Title: Enhancing Productivity of Garment Manufacturing Industries Through Flexible Line Balancing Method (Case in TAL Apparel)

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ABSTRACT

Assembly lines in garment industries are the basic flow oriented production systems, in which maximum production resources are assigned. In this new era of garment industries revolution, companies are struggling for remaining competitive in global market. But in Ethiopia competitiveness is still slow. In order to respond rapidly changed customer demand, firms need to enhance their productivity and efficiency. Line balancing is considered as one of effective methods in balancing complex system of production for reducing higher work in process inventories and bottleneck operations. Assembly line balancing in garments industry aims to know potential bottleneck operations in existing production system. Critical factors of the production in Tal garments manufacturing plc. was identified before assembly line balancing task for flexible line balancing system.

The first methodology taken to examine the current system of production was, critical factor identification using two years production report data of the Tal garments manufacturing plc. Other approach utilized was developing operator skill matrix for greater insight, qualified assignment, flexibility and versatility of the production system using Harvey balls. The third approach undertaken was, developing simulation model based on theoretical distribution of operations processing times to examine existing system performance and developing alternative simulation models. For developing the simulation model ten (10) samples of processing time observations were taken to determine the best fit distribution of processing times based on the least square error values using arena input analyzer.

Simulation with arena volume 14.0 software was selected with maximum relevance value in terms of flexibility & versatility, repeatability, time compression, monitoring, component integration, risk avoidance and long term applicability. The first approach used to gain critical factors like, quality workmanship, machine break down and longer repair time, quality control work in process inventory, follow up/lack of supervision wrong measurement or supply from water, to be vital few using pareto analysis. This operator skill based simulation model enable to enhance productivity of machines and labors from seven (7) pieces of shirt per day to 11 and 10 pieces of shirts per day respectively. As the researcher point of integration of critical factors and operator skill based assembly line balancing method will give new insight in balancing assembly lines of garment industries in the future studies.

Key words: productivity, assembly line balancing, critical factor, flexible, bottleneck operation and operator skill matrix

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- ALB: assembly line balancing
- SL: sewing line
- WIP: work in process
- SMV: standard minute value
- BPT: Basic pitch time
- Pcs: pieces
- GSD: general stitch data
- SPT: standard pitch time
- RPW: ranked positional weight
- PF&D: Personal, Fatigue, and Delay allowance
- VTS: video time study
- Averg: average
- MLT: manufacturing lead time
- TLT: total lead time
- SAM: standard allowed time
- Mgt: Management
- Devpt: development
- SBO: simulation based optimization
- AAMT: Advanced Analytical Methods of Training(AAMT)
- HCM: human capital management
- FSK: flexible skill knowledge
- B/H: button hole
- QC: quality control
- WS: water spider
- WIP: work in process
- O_i : observation number i
- Op. no: operation number
- Sqr. Error: square error
- m/c: machine
- seq. no: sequence number
- Oper. Operator
- O#. operation number
- Qty. quantity
- GDP: Growth Domestic Product
- KS: Kolmogorov–Smirnov

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

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. Assembly line design and structure consists of grouping and assigning a given set of tasks to a number of workstations so as 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.

Critical factors those reduces the fully utilization of resources and reasons for line stoppages should be identified before simulation modelling. Developing operator skill matrix for rotating and assigning operator at higher WIP inventories and merging operations at lower resource utilization is foundation stone for ALB tasks. Random assigning of operators to work stations may not have evidence for the assignment and bottleneck reduction. Reassignment of operators, adding and reduction of resources for balancing purpose is not guarantee for comprehensive and long term line balancing operations. A combination of critical factor identification and operator skill based line balancing line balancing through simulation method leads to maximum utilization of resources and enhance productivity of machines and labors. Critical factors in the production process were identified by recording losses of production by each factor and frequencies of occurrence in consecutives of three months of production.

Previous assembly line balancing (ALB) studies shows that application of assembly line balancing studies finding can reduce the length of production lines up to 42 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 which creates more smooth flows in production line [1].

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 reduced, 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 enhanced in reducing inputs of production. Reducing inputs in production time side, employee side, avoiding non-value-added activities, reducing work stations, increasing machine and raw material utilizations. Garments are priority sectors of the Ethiopian manufacturing sector having a substantial contribution to the GDP of the economy. Most of the apparel factories of Ethiopia are export oriented earning highly demanded foreign exchange. The Ethiopian industrial development strategy is characterized by export-led and labor-intensive industrialization. The country is emerging as the most important investment destination in its apparel sector [2].

However, it is also invested enormous challenges such has low productivity, low capacity utilization and quality, high level of bureaucracy and inefficiency in systems and processes, weak associations and regulatory bodies, weak market linkages, tailbacks in information technology, product design, lack of skilled professionals and absence of network in the international arena. Capacity utilization of domestic factories is not encouraging, and it ranges from 35% to 55% only [3].

Sewing machine utilization and man power utilization can be improved through developing flexible, critical factors identification and more variable inclusive simulation model. Ethiopia has some competitive advantages over other international competitors in textile and garments sub-sector, which include: trends of the relocation of global buyers and investors for textile and apparel product, a large number of trainable young and less costly workers, Comparative lower cost of production, and huge potential of indigenous raw cotton production. preferential trade agreement and access to all major countries in the world, huge domestic market potential, favorable government policy and financial support and incentives for manufacturing and exporting, Potential for 100% vertically integrated production facility, Engagement of International Agencies and non-government organizations are few out of thousands of opportunities.

In those studies incorporate simultaneously balancing and scheduling decisions such that integer solutions will: respect the cycle time and precedence relations, allow at most a given number of workers to perform tasks in the workpiece simultaneously, and allow each worker to perform one task at a time [4]. In general, the current Ethiopian garments industry are facing the problem of manual line balancing systems and poor utilization of their respective resources. Company competitiveness basically depends on delivering their products with in shortest lead time and higher quality. For delivering products of the company with in shortest lead time, cycle time of operations and process should be minimized as much as possible.

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. 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.

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.

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 which are critical factors of losses and successes based comprehensive models by taking Tal garments manufacturing plc. As case company.

1.2 Research Background

Apparel products are a seasonal demand; to place order with garment factories international buyer needs short production lead-time in order to meet their customer demand. The previous researchers were developed different ways of reducing wastes and increasing efficiencies as well.

But the complexity and dynamic behavior of the current garments manufacturing system requires flexible way of managing inconveniences and lower productivity. Many researchers have reported various productivity enhancing 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. But the basic goal of this research is critical factor based simulation techniques for reducing redundancy modelling and solving the production process problems at the ground level.

Even though they are a lot of possible reason for lower productivity of garment industries, improper balanced line, non- flexible model of line balancing, slow technology adoption, non-comprehensive simulation models for line balancing, insufficient training for operators and higher bottleneck operations. Assembly lines are the most important components of mass production systems. Non-balanced workload among workstations of assembly line increases work in progress (WIP) and waiting time of tasks to be processed and reduces utilization.

Assembly Line production is one of the best-used production systems. The main problem of Assembly Line balancing that often faced by the industries is the minimization of the number of workstations, cycle time and maximization of workload smoothness and work-relatedness [5].

Even though the basic objective of line balancing is minimization of work station and cycle time, the critical factors of bottleneck operations and other causes of unbalance should be known first.

The problems faced by the company are unknown and uncertain critical factors which limits the smooth flow of production system with minimum of bottleneck operations. Even though company perform different manual line balancing, the problem of poor machine utilization, higher cycle time and repetitive bottleneck operations with uncertain reason are occurring till this the time this research paper is written and presented. Problems of variations in line efficiencies are indicators of balancing the sewing lines without considering basic vital causes of variations in a given years using manual line balancing method.

This research focuses on identification of possible cause of lowering efficiencies in lines and balancing for assembly lines by considering and removing those bottlenecks through the sewing line by using arena simulation software and other appropriate tools. Because of poor line balancing culture and non-flexible methods of smoothing the production system efficiency of the sewing lines are still lower even though they are another factor as well.

1.3 Problem Statement

Ethiopia has long histories in garment and textile companies starting from 1939. Even though the country has different 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%. In Ethiopia the garment sector resource requirement is 40% of them available in and 60% of them are imported from abroad. Though the country has these opportunities, the sector production times are 45 to 60 days longer as compared with other countries [6].

Challenges available are lower line efficiencies, higher cycle time and delivery, poor resource utilization and most causes of deviation from the target value for production unit in day, a month a year are because of poor task assignment which causes higher work in process inventories, machine break down and higher rate of operator absenteeism. As the daily report of the Tal garments manufacturing company shows, hem operations and collar inserting tasks have maximum waiting time on average over 40 minutes and maximum amount of work in process inventories over 60 pieces of product.

Information obtained from the trainers and trainees show that, line balancing operations was done by simple and random assignments without considering operators skill level.

The case company named above has fourteen (14) sewing lines with forty six (46) operators without water spiders and supervisors, in each line by performing forty-six(46) operations for production of different long sleeve men shirts for global markets like Hong Kong, USA, China and etc.

Data from production report show that the average labor productivity of the company is ((1,401,500+1,393,500)/2)/14/286/46) = 7.0pcs. Per day and target productivity was 9 pcs. Per day.

