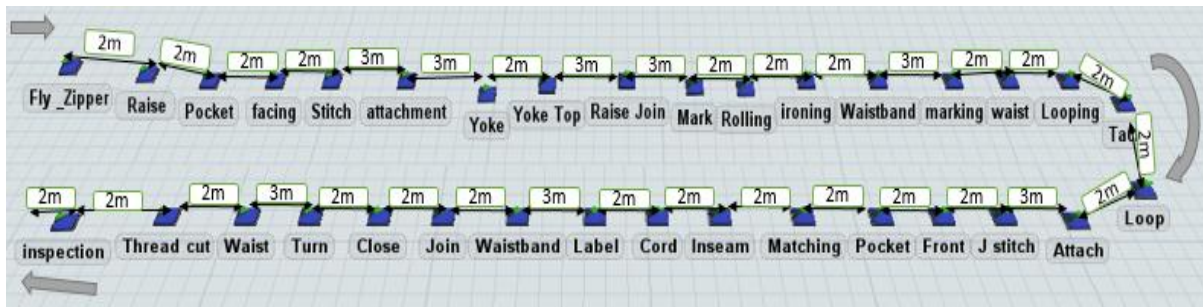


Figure 5.13: improved and arranged process flow

$$\text{Output per day} = (33 * 480)/31.36 = 474 \text{ output per day}$$

$$\text{Overall efficiency} = 474/600 * 100 = 79\%$$

$$\text{Output per labour/day} = 474/33 = 15 \text{ output per labour per day.}$$

$$\text{Reduced unwanted movement/year} = \text{existed movement} - \text{proposed distance movement} = 42273\text{m} - 67.6\text{m} * 305 = 42273\text{m} - 20618\text{m} = 21655\text{m/year}$$

Waiting time per year = 6.77min*305 = 2064.85min/year

Reduced Waiting time per year = 4239.5min - 2064.85min/year = 2174.65min/year

Product Loss due to waiting time per year = [2064.85min/year]/ 31.36 = 66per year

Reduced product loss per year = 93 per year - 66per year = 27 loss per year.

Loss in birr due to waiting time per year = 27per year * 800birr = 21600birr loss/year

Reduced loss in birr per year = 74400birr/year - 21600birr loss/year = 52800birr / year

5.6 Comparison of Existing System and Proposed System

The aim of this proposed simulation is to show the improved sewing line layout and balancing activities that assemble shirt parts and analyze their performance. Therefore, to improve the problems, the proposed simulation model for the line balancing of shirt production provides the planning manager with a simulation-based optimization tool that helps to gain information without disturbing the actual system and improves system effectiveness to increase the productivity of the company.

Table 5.14. Comparison of the existing and proposed assembly line

S.N	Performance measures	Existing system	Proposed System
1.	Average output/day (in quantity)	349 shirts	474 shirts
2.	Average Resource utilization (in %)	0.53	0.69
3.	Total number of machines (in quantity)	33	31
4.	Total number of operators (in quantity)	33	30
5.	Labor productivity (output/day)	12.6	15
6.	Line length (in meter)	138.6	67.6
7.	Overall performance (%)	58.2	79
8.	Waiting time due to unwanted movement/day(minute)	13.9min	6.77min
9.	Product loss per year(in quantity)	93	66
10.	Product Loss in birr due to waiting time (birr/year)	74,400	52,800

In the figure 5.14 showed to the comparison between the existed and improved system.

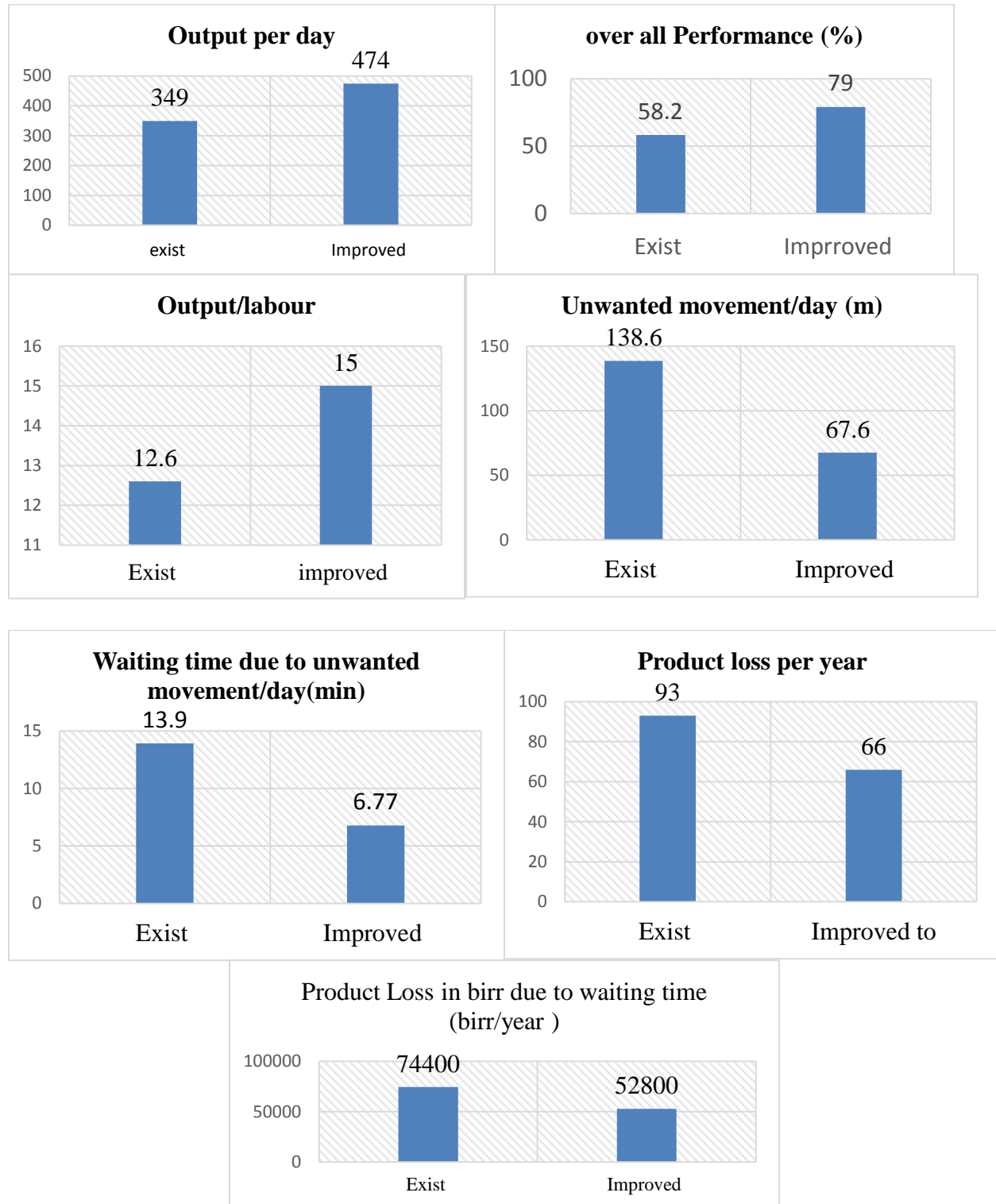


Figure 5.14: Comparison between exist system and improved system.