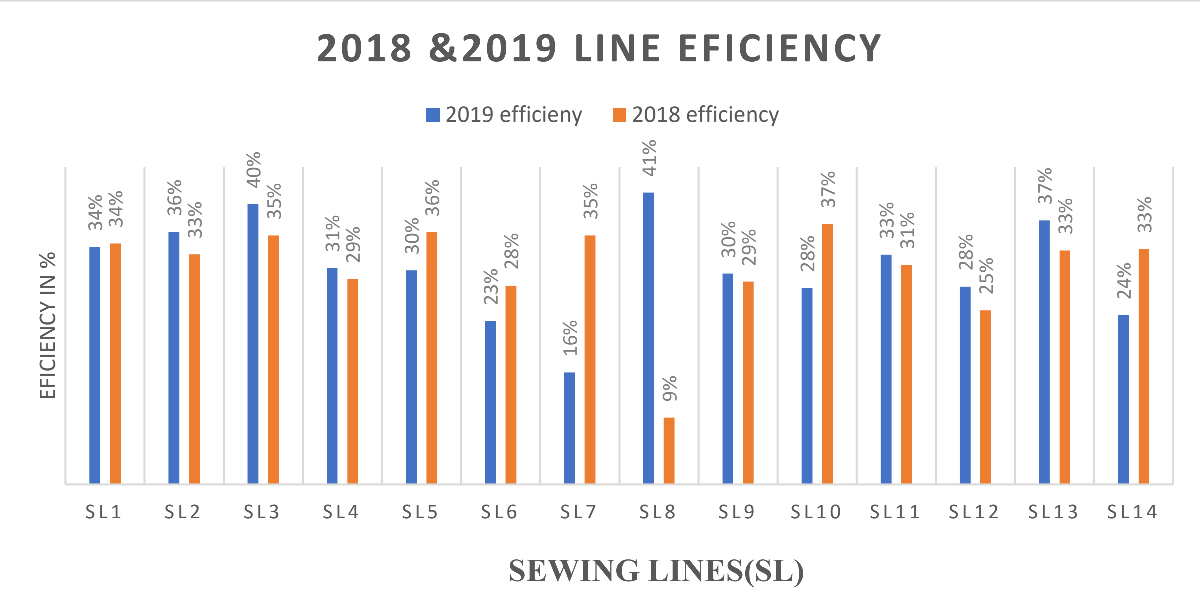


Figure 1. 1 sewing line efficiencies in 2018 and 2019 years

As it is observed from the line efficiencies and average yearly production report the labor efficiencies of each lines per day are 11, 11, 13, 10, 9, 7, 5, 13, 10, 9, 10, 9, 12, and 10 respectively. These data show that the average labor productivity of the company is 9 per day and machine productivity per day is 13. These performance measurement results are far away from target values of labor productivity per day and machine productivity per day are 13 and 18 respectively.

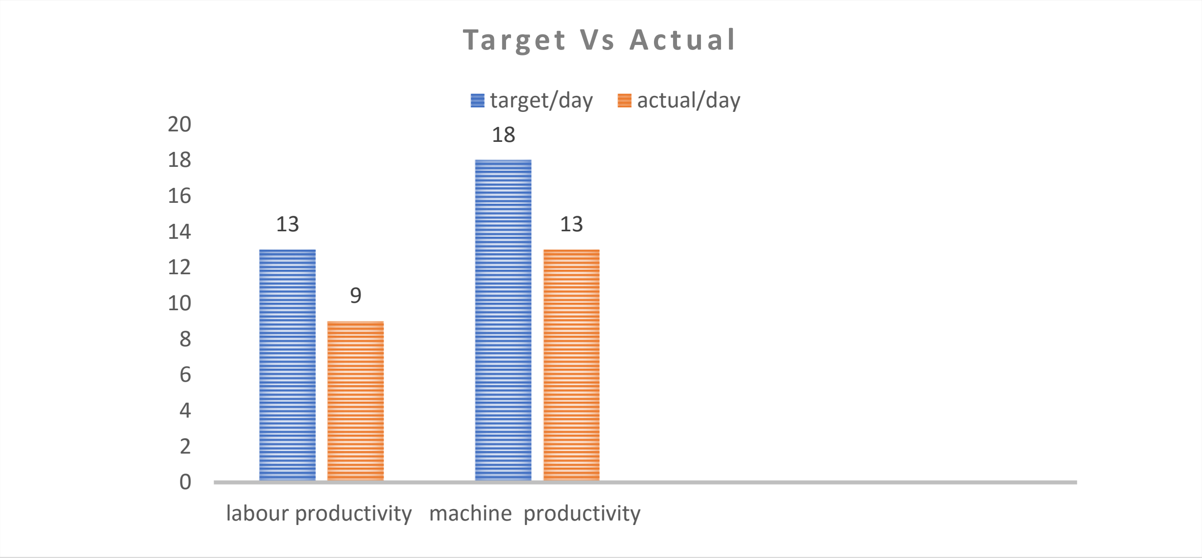


Figure 1. 2 Labor and machine productivity or utilization

1.4 Research Questions

The following research questions are emanated from the above problem of the company to be addressed in this research.

- What are the critical factors which are responsible for losses in production of the company?
- What are the principal bottleneck operations which reduces productivity the company?
- Is the company utilized the resources on hand at optimum level or not?
- In what manner operations can be merged in order to increase resource utilization and reduces number of WIP?

1.5 Research Objectives

A basic objective of this research is enhancing productivity of the Tal garments manufacturing company by developing comprehensive line balancing simulation model and identification of critical factors responsible for losses of production output.

Specific Objectives

- ✓ To identify critical factors of production and developing operator skill matrix
- ✓ To analyze existing assembly line performances and identifying bottleneck operations.
- ✓ To enhance productivity of the company by developing alternative simulation model f based on operator skill level

- ✓ To assigning tasks to work station in order to increase resource utilization and reducing maximum waiting time in a queue and WIP inventories.

1.6 Scope of the Study

Even though they are a lot of possible causes of lower productivity, starting from the supply chain management to final deliver to the end customer, this study focused only on those technical problems in assembly line section. The parameters of the study were limited in finding critical causes, identification of bottleneck operations and WIP of men's long sleeve shirt only out of other products. Developing alternative and more verified and validated simulation based on different scenarios helps to improve the section to be flexible and long term purpose of enhancing productivity. This comprehensive model is helpful for balancing the sewing line and developing flexible simulation model for the current and future productivity improvement strategies.

Even though the case company produces a lots of product kind, most of the time and well known product produced in the Tal garments manufacturing company is long sleeve men's shirt. As the report of the company shows in 2020 out of six shirts sold in America one shirt is the product of this company. As problem investigated shows most assembly line problems are appeared in this product type.

The theoretical benefit will be including of those basic resource variables in developing of simulation model those which are not included in previous studies. This study may use for higher resource utilization like labor and machine at the highest possible level in flexible and appropriate for applying future improvement strategies as well.

1.7 Significance of the Study

The empirical aspect of this study is reducing the higher deviation of actual outputs from target output per specified period of time by assigning proper tasks for proper work stations in way that removing non- value-added times and work station through line balancing methods.

Previous published materials or theories on line balancing through simulation algorithm are short fall in considering identification of critical factors lower productivity such as machine break down, operator absenteeism and other causes of production line stoppage. Even most papers of the area are considered this basic issue of investigation as a simple assumption in developing simulation model for line balancing issues. Expected outcomes:

- Critical factors of the process are identified
- Bottleneck operations of the assembly line are identified

- Queues in terms waiting time and number waiting in a queue and WIP inventories, are reduced.
- Productivity of labor, machine and company is improved

Table 1. 1 Benefits and beneficiaries of the research

Technical benefits	Economic benefits	Beneficiaries
Cycle time reduction	profit maximization	TAL apparel and Researchers
Making production system smooth	cost reduction	Students
Total idle time reduction	save time	Other apparel companies
Effective use of resources	Financial benefit	Organizations and universities

1.8 Organization of the Research

This research paper is organized in six chapters. The preceding chapter is an introductory part, which contains the research background, problem statements, research questions to be addressed, objectives, scope, and significance of the study. The next chapter is the literature review on critical factor segregations, productivity improvement on garment manufacturing companies, assembly line balancing, terminologies in assembly line balancing, formulas and modeling simulation also highlights review of studies on assembly line balancing, research gap and comparison of assembly line balancing algorisms. Chapter three focuses on the research design, data required, types of data and tool and method of data analysis assumptions and limitations

discussed. The fourth chapter deals with data collection and analysis for critical factor identification, theoretical time distribution for each operation, simulation model formulation, verification and validation of the developed model based on the previous existing data. Chapter five consists result and discussion mainly on critical factors identification and simulation model result analysis and alternative model development. At the final chapter the conclusion and recommendation of the research was addressed.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

A literature review is a validation of what has been published on a topic by previous scholars and researchers. The purpose of this chapter is to review the knowledge and studies that have been established on a topic and their strengths as well as weaknesses. It also identifies the previous research gaps and what needs to be further investigated. Moreover, this chapter focused on understanding productivity and line balancing, different improvements in apparel industry, general assembly line balancing and in apparel industry, assembly line balancing problems, related terminology, types of line balancing model definitions, concepts, and equations relating to productivity and line balancing. Implementation of different types of line balancing methods and their benefits. Developing comprehensive simulation model for the current and future production process improvement strategies also given high consideration in addition to identification of critical factors identification which are highly responsible for lower productivity of Ethiopian garment industry.

2.2. Overview of garment manufacturing industries and challenges faced

The global trend of the garment industry majorly related to intense laborious activities. As introduced before the most garment manufacturing industries in Ethiopia are at lower productivity and contribute lower incomes for the GDP of the country. Even the utilization of the sector is not encouraging report shows that it ranges from 35% to 55% [7]. They are different of reasons which causes slow production rate and higher bottleneck in garment manufacturing industries. But balancing sewing lines without considering those variables will not lead firms to flexible and long-term solutions for removing bottleneck operations and are not guarantees for applying current and future development strategies. It is highly required that developing computer simulation model which enables firms to be flexible and proper in applying different strategies for current and future development as well.

Despite the undeniably savage rivalry and quick changing client requests, today clothing ventures should continue to search for approaches to deliver different kinds of items in more limited lead-time with less creation costs and higher creation quality. Piece of clothing producing utilize light weight machines which are effortlessly moved during a line changeover. The training is to revamp the assembling line contingent upon the style needed to create. A similar machine plan may win for a few a long time for huge request amounts or it might keep going for a couple of days for low amounts furthermore, specific design custom fitted styles. As the design change quickly, the present pattern of article of clothing industry is to move towards quick change request and style amounts. Thus producing lines ought to respond quickly for fast changeovers [8].

The basic problems which cause the above lower utilization of garments industry focuses on the traditional way of production system. Most of the assembly line balancing methods and studies in previous time are not including the most variables which are the vital few causes which slowing down the productivity of the sector. Current trends, such as customers' demand for individual products and shorter product life cycles, are addressed by companies through a greater variety of products and variants. With regard to the line balancing of flow assembly systems, adjustments are associated with high investments, which requires a new planning approach for assembly line balancing.

Now a days most garments industries are facing problem with rapid changes in style and operator turn over which can fluctuate the skills of operator and tasks assigning to the work station. Previous approaches did not consider the re allocating, flexible and changeable way of balancing assembly lines in the way that traditional way of line balancing can be minimized. It is challenging more for balancing more complex manufacturing system with the traditional ways line balancing.

Under this paper it aims to cover this great problem of addressing the causes of re allocating tasks to the work station and problem of rapid style changes and higher fluctuation in skill of operator which are crucial problems for line balancing. Because of poor balancing system and methods, it was found that the assembly line is running for an average of 92 hours as overtime in a month for fulfilling the required demand [9].

Other study focusses on minimizing the cycle time (as primary objective) and the number of workers (as secondary objective) in assembly lines with multi-sided workstations. Garment manufacturing is one of the oldest, largest, labor intensive, and most dependable industries for developing countries in terms of export-oriented industrialization [10]. The problem of balancing line in garment industry is a big problem and it is difficult to find the optimal solution. Setting up the industrial sewing line by manual method, based on the experience of the line manager takes a long time while the line efficiency could not be highly achieved. To solve such problems previously a lot of assembly line balancing methods have been developed so far. Assembly line balancing method-based solution approaches are threefold: Heuristic methods, analytical methods and simulation techniques [11].

Heuristic approaches, meaning that they are based on logic and common sense rather than on mathematical proof. None of the methods guarantees an optimal solution, but they are likely to result in good solutions which approach the true optimum [12]. One of the vital views which did not given consideration in previous study was measuring reliabilities of machines which may have direct and indirect relation for flexible way of manufacturing and poor resource utilization. In the case of any machine breakdown, waiting the arrivals of the materials or part to complete the manufacturing operations, it would cause a stop in the work [13].

Today's apparel manufacturing is characterized by short product life cycles, volatile and unpredictable customer demands, tremendous product varieties and long supply process [14]. In the face of the increasingly force competition and fast-changing customer demands, today apparel enterprises must keep looking for ways to produce various types of products in shorter lead-time with fewer production costs and higher production quality. Garment industry is one of the most labor-intensive industries where the raw textile materials, by manipulating though workstations, are converted first to semi-products and then to final products. By its nature, the garment industry is very similar to other product assembly industries, for instance, the automotive industry. However, the 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 the 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 the garment industry in the process of machine and material manipulation [14].

Productivity is a measure of the efficiency and effectiveness to which organizational resources (inputs) are utilized for the creation of products or services (outputs) [15] [16]**.** In readymade garments industry, output can be taken as the number of products manufactured, while input is the people, machinery and factory resources required to create those products within a given time frame. In fact, in an ideal situation, input should be controlled and minimized while output is maximized. Productivity can be expressed in many ways but mostly productivity is measured as labor productivity, machine productivity or value productivity [17] [18].

In simple words productivity is the quantitative relationship between what we are producing and the resources inputs which are consumed [19]. Productivity gains are vital to the economy; because they allow us to accomplish more with less. A garment production system is a way how fabric is being transformed into a garment in a manufacturing system. Production systems are named according to the various factors such as number of machines used to make a garment, machines layout, total number of operators involved to sew a complete garment and number of pieces moving in a line during making a garment. Among the various production systems progressive bundle system and one-piece flow system are most commonly found in the readymade garments industries [20] [21] [22].

As a supply chain of the textile industry, the garment industry is one of the major industries in the world. The production process of garments is separated into four main phases: designing/ clothing pattern generation, fabric spreading & cutting, sewing, and ironing & packing. The most critical phase is the sewing phase. As the sewing is the heart of the apparel industry, proper design of the sewing line is needed to achieve the best output at maximum efficiency and productivity [22]. Assembly line balancing in the sewing line is to assign tasks to the workstations so that the machines of the workstation can perform the assigned task with a balanced loading with different labor skill levels [14].

2.3 Productivity Improvement on Garment Manufacturing

Higher productivity brings a higher profit margin in a business and increment in productivity level reduces garment-manufacturing cost. Hence, the 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 manpower, 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 [23]**.** Many researchers have reported various improvement techniques and performance measures with the aim of increasing garment manufacturing productivity. Lean manufacturing is a productivity improvement methodology or approach that considers the expenditure of resources on non-value-added activities to be a waste [24].

Value is defined as any activity carried out during the course of producing product or services that the customer willing to pay for [25]. Then by applying different techniques, it is mandatory to reduce non- value-added activities and increasing smoothness of sewing line activities. For removing non-value-added activities and bottleneck operations, modelling of comprehensive line balancing system is one best solution for long term smooth flow of production system.

Another approach for productivity improvement using lean manufacturing tools is proposed by [26] aimed to use and apply lean tools as way of improving manufacturing systems that lead for minimization of wastes and standardization of cycle time. On another research by [27] it shows improve productivity through optimization of cycle time by lean manufacturing techniques for reduction of non-value added activity. Moreover, [28] showed the Role of productivity improvement tools and techniques in the textile sector during manufacturing, mainly focused on time and motion study. [29] Showed to improve productivity by cellular manufacturing approach which is application of the principles of group technology in manufacturing. Cellular manufacturing used to create a concept known as single or one-piece flow. Equipment and the workstations are organized in sequences to allow for a smooth flow of materials and components through the process. The cell is made up of employs 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. By grouping similar products into families that can then 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 [30].

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 which is related with workstations in the production line which works in sequential steps. If the line is balanced well, the line balancing loss should be at a minimum. 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 assembly 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 [29]. 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 [31] effective productivity improvement model using multi skilled manpower in apparel industries is proposed by [32]. As discussed, productivity may improve by lean, cellular manufacturing, work study and line balancing. This research will follow assembly line balancing approach to improve productivity on the case factory and propose possible solutions to improve productivity.

2.4 Understanding Productivity and Line Balancing for assembly lines section

Today's apparel manufacturing is characterized by short product life cycles, volatile and unpredictable customer demands, tremendous product varieties and long supply process

[14]. Productivity is effective utilization of the resources to achieve set objectives or it can be defined as "quantity of output of a process per unit of resource input", which aligns with several approaches [33]. It arises when an increase in output occurs with a less than proportionate increase in input, or when the same output produced with fewer input".

Productivity improvements can also be understood at different levels. The productivity of individuals may be reflected in employment rates, wage rates, stability of employment, job satisfaction or employability across jobs or industries. Productivity of enterprises, in addition to output/worker, may be measured in terms of market share and export performance. The benefits to societies from higher individual and enterprise productivity may be evident in increased compositeness and employment or in a shift of employment from low to higher productivity sectors [34]. Another approach for productivity improvement using lean manufacturing tools is proposed by [25] aimed to use and apply lean tools as way of improving manufacturing systems that lead to reduction of wastes and standardization of cycle time [35] shows application of work-study to improve the productivity through the systematic analysis of existing operations, processes, work methods, and resources.

By using Ranked positional weight method number of work stations were reduced from 61 to 27 and efficiency of line was increased from 35.66% to 80.56% [35]. But in reality, processing time should not be assumed as deterministic time rather than probabilistic time.

With adding one skilled operator to the top stitch Cuff 5mm, thread cleaning and fasten Button and quality control operations the finish time on each operation was minimized to 21780, 22515 and 22573 sec respectively. The finish time of the last operation also was minimized to 24113 sec. Compared with the finish time of last operation on the real system it is found that the total efficiency was increased by 19% by using MySQL Data Base Management System (DBMS), Java language, Hyper Text Markup Language (HTML), Cascades Style Sheets (CSS) and SMARTY J [65]. But the gap here found during research literature review was unknown and undefined critical factors and undetermined skill of level of operators.

Assembly line systems typically include a high proportion of operations performed manually, which results in different operating times for the same operation that contributes to its complex nature. Besides, tasks are allocated to the workstations considering some restrictions including precedence constraints, cycle time and number of workstations and thus increasing its complexity However, assembly lines are used extensively in mass production systems to produce high quantity standardized outputs. For this reason, assembly line balancing techniques are becomes very crucial for proper functioning of the assembly line system [36].

2.5 Assembly Line Balancing for productivity enhancement

In 1913, Henry Ford completely changed the general concept of assembly by introducing Assembly Lines (ALs) in automobile manufacturing for the first time. Good assembly line is the line that has a high value of line efficiency [37]. 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 an efficient line because the line can produce higher outputs in the specific production time [38].

The aim of simulation was to observe bottleneck points and queues during production. As a result, it was found that there were many such issues in current production lines, thus it is necessary to redesign these lines to prevent time loss and the formation of queues [62].