From table 5.15, machines used some reduced machine for others production process and spar part replace during maintenance.

Table 5.15: Reduced machines and worker

Reduced types of machines and labor	Reduced in number
IRN	1
SNL	1
Workers	2

5.7 New discovery from previous studied

According to Yamane's (2020) study, increasing the assembly line's productivity from 42% to 58.42% without increasing the cost of the machines and the workers involves gathering information about the number of operators, processing times for individual operations, and the order of jobs to assign to workstations using simulation. However, in this study, critical production factors were not analysed, and the developed model did not fully consider the operator skill matrix.

According to the Tesfaye Bayeh (2019) study, the total output of the preparatory line increased from 238 to 280 pieces per day and that of the assembly line from 253 to 275 pieces per day. It was accomplish by time-study data collected from the real system export production line and analysed with an arena input analyser to develop a simulation model, but operator skill and critical production factors were not analysed.

Bongomin, O. (2020): Study to improve garment assembly line efficiency using line balancing technique and its applicability in two-line balancing scenarios while ignoring the operators' skill levels and important variables influencing the production

According to Shumon M, (2019) study, productivity improved through line balancing by using simulation modelling. By merging manual line balancing methods with computer simulation models, it increased the number of throughputs per day and labour output per day. It does not reduce costs or increase productivity cycle time. It decreases in non-value-added activity.

But in this study garment industry production improved by considering sequence of operations, operators skill, available space required, available resource and SMV of each operations are take in account.

5.8 Kanban lean tools in the bundling section for the effectiveness of the overall production process

Data collected from the customer order specifically for line two out of the three assembly lines and on the bundling section of Lucy Company and the line was producing men's dress shirt.

Materials used

- White board
- Kanban card

Preparing the Kanban board

The first step of implementing the study is preparing a Kanban board. In order to prepare the Kanban board, letters will assigned to the parts of the men's dress shirt to produce.

Such like -

- | | |
|--------------------------------|------------------------|
| ▪ A – for sleeve | E – for sleeve placket |
| ▪ B – for front panel | F – for pocket |
| ▪ C – for back panel with yoke | G – for collar |
| ▪ D – for yoke (label) | H – for collar band |
| ▪ I – for cuff | |

The board used in the bundling section particularly used to check the cutting parts whether they should have to stay on the shelf or out of the shelf by naming them as input and output.

Date –

Colors

Style – slim fit men’s dress shirt

Target

A – Sleeve				B – Front panel				C – Back with yoke			
				B1 – right front		B2 – left front					
Input		Output		Input	Output	Input	Output	Input		Output	
D – Yoke (label)				E – Sleeve placket				F – Pocket			
				E1 – Big sleeve placket		E2 – Small sleeve placket					
Input		Output		Input	Output	Input	Output	Input		Output	
G – Collar				H – Collar band				I – Cuff			
G1 – inside collar		G2 – outer collar		H1 – inside Collar band		H2 – outer collar band		I1 – inside cuff		I2 – outer cuff	
Input	Output	Input	Output	Input	Output	Input	Output	Input	Output	Input	Output

The above format with table shows the follow up Kanban board where the items can be under control in the bundling section. Then the authorized person, which is, literally the cutting department head can easily observe or visualize which components are in the sewing line so called as “output” and which components are on the shelf described as “input”.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In order to generate higher profits and improve customer satisfaction, the garment industry must focus on increasing productivity. Lucy Garment Industry, a producer of long sleeve slim fit shirts, faces several challenges, including an unclear flow of production, excessive work-in-progress (WIP), and high inventory levels. There is a significant gap between the expected output plan of 600 pieces per day and the actual output of 349 pieces per day, resulting in an overall performance of 58.2% and an output of only 11.6 pieces per laborer per day. Additionally, the company experiences issues such as excessive distance movement, financial losses, and factors that negatively affect productivity, such as unwanted movement, unbalanced operations, ineffective time management, low labor motivation, product loss, low output per laborer, and high inventory levels.

To address these challenges and improve productivity, this study implemented various strategies. As a result, the daily output increased from 349 pieces to 474 pieces, leading to an overall efficiency improvement from 58.2% to 79%. Furthermore, the output per laborer per day increased from 11.6 pieces to 15 pieces. The study also successfully reduced distance movement from 138.6m to 67.6m, resulting in a reduced loss of 21,600 ETB per year. Ineffective time reduced by 2,175 minutes per year, and labor requirements optimized by reducing the number of laborers by two. Additionally, spare parts utilized for machine maintenance, resulting in improved machine utilization.

To support these improvements, Kanban lean manufacturing tools, such as visual cards or billboards, used to enhance task management and reduce wastage. Effective and committed management played a crucial role in driving these productivity improvements. The study emphasizes the importance of involving all stakeholders at the organizational level to ensure successful implementation of the proposed strategies. Furthermore, the study provides recommendations for the implementation of the study results, outlining the basic requirements necessary for successful execution.

In conclusion, this study has successfully addressed the challenges faced by Lucy Garment Industry and proposed effective strategies to enhance productivity. By implementing the recommended measures, the company can achieve higher output, increased efficiency, reduced wastage, and improved overall performance. These improvements will ultimately lead to higher profitability and greater customer satisfaction in the highly competitive garment industry.

6.2 Recommendations

Based on the findings and conclusions of this study, the following recommendations proposed to improve the production system flow and overall productivity of Lucy Garment PLC:

1. **Optimize Resource Allocation:** Conduct a thorough analysis of resource utilization in the production system, including labor, machines, and materials. Identify and address any imbalances or inefficiencies in resource allocation to ensure optimal utilization and minimize bottlenecks.
2. **Improve Production Planning and Scheduling:** Enhance the accuracy and effectiveness of production planning and scheduling processes. This includes aligning the expected output plan with the actual capacity and capabilities of the production system, as well as considering factors such as machine downtime, maintenance schedules, and labor availability.
3. **Enhance Training and Motivation of Employees:** Provide comprehensive training programs to employees, focusing on improving their skills and knowledge related to their specific roles in the production system. Additionally, implement strategies to motivate and engage employees, such as recognition programs, performance incentives, and opportunities for growth and development.
4. **Continuously Monitor and Evaluate Performance:** Establish a system for ongoing monitoring and evaluation of the production system flow and productivity. Regularly review performance metrics, identify areas of improvement, and implement corrective actions as necessary.
5. **Foster a Culture of Continuous Improvement:** Encourage a culture of continuous improvement within the organization. This involves promoting a mindset of seeking out

opportunities for enhancement, encouraging employee suggestions and feedback, and implementing a system for capturing and implementing improvement ideas.

By implementing these recommendations, Lucy Garment PLC can optimize its production system flow, reduce inefficiencies, and improve overall productivity. These measures will not only enhance profitability but also contribute to increased customer satisfaction and a competitive advantage in the garment industry.