It is essential to know the current situation of a system in order to process orders on time. In order to increase productivity, it is essential to describe the behavior of a system and to generate alternative systems [62]. These researchers used simulation modelling for short term and long term productivity prediction of complex garment manufacturing system. On other side they show that the benefit gained from the simulation software for assembly line balancing and in terms of basic decision making tool in this way "the phase a company is determining the investments it needs to make and in facilitating the decision-making process when a choice between two current situations is required. These advantages, associated to simulation, enable its use as a decision making tool, without running the risks that can arise from stopping the production line, in order to manufacture other products, which leads to financial loss analyses Managers can prevent any unexpected situations by analyzing results using the simulation model." But in this research paper critical factors of production are not studied and line balancing by re assigning operators doesn't consider the skill level of operators.

On the other study researchers have proposed a new sewing layout, where the number of workers and helpers were changed 18 Persons to 20 persons, and increasing efficiencies of lines by 77% and productivity of labor 94pcs/hr. with improved output 129pcs/hr. to 235pcs/hr. So that total output 22048pcs/month increased with the cost of labor 16000tk/month [63]. But here under this research values of the improved system layout outputs ae not validated and the researcher by him states that outputs should be verified and validated using simulation techniques. And all assignments of operator did not say anything about operator skill level.

Assembly Line production is one of the best-used production systems. The e main problem of Assembly Line Balancing that is often faced by the industries is the minimization of the number of workstations & cycle time and maximization of workload smoothness and work-relatedness. It is used to assembling quickly large numbers of a uniform product [64]. Therefore for solving problem of random assignment of operators and machines for line balancing purpose, ALB designers and researchers should develop skill matrix of operators and guarantees for assigning.

2.6 Terminology Used in Assembly Line Balancing

In assembly line balancing systems, there are various terms normally used to measure before and after implementing the new findings. The following are explanations of several common terms used in line balancing systems.

Tact time

Producing a product on assembly lines requires dividing the total work into a set of elementary operations. A tact or task is the smallest, indivisible work element of the whole work content [39]. Task time or processing time is the time required to perform a task by any specific equipment needed to manufacture the product in order to fill the customer orders. The Same or different tools might be required to produce the tasks. Producing faster than tact time leads to over-production which is a type of waste whereas producing slower than the tact or task time makes in bottlenecks where the customer orders may not be filled in time.

The calculation of Takt time is based on the target production quantity per day and on the standard time per operation.

$$Takt\ time = \frac{Total\ Available\ Production\ Time}{Average\ Customer\ Demand}$$

$$\text{Or takt time} = \frac{Total\ time\ in\ minutes}{Units\ of\ product\ produced}$$

Takt time is one of the major important Lean metrics. By defining takt time the work flow you can:

- Establish a smooth flow of work.
- Optimize the capacity to meet customer demand.
- Reduce storage costs by removing overproduction.

Work-station: - is the area within a work place related with specific operators and / or machines for accomplishing the specific task. A workstation is a physical area where an employee with tools, a worker with one or more machines, or an unattended machine performs particular sets of work together. The actual number of workstations is the total number of workstations available on the entire production line, calculated as the next integer value of the number of workstations working. A minimum number of workstations can be calculated by total task of time (the time it takes to produce the product) divided by the cycle time [37].

Cycle time: The area within a workplace related 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 is also defined as how frequently finished product comes out of the production floor [40]. 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. Cycle time is the expected average total production time per unit produced. On an assembly line or in a work cell with multiple operators, each operator will have his own time associated with completing the work he is doing.

Takt time and cycle time are definitely not the same. Takt 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 [41].

To meet the 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.

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.

Cycle time = Machine Time + Material handling time. Or

$$\text{Cycle time} = \frac{\textit{total working hour per day}}{\textit{unit required per day}}$$

$$\text{Target per day} = \frac{\text{total man power} * \text{total working hour per day}}{\text{SMV}}$$

$$\text{Labor productivity} = \frac{\textit{production output per day}}{\textit{total number of workers}}$$

$$\text{Efficiency} = \frac{\text{out pieces per day}}{\text{number of workers} * \text{total working hours per day}} * 100\%$$

Bottleneck: is a delay in the transmission of materials that slow down the production rate. This can be overcome by balancing the production line. Bottleneck Operation is a task or a step that limits an entire systems of assembly lines capacity to produce at its optimum level that results in clogging productivity, profitability, and growth. Precedence rules of operation in assembly lines are assumed and kept in mind. In the assembly line, the products have to obey this rule. The product cannot be moved to the next station if it does not complete at the previous station. Idle time is a period when a system is not in use but, available [35].

Throughput time: For a manufacturing system, the throughput is generally expressed as an hourly or daily production rate i.e., the number of parts produced per hour or day. The reciprocal of the throughput or production rate is the production time per unit of the product. For transfer lines, the throughput approximates the reciprocal of the cycle time (transfer time + longest operation time). The manufacturer should be able to handle quick delivery, thus ensures a short throughput-time at high productivity rates.

Standard Minute Value (SMV): SMV is the standard time allowed an operator (worker) to complete a task. SMV or sometimes called SAM (Standard Allocated Minute) is the time value arrived at for a task. Based on the average rate of output that qualified workers will naturally achieve without overexertion. Provided that they know and adhere to the specified method and provided that they are motivated to apply themselves to their work.

Basic Time: The basic time of a job is determined by multiplying the rating factor to the observed time (cycle time). Basic time is also expressed as Normal time. In Basic Time no allowances are included.

Normally bundle allowances should be added 10% with basic time and Machine and Personal allowances added 20% with basic time [34]

Basic Time (BT) = Observed time in (minute) * Rating (%)

Standard minute = Basic Time + (Basic Time) * (Allowance Rate)

Standard time = Basic time (1 + allowance)

$$\text{Average processing time} = \sum T_i / n_i$$

Where, n is the number of cycles

T_i = observed time of observation i

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 the weather, seasons and occasions. Lead time carries huge importance when delivering products to the respective outlets is concerned. Must need to manufacture product in order to fill the customer orders. The Same or different equipment might be required to produce the tasks. Producing faster than task time results in over-production which is a type of waste whereas producing slower than task time results in bottlenecks where the customer orders may not be filled in time.

The manufacturing lead time (MLT) of a product is the total time required to process the product through the manufacturing plant. The total lead time (TLT) of a product is the total time elapsed from the instant at which raw materials are ordered until the instant the finished product is delivered [42]. 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 [43].

2.7. Basics of pitch time and distribution of workload

Pitch time is a ratio of total processing time (SAM) of garment and the number of workers to be set for the style [44].

Basic pitch time (BPT) and standard pitch time (SPT) are calculated as follows

$$\text{Basic pitch time} = \frac{\text{net processing time}}{\text{number of workers}}$$

$$S\text{tandard pitch time} = \frac{\text{product standard time}}{\text{number of workers}}$$

Allowance: Allowance is added to the 100% time determined by a time study to give a standard time which will provide the average operator capacity (i.e., before it is possible to complete and issue that standard time for a job, certain allowances are necessary to add to the basic time) [45]. For executing all of the work, a worker needs some time for personal and physical refreshment. Therefore, a worker needs some extra time allowed for performing the job. The reason for adding these allowances is that the work study engineer has only been considering the productive work of the operator and has no taken into account the periods of the rest that are required by the operator to enable him/her to recover from the energy expanded, nor the time that he/she needs to allow attention to personal needs. There are four categories of allowances that are added to a standard time [44].

Relaxation Allowance: Relaxation is the time allowed a worker to feel up personal needs and to get back from fatigue. Relaxation allowance is divided in two ways which are: A. Personal allowance B. Fatigue allowance

A. Personal Allowance: - Personal allowance is one kind of relaxation allowance which is most common allowance in garments. This allowance is provided for the need to leave the work place such as going to wash room and fetching a drink. The common figure is about 5% - 7% of basic time.

B. Fatigue Allowance: - Fatigue allowance is uncommon allowance in garments. It is a mental and physical tiredness developed by an employee due to continuous work. This allowance is given depending on the energy expended in doing the job and to alleviate monitory. Normally it is counted as 4% on basic time.

Contingency Allowance: - Contingency allowance depends on the worker, physical strength for doing the job. It is a small amount of allowance which is given to meet the legitimate delay of work. It is counted less than 5% of basic time.

Machine Delay Allowance: - Sometimes, machines are off due to mechanical or technical problems. These are applied to the total basic time for those elements which are concerned with the operation of machinery.

Line efficiency/operator efficiency: In apparel manufacturing, skills and expertise of a sewing operator is being presented in "Efficiency" term. An operator with higher efficiency produces more garments than an operator with lower efficiency in the same time frame. When operators work with higher efficiency, manufacturing cost of the factory goes down. Secondly, factory capacity is estimated according to the operator efficiency or line efficiency. Hence, efficiency is one of the mostly used performance measuring tools.

$$\text{Line efficiency (in \%)} = \frac{\text{Total units produced by the line}}{\text{Total minutes attended by all operators}} * 100$$

Where:

• Total minutes produced by the line: To get total produced minutes multiply production pieces by SAM.

• Total minutes attended by all operators in the line: Multiply number of operators by daily working hours and convert total hours into total minutes (multiplying by 60).

To calculate the efficiency of a line for a day, the following data (information) are required from the line supervisor or records.

1. Number of operators – how many operators worked in the line in a day?
2. Working hours (Regular and overtime hours) – how many hours each operators worked or how many hours the line run in a day?
3. Production in pieces – How many pieces are produced or total line output at the end of the day?
4. Garment SAM – What is the exact standard minute of the style (garment?)

2.8. Variation of Task Times

Another important factor of the production line is the value of the task times. The task times are classified as deterministic and stochastic. The automated manufacturing system or assembly lines which are equipped by flexible machines or robots are assumed to work at a constant speed hence the deterministic task times are well fit. Sometimes the variations of the task times may be significant in affecting the performance of the system; hence, the task times is stochastic [46]. When the lines are operated manually, the variation of the task time is expected due to the skills and motivation of the employees. Moreover, due to the learning effects or successive improvements of the production process variation between the task time may occur. This is supported by [47] that assembly line balancing problem are classified into two groups, stochastic and deterministic. When the assembly lines fully automated, all the tasks will have fixed operation times. Variability (stochasticity) comes into the picture when tasks are performed manually at the workstations [58].

2.9 Literature Gaps

Different related literatures analyzed to get insights and analyze the gaps on their productivity improvement approaches; mainly specific to line balancing in garment manufacturing. The recent literatures reviewed from different sources among these journals, articles and thesis works.

Table 2.1 Literature Gap

Author	Title	Approach	Gap	Findings and solution
[47]	Productivity Improvement through Line Balancing by Using Simulation Modeling	Collecting data for processing time of each operation, number of operators and precedence of tasks to assign to work stations by Simulation method	Critical factor of production are not taken under analysis and the model developed is not sufficiently included and gives evidence for assignment of operators to work stations based on skill level of operators.	Increasing the assembly line efficiency 9 from 42% to 58.42% without incurring additional costs for machines and operators

[48]	Changeability and flexibility of assembly line balancing as a multi-objective optimization problem	mixed integer linear optimization, adaptable and flexible assembly line balancing were developed	Reallocation of assembly tasks - inherent flexibility and changeability according to requirements were developed, but the model helps for one-time simulation only. It did not include new features for future improvement policies	Built multi objective optimization model to reduce cost of production
[49]	A hybrid adaptive variable neighborhood search approach for multi-sided assembly line balancing problem to minimize the cycle time	Metaheuristic algorithm based on variable neigh boor hood	Multi sided assembly line balancing with eliminating operator hindering in the line but not including the most unknown critical activities highly responsible for slowing down performance measures.	Cycle time (as primary) yes cycle time is reduced for operation under taken objective) and the work stations as well.
[50]	Simulation Metamodeling Approach to Complex Design of Garment Assembly Lines	ranked positional weight (RPW)	Ranked positional weight with consideration of resource constraint. But heuristic methods are not including all stochastic variables and all these algorisms are based common sense rather than mathematical proofs.	Reducing number of work station from 61 to 27, idle time reduced from 75.357 to 10.077, Line efficiency increases from 35.66% to 80.56%

[11]	The Heuristic Methods for Assembly Line Balancing Problem: A Case of Vietnam Garment industry	three different heuristic methods	Developing algorithms. Not considering operators skill and processing time, machine reliabilities, missing of stochastic nature of operations and variables.	Increasing number of products per day by comparing the three different heuristics methods. It based on simple comparison of heuristic methods.
[26]	Optimization of Cycle Time by Lean Manufacturing Techniques-Line Balancing Approach	Lean manufacturing Line balancing. Identify wastes as whole and finally balancing the sewing lines	The study did not show effects of the research with performance measures and critical activities for furtherance. All focuses on the current situations only.	To improve productivity and cost by optimization of Cycle Time and reduction of non-value-added activity.
[51]	Line Balancing for Improving Apparel Production by Operator Skill Matrix	Operator Skill Matrix, operators in sewing line may have different skills and companies need to know the skill matrix their operators have.	Even though the study performs for operator skill matrix, the skill matrix may be useful for modelling but by itself it can’t be long term effective tool for flexible line balancing.	Maximum utilization of manpower in labor-intensive assembly lines, by delegating workers to various operations based on their skill.
[52]	Optimal line design of garment assembly line using SBO (simulation-based optimization)	Number of Operator Number of machines Processing time.	One factor at a time scenarios generation, not applicable for woven garments but not including the ground factors	Line efficiency increased 72.56% to 75.3%

[53]	An improved approach to line balancing for garment manufacturing	Processing time	Optimization not done One factor at a time scenario. Excluding multi variate schemes	The gap between target and achieved is reduced.
[35]	Improvement of garment assembly line efficiency using line balancing technique	Assembly line balancing techniques	Balancing with resource and considering resources, but not including causes of variations	Examine its applicability under two-line balancing scenarios (without considering skill level of operators and critical factors affecting the production system).

In general, simulation is a practical and theoretical method of for understanding the high-level of dynamics of a complex manufacturing system. Simulation has several benefits and high different benefits including [58]. Researchers in different time, have put efforts to develop computer based algorisms for simplification and optimization of line balancing problems [66], [67], [68] & [69]. Simulation of real production system have also been employed in many manufacturing organizations for designing new system, developing, implementing, and analyze manufacturing system's problem of interest. As [70] defines "computer simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and evaluating various strategies for the operating system".

- **Time compression** – the potential to simulate long years of real system with in shorter running time
- **Component integration** – the ability to integrate complex system components or entities to study their interactions and the effect of interactions in a system.
- **Risk avoidance** – hypothetical or potentially dangerous systems can be studied without the financial or physical risks that may be involved in building and war and chemical manufacturing systems and studying a real system with minimum cost.
- **Physical scaling** – the ability to study much larger or smaller versions of a system in shorter and minimum cost and convenience.

- **Repeatability** – the ability to study different systems in identical environments or the same system in different environments or scenarios for different improvement scenarios
- **Control** – everything in a simulated environment can be precisely monitored and exactly controlled with minimum level of uncertainty.

Computer simulation modeling has been applied to manufacturing industry since the late 1960's when IBM introduced its General-Purpose Systems Simulator (GPSS) package. Simulation was found to be a very useful means of analyzing the dynamics entities flow through a manufacturing system. In order to examine the following effects in a given system.

- Identify current or potential bottleneck operations and their effect on productivity.
- Examine effects of changing resource capacity in terms of cost and profit (e.g. adding or subtracting operators or units of equipment, shifts and purchasing extra machineries)
- Analyze effects of different batch sizing policies on inventory levels, throughput and lead times.
- To examine effects of random equipment breakdowns and the potential impact of applying maintenance strategies.
- To examine the relative impact on material flow velocity of reducing process variability in alternative targeted areas.
- To 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 [58].

2.10 Assembly line balancing by simulation modelling with operator skill matrix.

Assembly line balancing models should be done with integral identification of critical factor of production and operator skill matrix. Most of assembly line balancing problems are solved in the way of assigning operators to work stations for reducing bottleneck operations and making production system smooth and backlogs free.as reports from industry park shows, now a days in Ethiopian industries operator turn over and absenteeism are major problems for manufacturing firms. In order to develop simulation modelling of assembly lines developing updatable operator skill matrix and identifying critical factors of production are imperative duties of modelling.

Skill matrix is visual representation of skill level the company process operators need to perform the given the process. Developing skill matrix with different methods help company managers to know whether a company have sufficient operators at right number of operators and right skill level and positions. In assembly line balancing process supervisors and managers faced the problem of assigning right skill operators for back up absences during holiday, illness and over time operations. Therefore in order to avoid random assigning of operators for balancing, managers and supervisor need to have well designed and updated skill matrix sheet on their process shop.

2.11 Benefits Gained from Identifying Critical Factors and Designing Operator Skill Matrix

Here are some of benefits that come from having and identifying critical factors in firms:

- Greater success of firms by reducing wastes and reworks
- Helps to eliminate unrelated performance measures or focusing on principal factors only
- Helps to prioritize resource allocations and assigning operators at the right time and right skill level
- To assemble a team works based on appropriate skills for the critical factors
- To have employee feedback in organized method
- To establish and manage proper lead times and reducing longer leads times and uncertainty in production process
- To know proper order point and quantities to deliver products to customers
- To identify firm's capacity to produce, to compete and shorter time to avail in the market [71].

Benefits of developing operator skill matrix in simulation modelling:

Greater insight into tasks & requirements: Using a skills matrix, managers and supervisors of the company can easily understand exactly which skills and competences are required to perform a given operation.

Qualified replacements & peak period planning: skill matrix used for replacing during sick leave of operators and staffs or peak periods with high demand in other operations and over time production period.

Progress monitoring: When managers and supervisors maintaining their skills matrices of operators and staffs properly, they'll provide them with a very clear picture of the progress they are making at both a team and individual level of production

Flexibility & versatility: since Skills matrices are known for their flexibility and versatility, supervisors and human resource managers can update skill levels of operators and staffs easily

Key players: for incentives and upgrading companies need to identify key players of the company. Key players are most valuable operators/staffs or key players with special qualities that deliver above-average value and should be encouraged.

Greater clarity: Skills matrices provide firm employees with a clear insight into the roles they perform within their organization and output they made in.

Greater transparency: Transparency about skills and competences has a positive effect for everyone concerned.

Clearer development paths: skill matrix also form a springboard for mapping out career paths and professional development programs. By pinpointing where potential shortfalls exist within the firms in terms of skills and competences, employers can then set learning objectives and training programs for their human resources effectively and efficiently. And certainly reveal the full extent of the growth potential within the organization and competition with in the world market though shorter lead time within right quantity and quality.

Reduced stress & workload: Workloads can often become overwhelming whenever a team member is off sick or absent for an extended period. But this can be anticipated and mitigated using skills matrices. A clear picture of who has which skills allows super visors and production managers to strategically reassign operators work stations or department so that increased stress levels, workloads and absences remain manageable. This will also go a long way to preserving a pleasant and stress-free working environment.

The following table summarizes advantages, disadvantages and gaps in summary with the proposed study [72].