6.3 Future Work

While this study has provided valuable insights into improving the production system flow and productivity of Lucy Garment PLC, there are several areas that could be explored further in future research. These include:

- ✓ **Implementation of Advanced Technologies:** Investigate the potential benefits of incorporating advanced technologies, such as automation, artificial intelligence, and data analytics, into the production system. Explore how these technologies can optimize resource allocation, improve process efficiency, and enhance decision-making.
- ✓ **Employee Empowerment and Engagement:** Investigate the impact of empowering and engaging employees in the decision-making process. Examine how involving employees in problem-solving, decision-making, and process improvement initiatives can enhance productivity, job satisfaction, and overall organizational performance.
- ✓ **Performance Measurement and Benchmarking:** Further, develop and refine performance measurement metrics and benchmarking practices specific to the garment industry. Explore industry-specific key performance indicators (KPIs), establish industry benchmarks, and compare the performance of Lucy Garment PLC with other similar organizations to identify areas for improvement.
- ✓ **Long-Term Impact Evaluation:** Conduct a long-term evaluation to assess the sustainability and durability of the proposed improvements. Monitor and analyze the performance of the production system over an extended period to ensure the implemented changes continue to deliver the desired outcomes.

By exploring these areas in future research, a deeper understanding of production's system flow optimization and productivity improvement in the garment industry can be achieved. This will contribute to the development of more effective strategies and practices to enhance operational performance and competitiveness.

REFERENCE

1. Mulugeta, L., 2021. Productivity improvement through lean manufacturing tools in Ethiopian garment manufacturing company. *Materials Today: Proceedings*, 37, pp.1432-1436.
2. ETIDI, 2018. Investment Opportunity in the Cotton, Textile and Garment Industry in Ethiopia, Ethiopian Textile Industry Development Institute.
3. Debeli, D.K., Woldegiorgis, A.G. and Abate, M.T., 2023. Education and Investment Opportunities in the Textile Sector in Ethiopia—an Overview. *Quality Education and International Partnership for Textile and Fashion: Hidden Potentials of East Africa*, pp.139-156.
4. Legesse, D.A. and Singh, A.P., 2014. Productivity improvement through lean manufacturing tools: a case study on Ethiopian garment industry. *Int. J. Eng. Res. Technol*, 3(9).
5. Woldeyohannes, B. and Alebachew, T., 2020. Assessment Practices and Challenges of Training and Development at the Ethiopian Textile Industry Development Institute (ETIDI). *Assessment*, 68.
6. Rundassa, M.W., Azene, D.K. and Berhan, E., 2019. Comparative advantage of Ethiopian textile and apparel industry. *Research Journal of Textile and Apparel*, 23(3), pp.244-256.
7. Gelaw, Y.A., 2021. Experimental Study and improving the productivity of Assembly line Balancing in Teleja Garment Manufacturing in Ethiopia.
8. Kitila, L.M., Productivity Improvement through Lean Manufacturing Tools: A Case Study of Nazareth Garment Share Company. *Editorial Board*, p.69.
9. Tesfaye, G., Berhane, T., Zenebe, B. and Asmelash, S., 2016. A linear programming method to enhance resource utilization case of Ethiopian apparel sector. *International Journal for Quality Research*, 10(2).
10. Yemane, A., Gebremicheal, G., Meraha, T. and Hailemicheal, M., 2020. Productivity improvement through line balancing by using simulation modeling. *Journal of Optimization in Industrial Engineering*, 13(1), pp.153-165.
11. Shiferaw, A., 2017. Productive capacity and economic growth in Ethiopia. *United Nations, Department of Economics and Social Affairs*.

12. Sorri, R., 2010. Performance measurement and improvement of Ethiopian garment industries. *Addis Ababa University, Faculty of Technology, School of Graduate Studies, Department of Mechanical Engineering (August)*.
13. Wagaye, B.T. and Walle, G.A., 2018. Overview of Ethiopian textile industry. *Journal of textiles and polymers*, 6(2), pp.117-120.
14. Güner, M.G. and Ünal, C., 2008. Line balancing in the apparel industry using simulation techniques. *Fibres & Textiles in Eastern Europe*, 16(2), pp.75-78.
15. <https://www.allianceexperts.com/trends-in-the-textile-industry-in-Ethiopia/>
16. Jaganathan, V.P., 2014. Line balancing using largest candidate rule algorithm in a garment industry: a case study. *International journal of lean thinking*, 5(1), pp.25-35.
17. Kitaw, D., Matebu, A. and Tadesse, S., 2010. Assembly line balancing using simulation technique in a garment manufacturing firm. *Zede journal*, 27, pp.69-80.
18. Sime, H., Jana, P. and Panghal, D., 2019. Feasibility of using simulation technique for line balancing in apparel industry. *Procedia Manufacturing*, 30, pp.300-307.
19. Legesse, D.A. and Singh, A.P., 2014. Productivity improvement through lean manufacturing tools: a case study on Ethiopian garment industry. *Int. J. Eng. Res. Technol*, 3(9).
20. Yemane, A., Haque, S. and Malfanti, I.S., 2017. Bottleneck identification using time study and simulation modeling of apparel industries. In *Proceedings of the International Conference on Industrial Engineering and Operations Management Bogota, Colombia*.
21. Parvez, M., Amin, F. and Akter, F., 2017. Line balancing techniques to improve productivity using work sharing method. *IOSR Journal of Research & Method in Education (IOSRJRME)*, 7(03), pp.07-14.
22. Moktadir, M.A., Ahmed, S., Zohra, F.T. and Sultana, R., 2017. Productivity improvement by work study technique: a case on leather products industry of Bangladesh. *Ind. Eng. Manag*, 6(1), p.1000207.
23. Islam, M.M., Hossain, M.T., Jalil, M.A. and Khalil, E., 2015. Line balancing for improving apparel production by operator skill matrix. *International Journal of Science, Technology and Society*, 3(4), pp.101-106.
24. Tesfaye B., 2019. Productivity Improvement through Line Balancing: Case Study of Nazareth Garment Share Company. *Addis Ababa University, Faculty of Technology, School of Graduate Studies, Department of Mechanical Engineering*.

25. Sudarshan, B. and Rao, D.N., 2014. Productivity improvement through modular line in Garment industries. In *5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR)* (pp. 1-6).
26. Kumar, N. and Mahto, D., 2013. Assembly line balancing: a review of developments and trends in approach to industrial application. *Global Journal of Researches in Engineering Industrial Engineering*, 13(2), pp.29-50.
27. Bon, A.T. and Shahrin, N.N., 2016, March. Assembly line optimization using Arena simulation. In *Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management, Kuala Lumpur, Malaysia* (pp. 2225-2232).
28. Firake, S.T. and Inamdar, D.K., 2014. Productivity improvement of automotive assembly line through line balancing. *International Journal of Technical Research and Applications*, 2(3), pp.124-128.
29. Schweikhart, S.A. and Dembe, A.E., 2009. The applicability of Lean and Six Sigma techniques to clinical and translational research. *Journal of Investigative Medicine*, 57(7), pp.748-755.
30. Berhe, E., Abebe, B. and Azene, D., 2017. A new perspective to productivity measurement. *Total Quality Management & Business Excellence*, 28(1-2), pp.205-217.
31. Phusavat, K., 2013. Productivity management in an organization: measurement and analysis. *ToKnowPress Monographs*.
32. Mullisa, A.G. and Abdul-Kader, W., 2023. Performance improvement: a lean manufacturing case of metal tools factory. *International Journal of Industrial and Systems Engineering*, 44(4), pp.475-498.
33. Nunesca, R.M. and Amorado, A.T., 2015. Application of Lean manufacturing tools in a garment industry as a strategy for productivity improvement. *Asia Pacific Journal of Multidisciplinary Research*, 3(4), pp.46-53.
34. Bongomin, O., Mwasiagi, J.I., Nganyi, E.O. and Nibikora, I., 2020. Improvement of garment assembly line efficiency using line balancing technique. *Engineering Reports*, 2(4), p.e12157.
35. Hanan, O.A. and Seedahmed, A.I., 2019. Garment assembly line balancing using modeling and simulation. *International Journal of Scientific Engineering and Science*, 3(3), pp.4-7.