Table 2.2 Comparison of Assembly Line Balancing Algorism

Algorism	Advantage	Disadvantage	Relation with this paper
1.Heuristic			
Ranked positional weight	All these methods are performed for cycle time reduction and work station reduction for increasing line efficiencies by	All methods did not consider the stochastic nature of operation time and variables. Can't be applied for variety of products.	The only focus of the methods is reducing cycle time and number of work station by task sharing without analyzing the current
Enumeration method			
Hoffman method			
Moddie-Young method			
COMSOAL method			

Dynamic programming method	reducing bottleneck operations and increasing smoothness of working system	Did not have flexible manner of line balancing.	critical factors of the company. The final balanced line will not perform a long-term performance measurement
2. Simulation	More appropriate for the stochastic nature of the dynamic system and flexible manner of line balancing. Reduce more of the company costs.	Not appropriate for variety of product styles.	Previous studies did not address problem of unknown critical factors production and Operator skill matrix for Balancing assembly lines.
3. Analytical	Expert based and better accurate result for one time balancing the lines	It is common sense of balancing the lines and inadequate mathematical proofs	Not comfortable for stochastic nature of the processing time, breakdowns, market fluctuations and operator turn overs.

Table 2. 3 ALB algorisms and their relevancy values in different benefits they contribution

Relevancy	Heuristic	Simulation	Analytical
Flexibility & versatility	2	4	2
Repeatability	3	4	1
Time compression	3	4	1
monitoring	3	3	2
Component integration	3	4	0
Risk avoidance	1	3	2
Long term applicability	3	2	3
Total value	18	24	11

4 = very important, 3 = important, 2 = fairly Important and 1 = not important, 0 = never related each other

The value of total importance in terms of relevancy with the title and objective of the research, simulation software has higher value and selected for the input and output analysis.

CHAPTER THREE
METHODOLOGY OF THE RESEARCH

This research paper under the title "Enhancing Productivity of Garment Manufacturing Industries Through Flexible Line Balancing Method" is applied and experimental type of research which deals with, modelling of assembly line balancing based on the operator skill matrix and critical factors of production. Applicable and long term modelling of assembly line balancing for productivity improvement strategies depends on critical factors of production and operator skill matrix. Poorly balanced assembly lines, higher work in process, lower efficiency and the vital causes of these problems will be identified prior to developing the simulation model of assembly line system. Simulation Modelling without skill matrix of operators is valueless for assembly line balancing purposes.

3.1 Literature Survey

Literature survey is being done to analyze, developing the research idea and finding the gap from previously published journals on assembly line balancing methods, tools, data type and results they generated from the analysis. Surveys of literatures from journal articles, company reports, books, conference proceedings, dissertations, websites and internet books are done for finding the best tools, techniques, methods and easy ways of achieving the ultimate goals of this paper. For the literature survey and over 130 articles are downloaded from different journals and out of these materials seventy (70) articles and five (5) websites are cited for different purposes of literature review starting from 1991 to 2021 years.

3.2 Data Collection and Analysis

Data collection for analyzing depends on the nature of the research under investigation. Data under this paper are categorized under primary and secondary data for both qualitative and quantitative types. For this research primary and secondary data collected from the production lines of the case company to examine the existing production system performance and critical factors of production as a reason to losses in production containing the production output, critical factors, skill of operator skill levels, inputs involved, production process, number of operators and machines required and processing time for each operation.

3.2.1 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, number of sewing lines, number of operators, kinds of current layout, number of work station, processing time, activity precedence, production capacity and etc.

Strategies: Well-structured surveys, interviews, questionaries' and etc. will be taken.

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

Source of data: Case Company

Statistical tools: Histograms, excel sheets, arena input analyzer, cause and effect diagram using

Participants: Researcher, line super visors, production managers and others

3.2.2 Secondary data

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

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

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

Statistical tools: Histograms, excel sheets, arena input analyzer, importance rating tools, tables and etc.

Participant: researcher

3.3 Sampling strategy

For this paper samples of different type were taken to collect both primary and secondary data under the consideration of determining proper number of samples for better decision making process [60]. The samples taken are, samples for determining number of processing time observations required in for determining the best theoretical distribution of operation processing time. Because it is impossible to determine the number of observations required for the whole operation performed, under tis paper operation number 45 (Button holing for front placket and collar) was select since observation of it has mean processing time good approach relatively with other operations. Five preliminary sample observation was recorded using stop watch for the sample operation number 45 under table 3.1

Table 3.1 Preliminary sample for operation number 45

Observations	Processing time in seconds (x)
1	26
2	23
3	31
4	23
5	21
Sample mean ($\overline{\boldsymbol{X}}$)	24.8
Sample std. dev (S)	3.9
Number of observations required (N)	10

Sample standard deviation was calculated using eqn. 3.1 and 3.2 respectively

$$S = \sqrt{\frac{(X-\overline{X})}{n-1}}\text{.........eqn. 3.1}$$

$$N = \left(\frac{zs}{h\overline{X}}\right)^2\text{.........eqn. 3.2}$$

Where:

N = the number of observations or required for analysis

n = preliminary samples,

x = observations recorded with stopwatch in second

x = mean of initial preliminary sample,

s = standard deviation

h = half the precision interval in percent,

z = number of normal standard deviations needed for desired confidence level.

Because of most industries and processing system needs higher confidence interval in most cases 95% confidence intervals the corresponding value of normal standard deviation and half the precision interval known to be 2.0 and 0.1 respectively. Based on these two values and eqn. 3.2 we can determine number of observations required for the processing time distribution of each operation to be 9.89 which is approximately 10 observations. As the confidence level increases, the margin of error increases . That means the interval is wider. So, it may be that the interval is so large it is useless. so 95% confidence interval is pretty.

$$\text{N} = \frac{2.0*3.9}{0.1*24.8} = 9.892 \cong 10 \text{ observations}$$

Other sampling was taken determining number respondents required for collecting data of critical factor analysis. As the researcher discussed with production manager and other conserved bodies number of respondents available for the questionaries' raised and have sufficient information for the case was only twenty five individuals from different departments

3.4 Tools Selection

As per objectives and research questions of this paper arena simulation software was selected as a primary tool. Arena simulation volume 14.0 was used for examining the exist system performance and application of productivity improvement scenarios. For determining theoretical distributions of processing times of operations arena input analyzer was used sufficiently. Men's long sleeve shirt have over 46 operations at assembly process only, application of improvements scenarios manually is costive in terms of time compression, component integration, risk avoidance, physical scaling and repeatability. For critical factor identification and developing skill matrix of operators pareto analysis and excel 2019 sheets was used respectively. For designing production flow diagrams and research design Visio 2019 was used.

3.5 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 was performed, and then different proposed models were developed and measured for their performance. The simulation model for processing and running with different scenario was built using Rockwell Arena® version 14.0 simulation software. The formulation span of time of the model is based on the existing shirt processing assembly line flow production diagram which observed during production flow process observation time for consecutives of three months.

3.5.1 Model Verification

Model verification is the process to ensure that the developed simulation model is correctly implemented with respect to the conceptual model with sufficient accuracy [58]. Verification is practically seen as debugging the simulation model, which can be done with several tools such as animation by running the model. Other entity pictures are added after batching of entities as a single entity picture for verification of entities are correctly matched together. Simulation model trial runs for 30 replications were made under a variety of settings of the input parameters, to check the model output results for appropriateness.

3.5.2 Model Validation

Model validation is the task of demonstrating that the model is a reasonable replica of the actual system. Verification techniques are general while the approach taken to model validation is likely to be much more specific to the model developed, and the actual system, in question. Two different methods model validation were used, one face validation which is some one looks at the model developed it seems and give a message that the model is replica of the real shirt assembly production system. The second method was statistical validation i.e. statistical outputs like daily production output, pcs of shirts on average for daily output for the actual system and pcs of shirts. Other waiting time and WIP in production system validated the simulation model.

3.5.3 Number of Replications

Number of replications is number of simulations runs that should be executed to analyze statistically the differences between the simulation model and the real system to increase the output reliability. The output result become more accurate by doing more replication thereby possible to estimate the error introduced in modeling the real system. It has an integer value greater or equal to one [61].

For this research paper 30 simulations run were done for 480 minutes. Input distributions of simulation, processing time and others are probabilistic, the simulation outputs are also in variable number. In order to considering this variability in output result, it is better to have a number appropriate number of replications for proper decisions.

Number of replications analysis began with selecting ten primary number of simulations run. Summary statistics from this initial set of replications are then used to calculate whether additional replications are required at a particular level of confidence. Sufficient number of replications to have reasonable statistical confidence given that additional replications can always be subsequently added [41] [58]. Assumptions during simulation model, observation recording and critical factor identification was made.

3.6 Result and Discussion

After examining the existing system performance by experimentation and simulation runs, alternative models are developed. The best scenario was selected for more productivity of the system. At the end analysis conclusion, recommendation and future works were driven.

3.7 Research Design and Frame Work

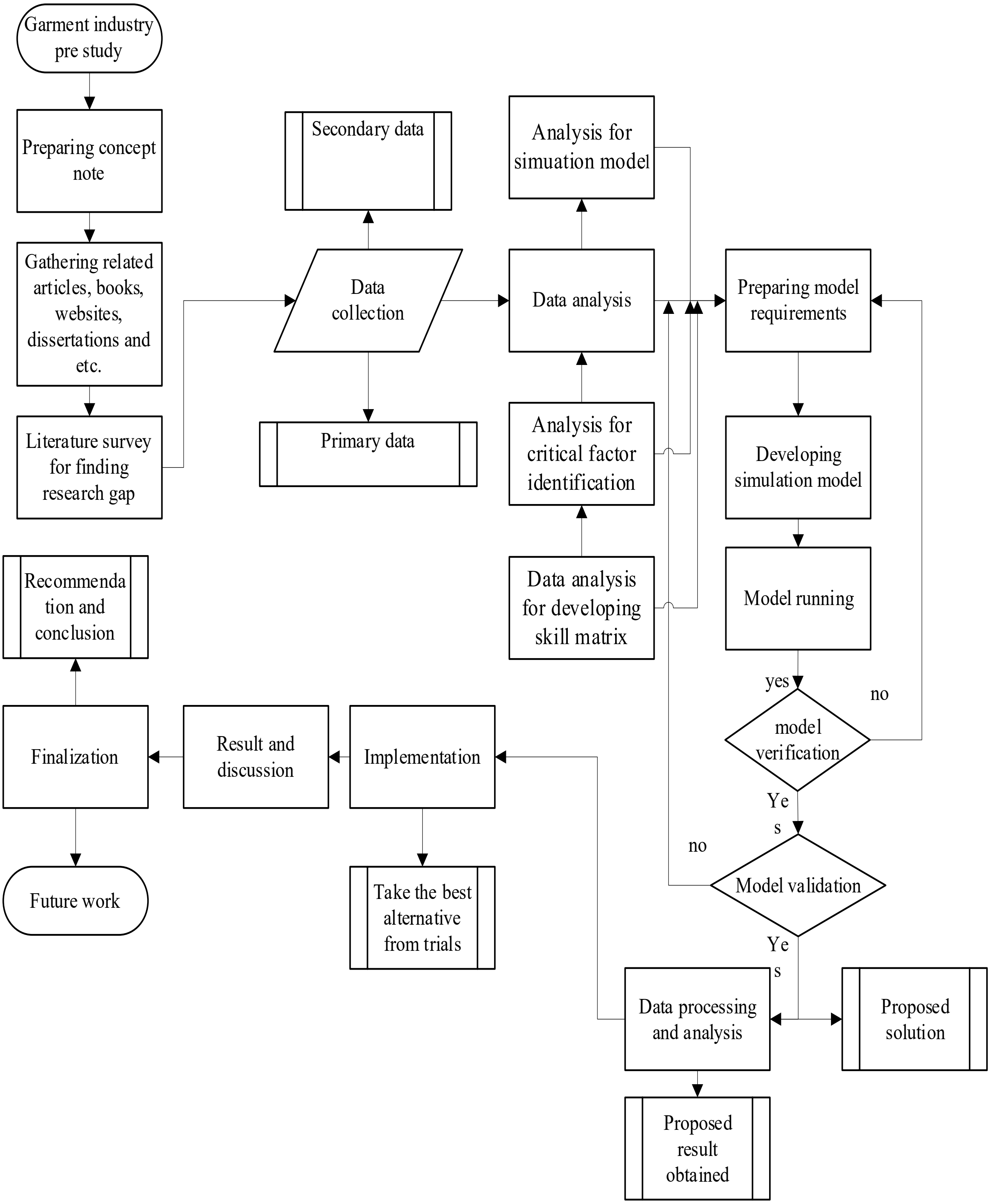


Figure 3.1 Research framework and design

CHAPTER FOUR
DATA COLLECTION AND ANALYSIS

4.1 Company overview

The story of TAL Apparel is in many ways the story of one man, CC Lee who was affectionately known as "The Textile Man". As an industrialist who moved to Hong Kong from Shanghai in 1946, CC Lee founded a local cotton spinning company that grew into a global garment giant.

For over 70 years, TAL Apparel has been the pioneer in manufacturing garments; creating processes and supply chain solutions, tailored to the exact needs of its customers. Today, the case is the world leader in producing technologically advanced garments that combine superior styles, comfort and functionality. Pioneering innovation, perfecting the art. The case company located in Ethiopia at Sidama region, Hawassa Industrial Park 271km far from Addis Ababa. It currently occupies 6 sheds. TAL manufactures various wearing and apparel, in particular shirts, which it supplies to Jespeni (USA). Here in Ethiopia the company is 11th country apparel company in the world and out of six shirts in USA one is this case company's product and highly accepted garment product in the world. The case company named above has fourteen (14) sewing lines with forty six (46) operators in each line by performing forty-six (46) operations for production of different style shirts for global markets like Hong Kong, USA, China and part of its production for Ethiopian market.

Operations of company are carried out during a daily two (2) shifts of 8 hours, with six (6) working days per week including Saturday full time, extra time being performed only in emergency cases and not on regular basis. The potential of production with the above working shifts and working time per day is approximated to one hundred sixteen thousand and seven hundred (116,700) pieces of shirts per month.

The company has over one thousand two hundred (1200) human resources for staff, operators, transportation, cleaning and securities. All workers are allowed to have lunch for first shift workers and dinner for second shift workers by company's expenses in its own canteen.

The cost associated indicates that, the company is highlighted by 55%- 60% for fabrics, 10% accessories like threads, buttons and etc. 10% workforce; 9-10% administrative cost and the remaining 15-20% as profit margin.

Texture is the essential material for assembling pieces of clothing. Articles of clothing are made by utilizing completed textures. There are various sorts of texture utilized in pieces of clothing producing. The case company uses both woven and knitted fabrics as their requirement based on their specific benefits and advantages. Woven textures are best for their various kinds of design. This sort of texture can be effectively cut into various shapes and incredible for creating various styles in the articles of clothing. Weave textures for their solace, surface, wrinkle opposition, and versatility. Essentially, sew texture is not difficult to sew with the correct machine and sewing method. Accessories and other required materials also selected based on different specification and styles of shirts.

4.2 Organizational structure of the company

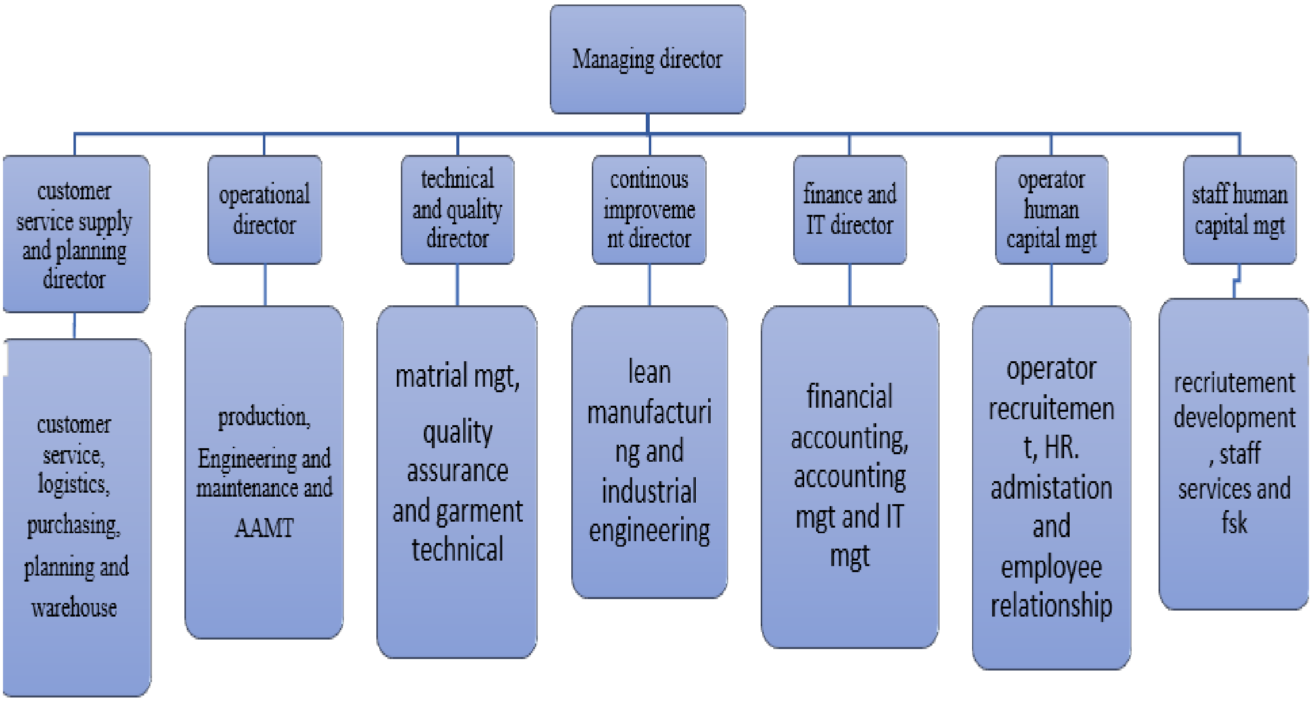


Figure 4.1 organizational structure of the company

The creation division of the manufacturing plant comprises various areas; Cutting, sewing (assembly), completing and pressing. In cutting segment various pieces of the item arranged and put as pack. At that point the slice parts moved to get together creation floor. The gathering area partitioned in to two areas. Preliminary area, for subassembly of various parts and last get together segment for each line to make the last articles of clothing. When the pieces of clothing sewed and prepared, they moved to completing and pressing areas.

The shirt assembly lines of the company constitutes straight lines type of production. Those parts in sewing lines or sub assembled parts transferred to subsequent work stations manually by using flat and strait table. After processing of the part in respected operation, the operator or helper places the component on the table where subsequent operation is to take place. If operation is to be undertaken on station not adjacent to the previous, additional helpers (water spider) are used to transfer components

4.3 Production Flow Process of Shirt Production System

The case company produces men’s long sleeve shirts for different size levels and styles. In shirt production system the first production point is cutting operation at which fabrics are cut in to different shirt parts with the help of spreader machine, spreader table with air cushion straight knife and bias cutting and winding machines to be assembled together for producing the final shirt product. Those parts will be transferred to the store which is called super market of different shirt parts to be assembled together.

The second and the basic aim of this research garment section is sewing section at which preparation and assembling operations are takes place. Assembled parts will transfer to Each and every part of shirt after sewing passes through the inspection table/ point, where the garments are thoroughly and carefully checked to detect/find any defect if present in the garment. If the defect is possible to overcome, then the garment is sent to the respective person for correction. If the defect is not correction able, then the garment is separated as wastage.

The following diagram depicts the whole process of production flows in shirt.