36. Mapfaira, H., Mutingi, M., Kommula, V.P., Baiphisi, D. and Kemsley, M., international journal of engineering sciences & research technology productivity improvement using simulation modeling and lean tools: a case study.
37. Esfandyari, A., Osman, M.R., Ismail, N. and Tahriri, F., 2011. Application of value stream mapping using simulation to decrease production lead time: a Malaysian manufacturing case. *International Journal of Industrial and Systems Engineering*, 8(2), pp.230-250.
38. Firake, S.T. and Inamdar, D.K., 2014. Productivity improvement of automotive assembly line through line balancing. *International Journal of Technical Research and Applications*, 2(3), pp.124-128.
39. Kader, S. and Akter, M.M.K., 2014. Analysis of the factors affecting the lead time for export of readymade apparels from Bangladesh; proposals for strategic reduction of lead time. *European Scientific Journal*, 10(33).
40. Mulugeta, N., 2011. Assembly Line Modeling and Simulation of Footwear Manufacturing (A Case Study on Ramsey Shoe Factory) (Doctoral dissertation, Addis Ababa University).
41. Kayar, M. and Akyalçin, Ö.C., 2014. Applying different heuristic assembly line balancing methods in the apparel industry and their comparison. *Fibres & Textiles in Eastern Europe*, (6 (108), pp.8-19.
42. Rambašek, L.K., Kalaoğlu, F. and Araújo, M., 2007. Analysis of Assembly Line Balancing in Garment Production by Simulation. *University Of Minnesota*.
43. Wickramasekara, A.N. and Perera, H.S.C., 2016. An improved approach to line balancing for garment manufacturing. *Vidyodaya journal of management*, 2(1).
44. Rajput, D., Kakde, M., Chandurkar, P. and Raichurkar, P.P., 2018. Enhancing efficiency and productivity of garment industry by using different techniques. *International Journal on Textile Engineering and Processes*, 4(1), pp.5-8.
45. Jadhav, S.S., Sharma, G.S., Daberao, A.M. and Gulhane, S.S., 2017. Improving productivity of garment industry with time study. *International Journal on Textile Engineering and Processes*, 3(3), pp.1-6.
46. Krishany, S. and Deegahawature, M.M.D.R., 2016. Factors affecting production performance: a case of Sri Lankan apparel industry.
47. Perera, H.A.D., 2016, October. Productivity improvement through lean tools in a Sri Lankan small and medium enterprise: A case study. In *2016 Manufacturing & Industrial Engineering Symposium (MIES)* (pp. 1-6). IEEE.

48. Oka, C., 2016. Improving working conditions in garment supply chains: the role of unions in Cambodia. *British journal of industrial relations*, 54(3), pp.647-672.
49. Firake, S.T. and Inamdar, D.K., 2014. Productivity improvement of automotive assembly line through line balancing. *International Journal of Technical Research and Applications*, 2(3), pp.124-128.
50. Kayar, M. and Akalin, M., 2014. A research on the effect of method study on production volume and assembly line efficiency. *Textile and Apparel*, 24(2), pp.228
51. Islam, M.M., Hossain, M.T., Jalil, M.A. and Khalil, E., 2015. Line balancing for improving apparel production by operator skill matrix. *International Journal of Science, Technology and Society*, 3(4), pp.101-106.
52. Kamid, S.D., 2007. *Improving Productivity of Assembly Line in a Manufacturing Company: Printed Circuit Board Assembly* (Doctoral dissertation, Universiti Tun Hussein Onn Malaysia).
53. Islam, M.S. and Liang, G.Q., 2012. Supply chain management on apparel order process: a case study in Bangladesh garment industry. *Asian Journal of Business and Management Sciences*, 2(8), pp.60-72.
54. Shikdar, A.A. and Das, B., 2003. The relationship between worker satisfaction and productivity in a repetitive industrial task. *Applied ergonomics*, 34(6), pp.603-610.
55. Jayakumar, A. and Krishnaraj, A.K., 2017. Productivity improvement in stitching section of a garment manufacturing company. *Int. J. Innov. Res. Adv. Eng*, 4, pp.8-11.
56. Rahman, S.A., Rahman, M.F., Kamal, T. and Tseng, T.L.B., A simulation-based approach for line balancing under demand uncertainty in garments industry.
57. Haque, T.M., Hossain, R.M. and Hasan, S.M., 2018. Bottleneck problem reduction of a garment manufacturing industry in Bangladesh by using line balancing technique. *International Journal of Research in Advanced Engineering and Technology*, 4(2), pp.28-32.
58. Wickramasekara, A.N. and Perera, H.S.C., 2016. An improved approach to line balancing for garment manufacturing. *Vidyodaya journal of management*, 2(1).
59. Mekala, N., Sanju, S.D., Thamaraiselvan, V. and Kavya, M., 2021, February. Implementation of Industrial Engineering concepts in Apparel Industry to improving Productivity and it's cost reduction. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1059, No. 1, p. 012027). IOP Publishing.
60. <https://garmentsmerchandising.com/how-to-calculate-allowance-time-in-garment/>
61. <https://www.onlinetextileacademy.com/benefits-productivity-improvement/>
62. Rahman, H., Roy, P.K., Karim, R. and Biswas, P.K., 2014. Effective way to estimate the standard minute value (SMV) of a t-shirt by work study. *European Scientific Journal*, 10(30).

ANNEX A: I. RATING DATA FOR OPERATORS SKILL

	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	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
1	4	4	4	3	2	3	4	4	4	4	4	3	3	4	2	2	3	3	2	4	4	2	4	4	4	4	4	4	3	4	4	2	4	2	4	3	3	2	4	2	4	3	3		
2	2	4	3	2	2	1	2	3	4	4	2	3	3	2	4	2	1	4	1	2	4	4	4	4	4	4	4	3	3	2	1	4	4	3	3	3	3	3	3	3	3	3	3		
3	4	4	4	4	3	4	3	2	4	4	3	2	1	3	3	2	3	3	4	4	4	4	4	4	4	4	4	1	3	4	3	4	3	4	3	4	3	2	3	2	3	3	3		
4	3	4	2	4	4	4	3	3	4	4	2	3	2	3	3	3	4	2	3	4	4	4	4	4	4	4	4	3	4	3	2	3	3	4	3	3	4	4	4	4	4	4	4		
5	3	2	3	2	4	4	4	3	4	4	1	3	3	3	4	2	2	1	4	2	4	4	4	4	4	4	4	1	3	4	3	2	4	2	4	2	4	2	4	2	4	2	4		
6	2	4	3	4	3	4	2	2	4	4	2	3	4	2	4	3	3	1	4	4	2	2	2	3	2	1	3	2	2	1	2	3	2	1	2	2	2	2	2	2	2	2	2		
7	2	1	1	1	1	3	4	4	4	4	2	3	2	1	4	2	2	2	4	3	4	4	4	4	4	4	4	4	2	3	3	2	2	3	3	2	2	2	2	2	2	3	3		
8	4	4	4	3	3	4	4	4	4	4	3	3	2	4	3	3	2	3	3	2	4	4	4	4	4	4	3	1	4	2	1	3	3	4	4	4	4	4	4	4	4	4	4		
9	2	4	1	2	2	3	2	1	4	4	3	2	2	3	2	3	2	4	4	2	4	4	4	4	4	4	2	1	1	3	1	2	2	3	3	0	0	0	0	0	0	0			
10	3	4	2	2	3	4	2	1	4	4	3	3	2	3	3	3	4	2	4	2	4	4	4	4	4	4	3	3	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0		
11	1	1	1	1	1	3	4	3	4	4	4	4	4	2	4	4	2	3	4	3	4	4	4	4	4	4	2	1	2	1	3	3	4	4	0	0	0	0	0	0	0	0	0		
12	3	1	3	3	2	3	4	3	4	4	3	4	4	4	4	3	2	2	2	3	4	4	4	4	4	4	1	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0		
13	2	1	3	1	1	4	2	0	4	4	2	3	3	4	2	3	3	2	3	3	4	4	4	4	4	4	3	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	
14	2	1	3	2	4	2	0	4	4	4	3	2	3	4	4	2	4	2	3	2	4	4	4	4	4	4	2	3	1	2	0	0	1	1	1	1	1	1	1	1	1	1	1		
15	1	1	0	0	0	0	3	0	4	4	3	3	3	2	4	4	4	4	4	4	4	4	4	4	4	4	1	1	3	3	0	2	0	1	1	1	1	1	1	1	1	1	1	1	
16	1	1	0	0	1	2	0	3	4	4	3	3	3	2	4	4	4	2	4	1	4	4	4	4	4	4	1	2	4	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	
17	1	1	0	3	0	0	2	0	4	4	0	3	3	3	4	4	4	2	2	4	4	4	4	4	4	4	2	2	1	3	2	4	4	4	4	4	4	4	4	4	4	4	4	2	2
18	2	1	0	0	0	0	2	2	4	4	3	3	3	2	4	3	3	4	4	2	4	4	4	4	4	3	2	3	2	3	2	3	3	4	1	1	1	1	1	1	1	1	1	1	
19	2	1	3	3	2	0	0	0	4	4	2	1	3	2	3	3	2	2	4	4	4	4	4	4	4	4	3	3	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
20	2	3	0	0	0	1	0	3	4	4	0	0	3	3	2	3	4	2	4	4	4	4	4	4	4	4	2	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
21	2	1	1	3	2	0	3	1	4	4	2	3	3	3	1	4	2	2	1	3	4	4	4	4	4	4	1	2	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
22	2	1	0	1	2	0	0	1	4	4	2	2	3	4	2	1	2	2	3	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
23	2	3	3	0	0	1	0	1	4	4	2	2	2	2	2	2	2	2	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
24	2	1	1	0	1	1	2	1	4	4	2	2	2	2	2	2	2	2	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
25	2	1	0	0	1	0	2	1	4	4	2	2	2	2	2	2	2	2	4	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
26	2	3	1	1	4	1	1	1	4	4	2	2	2	2	2	2	2	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
27	2	1	0	0	2	0	2	1	4	4	1	1	1	1	1	1	2	4	4	4	4	4	4	4	4	4	1	4	4	2	1	3	4	2	2	2	2	2	2	2	2	2	2	2	
28	2	3	0	2	0	1	0	1	4	4	1	2	2	3	4	2	3	4	4	4	4	4	4	4	4	4	1	2	4	4	1	4	2	3	4	3	4	3	4	3	4	3	4	3	
29	2	1	0	0	2	0	2	0	4	4	2	2	2	2	2	2	2	2	4	4	4	4	4	4	4	4	2	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
30	2	2	3	3	2	3	2	1	4	4	3	1	4	3	3	3	3	2	2	4	4	4	4	4	4	3	1	4	2	4	4	4	3	2	2	2	2	2	2	2	2	2	2	2	2
31	2	1	0	0	0	0	2	1	4	4	1	2	4	2	4	2	2	3	2	1	4	4	4	4	4	3	3	4	2	1	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
32	2	2	3	0	3	2	2	0	4	4	1	3	4	3	2	4	2	3	2	3	4	4	4	4	4	3	1	4	2	1	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4
33	2	3	0	1	1	2	2	1	4	4	3	2	2	2	4	2	2	4	3	2	4	4	4	4	4	4	2	4	2	3	4	1	4	4	4	4	4	4	4	4	4	4	4	4	4

II. WORKERS SKILL MATRIX RATING FOR ALL OPERATIONS IN (%)

Operator	Operation	Workers skill Matrix rating for all operations (%)
1.	collar run stitch	83
2.	collar turn and iron	70
3.	collar top stitch	81
4.	collar band hem	83
5.	collar attach to band	76
6.	collar trimming marking and notching	66
7.	collar band centre stitch	68
8.	run stitch cuff	81
9.	turn cuff	65
10.	iron cuff	67
11.	top stitch cuff	70
12.	form button hole placket	66
13.	crease button hole placket	65
14.	top stitch button hole placket	64
15.	sew button placket	53
16.	attach pocket	62
17.	sew label at placket	63
18.	attach back yoke with back panel	65
19.	back yoke topstitch	70
20.	notch sleeves	68
21.	iron upper and lower sleeves placket	68
22.	attach plackets	68
23.	close lower placket	71
24.	close upper placket and make	71
25.	Collar close and insert label	68
26.	side seam	75
27.	Set front and back and mark neck for collar	58
28.	shoulder attach	65
29.	Shoulder top stitch	65
30.	Top stitch armhole	73
31.	Bottom hem	62
32.	BH front placket and collar	68
33.	Button attach	68

ANNEX B: SEWING MACHINES USED IN CASE COMPANY AND THEIR APPLICATION AREA

S.no	Machine type	Brand	Model	Quantity	Description
1	Double needle chain stitch sewing machine	Juki	Mh-380	1	used for lapped seam sewing like side seam
2		Juki	DDL-8700-7	8	Used to attach collar
3	Double needle chain stitch Ms machine	Juki	Ms 1190	1	Used to sew armhole
4	Button setting	Juki	LKIPO3A-ss	3	Used for button setting
5	Button hole sewing	Juki	LBH-1790s	2	To sew buttonholes
6	Single needle lock stitch	Juki	DLN-5410N-7	3	Used for collar sewing
7	Single needle lock stitch	Juki	DDL-8700-7	6	Used to sew cuff
8	Single needle lock stitch	Juki	DLU-5490N-7	5	Used to stitch collar and cuff stitch
9	Single needle lock stitch with cutting blade	Juki	DDL-8700-7	1	It cuts extra collar band etc.
10	Double needle chain stitch machine	Juki	MS-380	1	Used to sleeve and side seam sewing
11	Single needle lock stitch	Juki	DMN-5420N-7	2	Used for Collar sewing
12	Single needle lock stitch	Juki	DDL-8700-7	6	Used for placket attach with sleeve
13	5 thread Over lock machine	Juki	MO-6716s	4	Used to sew side seam
14	KANSN chain stitch machine	Juki	41234	1	This machine is used for overcoat sewing

ANNEX C: DISTANCE MOVEMENT OF OPERATIONS

Operations	Move's(m)	Move's time(sec)
Collar run stitch	4	24
Collar turn and iron	9	56
Collar top stitch	3	18
Collar band hem	5	30
Collar attach to band	3	18
Collar trimming marking and notching	3	18
Collar band centre stitch	6	36
Run stitch cuff	4	24
Turn cuff	3	18
Iron cuff	8	48
Top stitch cuff	3	18
Form button hole placket	2	12
Crease button hole placket	6	36
Top stitch button hole placket	2	12
Sew button placket	6	36
Attach pocket	10	60
Sew label at placket	2	12
Attach back yoke with back panel	6	36
Back yoke topstitch	2	12
Notch sleeves	5	30
Iron upper and lower sleeves placket	3	18
Attach plackets	8	48
Close lower placket	6	36
Close upper placket and make	2.1	12
Collar close and insert label	2	12
Side seam	6	36
Set front and back and mark neck for collar	4	24
Shoulder attach	2	12
Shoulder top stitch	6	36
Top stitch armhole	2	12
Bottom hem	2	12
BH front placket and collar	2	12
Button attach	1.5	12
Total	138.6m	836sec
		13.9min

ANNEX D: STATITISTICAL OUTPUT REPORT FOR EXISTING SYSTEM ON SIMULATION MODELING

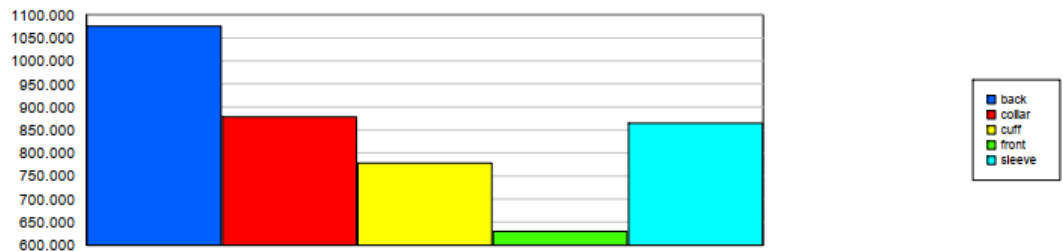
I. Entity

Replications: 30 Time Units: Seconds

Entity

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
back	1075.43	2.07	1064.00	1086.00
collar	878.20	0.23	877.00	879.00
cuff	778.27	0.17	778.00	779.00
front	630.00	0.00	630.00	630.00
sleeve	864.57	1.96	856.00	875.00



II. Queue waiting time of operations

12:10:03PM

Category Overview

August 27, 2023

Assembly line simulation by Bezawork A.

Replications: 30 Time Units: Seconds

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel.Queue	201.64	0.26	200.35	202.79	0.00	416.59
attach plackets.Queue	554.29	2.62	539.27	566.14	0.00	1205.11
attath pocket.Queue	0.01986324	0.00	0.00155545	0.04828040	0.00	15.5386
back yoke topstitch.Queue	277.52	0.91	274.09	284.63	0.00	588.24
Batch back with front.Queue	16.0795	0.04	15.7991	16.2547	0.00	83.5182
Batch collar with assembled shirt.Queue	16.6903	0.09	16.2352	17.1788	0.00	136.45
Batch cuff with assembled shirt.Queue	19.1475	0.11	18.5819	19.8832	0.00	173.40
Batch sleeve with back assembled front.Queue	15.5838	0.06	15.2026	15.9528	0.00	66.4958
BH front placket and collar.Queue	0.6849	0.05	0.4514	1.0043	0.00	28.2167
Bottom hem.Queue	1735.63	13.05	1649.63	1810.05	0.00	3518.66
Button attach.Queue	0.05285623	0.03	0.00	0.2941	0.00	31.0166
close lower placket.Queue	3.5198	0.27	2.1350	5.4224	0.00	39.5714
close upper placket and make.Queue	2557.07	15.81	2485.67	2623.76	0.00	5048.15
collar attach to band.Queue	72.7818	1.54	64.3372	80.6624	0.00	203.22
collar band centre stitch.Queue	0.00059787	0.00	0.00	0.01323552	0.00	5.2942
collar band hem.Queue	0.07085931	0.01	0.00997597	0.1758	0.00	15.2652
Collar close and insert label.Queue	1772.85	12.72	1682.95	1840.15	0.00	3499.03
collar run stitch.Queue	830.90	1.15	825.98	836.81	0.00	1707.87
collar top stitch.Queue	0.00547060	0.00	0.00	0.02331600	0.00	7.0739
collar trimming marking and notching.Queue	0.00253007	0.00	0.00	0.01612830	0.00	3.6294
collar turn and iron.Queue	0.00	0.00	0.00	0.00	0.00	0.00
crease button hole placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
form button hole placket.Queue	2301.91	18.91	2216.02	2412.76	0.00	4808.81
iron cuff.Queue	0.00	0.00	0.00	0.00	0.00	0.00
iron upper and lower sleeves placket.Queue	60.4495	1.89	46.0028	70.1330	0.00	186.33
notch sleeves.Queue	811.00	1.36	805.98	820.32	0.00	1679.80
runstitch cuff.Queue	810.62	1.17	803.89	816.31	0.00	1672.17
Set front and back and mark neck for collar.Queue	0.6657	0.03	0.5379	0.8061	0.00	18.1829
sew button placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
sew label at placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
shoulder attach.Queue	139.59	1.11	134.31	146.38	0.00	488.16
Shoulder top stitch.Queue	7.0709	0.68	3.3875	11.5344	0.00	93.3777
side seam.Queue	0.3079	0.02	0.1877	0.4380	0.00	27.6861
Top stitch armhole.Queue	0.00472130	0.00	0.00	0.01475148	0.00	2.5049
top stitch button hole placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
top stitch cuff.Queue	37.2156	1.58	28.0746	44.0431	0.00	144.59
turn cuff.Queue	0.00	0.00	0.00	0.00	0.00	0.00

III. Number waiting of operations

12:10:03PM

Category Overview

August 27, 2023

Assembly line simulation by Bezawork A.

Replications: 30 Time Units: Seconds

Queue

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel.Queue	2.5275	0.00	2.5113	2.5420	0.00	44.0000
attach plackets.Queue	10.7779	0.05	10.4857	11.0084	0.00	29.0000
attath pocket.Queue	0.00036964	0.00	0.00002900	0.00089855	0.00	1.0000
back yoke topstitch.Queue	3.4690	0.01	3.4261	3.5579	0.00	28.0000
Batch back with front.Queue	0.4996	0.00	0.4923	0.5042	0.00	2.0000
Batch collar with assembled shirt.Queue	0.4971	0.00	0.4848	0.5118	0.00	2.0000
Batch cuff with assembled shirt.Queue	0.4969	0.00	0.4813	0.5152	0.00	2.0000
Batch sleeve with back assembled front.Queue	0.4960	0.00	0.4849	0.5085	0.00	2.0000
BH front placket and collar.Queue	0.00804361	0.00	0.00529823	0.01175134	0.00	1.0000
Bottom hem.Queue	22.6221	0.16	21.5860	23.5072	0.00	47.0000
Button attach.Queue	0.00061978	0.00	0.00	0.00344192	0.00	1.0000
close lower placket.Queue	0.06843976	0.01	0.04151400	0.1054	0.00	2.0000
close upper placket and make.Queue	49.7529	0.30	48.4373	50.9786	0.00	101.00
collar attach to band.Queue	1.0109	0.02	0.8936	1.1203	0.00	6.0000
collar band centre stitch.Queue	0.00000830	0.00	0.00	0.00018383	0.00	1.0000
collar band hem.Queue	0.00098416	0.00	0.00013856	0.00244121	0.00	1.0000
Collar close and insert label.Queue	26.5267	0.19	25.2236	27.5640	0.00	54.0000
collar run stitch.Queue	11.5692	0.02	11.5006	11.6514	0.00	49.0000
collar top stitch.Queue	0.00007598	0.00	0.00	0.00032383	0.00	1.0000
collar trimming marking and notching.Queue	0.00003514	0.00	0.00	0.00022400	0.00	1.0000
collar turn and iron.Queue	0.00	0.00	0.00	0.00	0.00	0.00
crease button hole placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
form button hole placket.Queue	45.7560	0.38	44.0023	47.9865	0.00	96.0000
iron cuff.Queue	0.00	0.00	0.00	0.00	0.00	0.00
iron upper and lower sleeves placket.Queue	1.1754	0.04	0.8945	1.3637	0.00	8.0000
notch sleeves.Queue	15.7976	0.03	15.6999	15.9792	0.00	69.0000
runstitch cuff.Queue	10.1608	0.01	10.0765	10.2323	0.00	44.0000
Set front and back and mark neck for collar.Queue	0.01033264	0.00	0.00834912	0.01248362	0.00	1.0000
sew button placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
sew label at placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
shoulder attach.Queue	2.1655	0.02	2.0845	2.2618	0.00	11.0000
Shoulder top stitch.Queue	0.1096	0.01	0.05234083	0.1782	0.00	3.0000
side seam.Queue	0.00489066	0.00	0.00297139	0.00698094	0.00	1.0000
Top stitch armhole.Queue	0.00007509	0.00	0.00	0.00023459	0.00	1.0000
top stitch button hole placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
top stitch cuff.Queue	0.4652	0.02	0.3509	0.5505	0.00	4.0000
turn cuff.Queue	0.00	0.00	0.00	0.00	0.00	0.00

IV. Resource usage

12:10:03PM

Category Overview

August 27, 2023

Assembly line simulation by Bezawork A.

Replications: 30 Time Units: Seconds

Resource

Usage

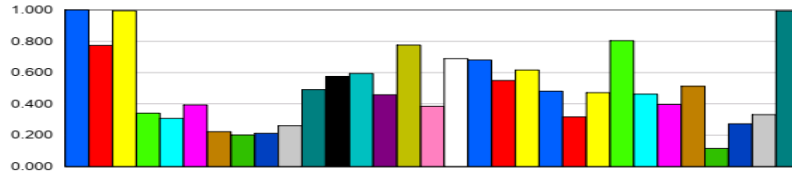
Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
BH for forming button hole placket	1.0000	0.00	1.0000	1.0000	0.00	1.0000
close lower placket machine	0.7736	0.00	0.7682	0.7797	0.00	1.0000
close upper placket and make machine	0.9956	0.00	0.9951	0.9959	0.00	1.0000
DNL for collar band hem	0.3401	0.00	0.3380	0.3433	0.00	1.0000
DNL for top stitch button hole placket	0.3073	0.00	0.3040	0.3107	0.00	1.0000
helper for collar trimming	0.3933	0.00	0.3910	0.3960	0.00	1.0000
helper for creasebutton hole placket	0.2220	0.00	0.2202	0.2247	0.00	1.0000
helper for turn cuff	0.2013	0.00	0.1998	0.2028	0.00	1.0000
helper with IRN for collar turn	0.2115	0.00	0.2097	0.2130	0.00	1.0000
IRN for cuff	0.2603	0.00	0.2578	0.2623	0.00	1.0000
iron upper and lower sleeves placket machine	0.4906	0.00	0.4862	0.4946	0.00	1.0000
JUKI LBH	0.5747	0.00	0.5668	0.5858	0.00	1.0000
label attaching machine	0.5940	0.00	0.5877	0.6002	0.00	1.0000
notching sleeve machine	0.4578	0.00	0.4543	0.4613	0.00	1.0000
pocket attaching machine	0.7760	0.00	0.7675	0.7836	0.00	1.0000
Resource 11	0.3846	0.00	0.3811	0.3883	0.00	1.0000
Resource 12	0.6886	0.00	0.6831	0.6933	0.00	1.0000
Resource 13	0.6807	0.00	0.6706	0.6885	0.00	1.0000
Resource 14	0.5490	0.00	0.5446	0.5522	0.00	1.0000
Resource 15	0.6160	0.00	0.6099	0.6241	0.00	1.0000
SNL auto	0.4812	0.00	0.4777	0.4847	0.00	1.0000
SNL for collar band centre	0.3166	0.00	0.3141	0.3195	0.00	1.0000
SNL for collar run stitch	0.4721	0.00	0.4692	0.4756	0.00	1.0000
SNL for placket attaching	0.8046	0.00	0.8002	0.8103	0.00	1.0000
SNL for runstitch cuff	0.4619	0.00	0.4593	0.4646	0.00	1.0000
SNL for sew button placket	0.3964	0.00	0.3922	0.3995	0.00	1.0000
SNL VT for collar attch to band	0.5125	0.00	0.5096	0.5159	0.00	1.0000
SNLS for attaching back yoke	0.1148	0.00	0.1141	0.1155	0.00	1.0000
SNLS for back yoke top stitch	0.2724	0.00	0.2704	0.2763	0.00	1.0000
SNLS for top stitch	0.3309	0.00	0.3287	0.3328	0.00	1.0000
SNLSM	0.9937	0.00	0.9935	0.9941	0.00	1.0000

Assembly line simulation by Bezawork A.

Replications: 30 Time Units: Seconds

Resource

Usage



ANNEX E: REPORT FROM SIMULATION OUTPUT OF IMPROVED SYSTEM

i. Entity

assembly simulation model by Bezawork A.

Replications: 30 Time Units: Seconds

Key Performance Indicators

System

Number Out

Average

474

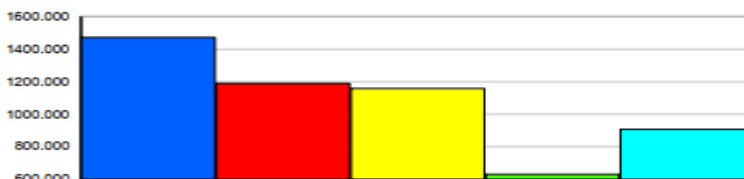
assembly simulation model by Bezawork A.

Replications: 1 Time Units: Minutes

Entity

Other

Number In	Value
back	1473.00
collar	1190.00
cuff	1159.00
front	630.00
sleeve	907.00



assembly simulation model by Bezawork A.

Replications: 1 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
cuff	14.6752	0.932100525	4.8679	46.9907
NVA Time	Average	Half Width	Minimum Value	Maximum Value
cuff	0.00	0.000000000	0.00	0.00
Wait Time	Average	Half Width	Minimum Value	Maximum Value
cuff	157.68	(Correlated)	1.3071	612.04
Transfer Time	Average	Half Width	Minimum Value	Maximum Value
cuff	0.00	0.000000000	0.00	0.00
Other Time	Average	Half Width	Minimum Value	Maximum Value
cuff	0.00	0.000000000	0.00	0.00
Total Time	Average	Half Width	Minimum Value	Maximum Value
cuff	75.4612	(Correlated)	3.9706	153.37

Other

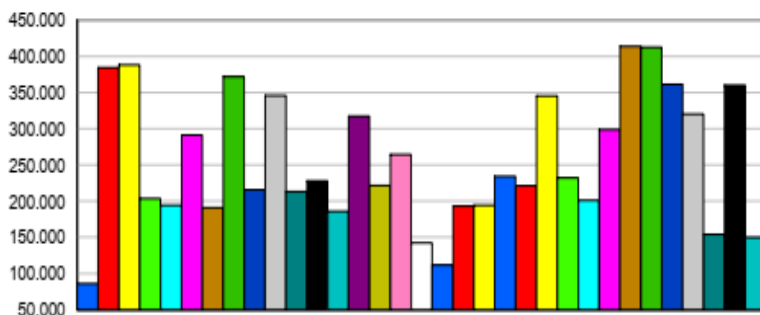
ii. Accumulated time bar chart

assembly simulation model by Bezawork A.

Replications: 1 Time Units: Minutes

Process

Accumulated Time



iii. Time per Entity

11:53:55AM

Category Overview

August 27, 2023

assembly simulation model by Bezawork A.

Replications: 1 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
attach back yoke with back panel	0.1533	0.001034716	0.1242	0.1864
attach plackets	0.6861	0.003770427	0.5919	0.7748
attath pocket	0.6931	0.003900076	0.6251	0.7749
back yoke topstitch	0.3630	0.002441429	0.3276	0.5248
BH front placket and collar	0.4087	0.005730048	0.3417	0.7346
Bottom hem	0.6125	0.003823693	0.5427	0.8352
Button attach	0.4025	0.004146496	0.3462	0.6115
close lower placket	0.6638	0.003760291	0.5531	0.7831
close upper placket and make collar attach to band	0.3848	0.035077336	0.00076669	2.3239
collar band centre stitch	0.6177	0.003266858	0.5584	0.6911
collar band hem	0.3805	0.002620053	0.3450	0.5285
collar band hem	0.4069	0.002498813	0.3628	0.5894
Collar close and insert label	0.3733	0.040066592	0.00083206	3.1724
collar run stitch	0.5665	0.002716231	0.5083	0.6249
collar top stitch	0.3953	0.002244181	0.3610	0.5722
collar trimming marking and notching	0.4720	0.002515024	0.4260	0.6001
collar turn and iron	0.2538	0.002130290	0.2285	0.3989
crease button hole placket	0.1994	0.001313338	0.1750	0.2250
form button hole placket	0.3448	0.025343545	0.00031968	2.9897
iron cuff	0.3469	0.002250115	0.3110	0.4820
iron upper and lower sleeves placket	0.4177	0.003810183	0.3633	0.6034
notch sleeves	0.3945	0.004412461	0.3448	0.7677
runstitch cuff	0.6162	0.003540079	0.5586	0.6914
Set front and back and mark neck for collar	0.4140	0.004276711	0.3442	0.6599
sew button placket	0.3590	0.002730670	0.3250	0.5000
sew label at placket	0.5331	0.001894928	0.4929	0.5990
shoulder attach	0.7384	0.005069608	0.5486	0.9289
Shoulder top stitch	0.7364	0.004509571	0.6090	0.8416
side seam	0.6452	0.005597293	0.5492	1.0419
Top stitch armhole	0.5719	0.004394884	0.4917	0.6583
top stitch button hole placket	0.2751	0.002145160	0.2418	0.3082
top stitch cuff	0.6430	0.004260026	0.5805	0.9022
turn cuff	0.2673	0.001162442	0.2500	0.3578

iv. Waiting time per Entity

11:53:55AM

Category Overview

August 27, 2023

assembly simulation model by Bezawork A.

Replications: 1 Time Units: Minutes

Process

Time per Entity

Wait Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
attach back yoke with back panel	5.2877	0.838271666	0.00	10.6826
attach plackets	9.2643	1.46796	0.00	19.0051
attath pocket	10.3916	1.76515	0.00	22.1680
back yoke topstitch	7.2627	1.14484	0.00	14.7204
BH front placket and collar	0.1439	0.050139449	0.00	1.4239
Bottom hem	28.1915	(Correlated)	0.00	56.1112
Button attach	0.1018	0.056877467	0.00	1.7058
close lower placket	0.05808485	0.015362377	0.00	0.3383
close upper placket and make	0.1325	(Correlated)	0.00	1.6965
collar attach to band	1.7734	0.299936165	0.00	4.0578
collar band centre stitch	0.00001122	0.000022894	0.00	0.00628473
collar band hem	0.00071706	0.000586686	0.00	0.0925
Collar close and insert label	28.2915	(Correlated)	0.00	56.3562
collar run stitch	19.5467	3.10209	0.00	39.5183
collar top stitch	0.00010295	0.000145434	0.00	0.02952763
collar trimming marking and notching	0.00008486	0.000120920	0.00	0.02544213
collar turn and iron	0.00	0.000000000	0.00	0.00
crease button hole placket	0.1215	0.031505596	0.00	1.0416
form button hole placket	11.9568	1.90239	0.00	26.1565
iron cuff	0.00	0.000000000	0.00	0.00
iron upper and lower sleeves placket	0.7538	(Correlated)	0.00	2.4031
notch sleeves	13.6576	2.17207	0.00	27.5422
runstitch cuff	21.2484	3.36465	0.00	42.8642
Set front and back and mark neck for collar	0.02443194	0.005765419	0.00	0.2586
sew button placket	1.1839	(Correlated)	0.00	3.8133
sew label at placket	0.00	0.000000000	0.00	0.00
shoulder attach	6.4683	1.19405	0.00	13.7211
Shoulder top stitch	0.3334	(Correlated)	0.00	1.4202
side seam	0.1142	0.035091063	0.00	0.8491
Top stitch armhole	0.08066633	0.019308135	0.00	0.6994
top stitch button hole placket	0.2653	(Correlated)	0.00	1.5732
top stitch cuff	1.0146	0.187090599	0.00	2.6406
turn cuff	0.00	0.000000000	0.00	0.00