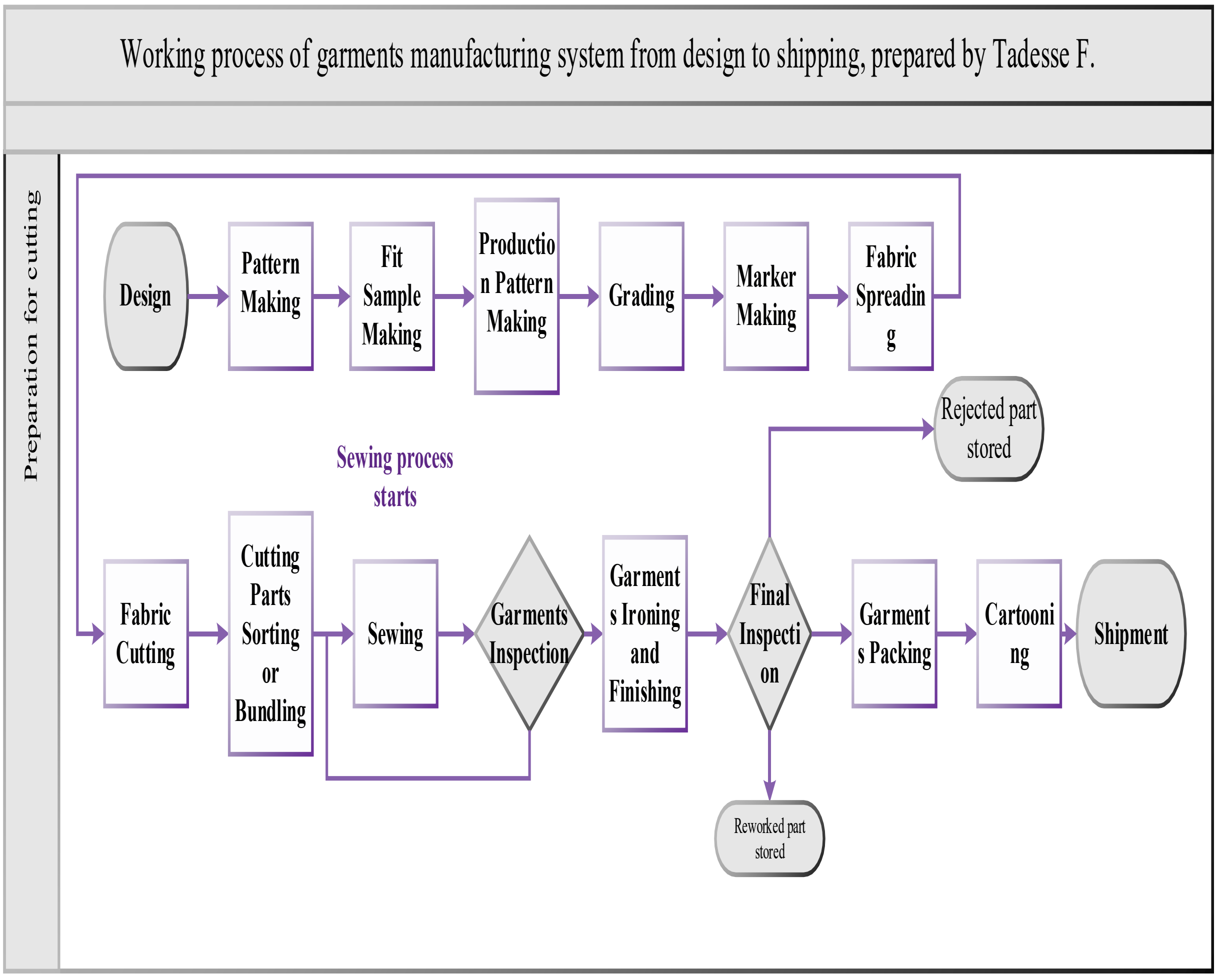


Figure 4.2 General Production Flow Process

General flow of basic three work station and inspection model of shirt production

4.4 Existing Production Flow of Shirt Assembly Process

During company observation and data collection process the researcher categorized shirt production process into two basic processes. The two basic process taken place in sewing work station are preparatory process and assembly process. Preparatory process contains operations undertaken in collar preparation section, cuff preparation section, pocket section, sleeve section, front and back section. Assembly process contains over twelve basic assembly operations.

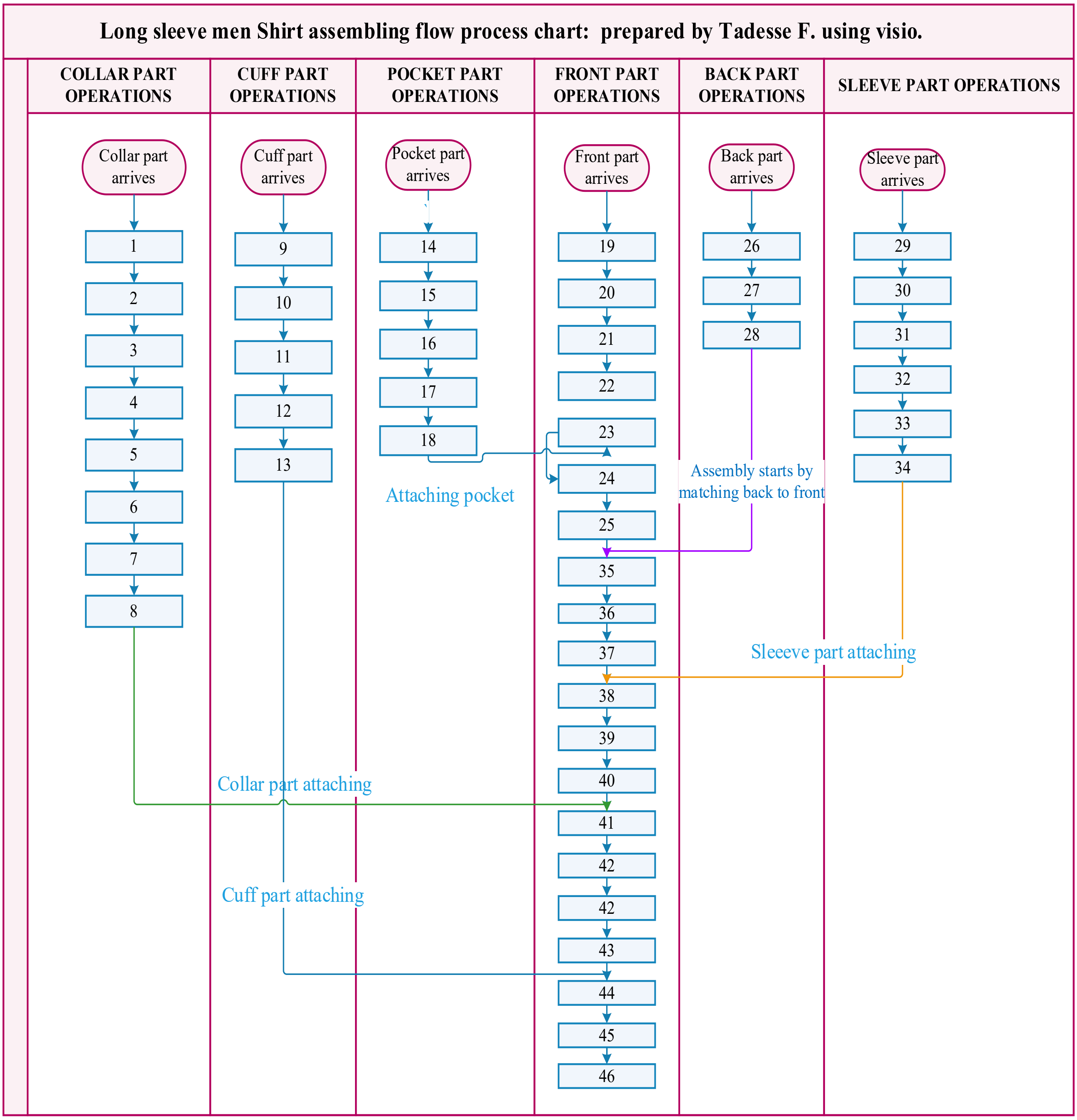


Figure 4.3 Existing System Production Flow Process

Inline inspection process: Inline Inspection means **checking the quality of the product in the process for all processes at** the end of the process when product is completely made. At this checkpoint quality checker checks all operations done up to that point and this process is not considered in assembly line balancing modelling. Inline inspection is the end process and excluded from the design process.

Table 4.1 Basic Sections of Shirt and Operations Description

Seq.no.	Operation description	Seq.no.	Operation description
	Collar section	24	Attach pocket (1 pocket)
1	Mark lining	25	Sew label at placket
2	Collar run-stitch		Back section
3	Collar turn and iron	26	Join upper yoke panel
4	Collar top-stitch	27	Attach back yoke with back panel
5	Collar band hem	28	Pack yoke top stitch
6	Collar attach to band		Sleeve section
7	Collar trimming and making	29	Cut sleeve at placket position
8	Collar band Centre stitch	30	Notch sleeve
	Cuff section	31	Iron upper and lower sleeve placket
9	Cuff hem	32	Attach plackets
10	Run stich cuff	33	Close lower placket
11	Turn cuff	34	Close upper placket
12	Iron cuff		Assembly process
13	Top stitch cuff	35	Set front and back and mark neck for collar
	Pocket section	36	Shoulder attach
14	Mark pocket	37	Shoulder top stitch
15	Pocket mouth iron	38	Sleeve attach
16	Hem pocket	39	Top stitch armhole
17	Crease pocket	40	Side seam
18	Trim pocket	41	Collar attach
	Front section	42	Collar close and insert label
19	Mark front for pocket position	43	Cuff attach and close
20	Form button hole placket	44	Bottom hem
21	Crease button hole placket	45	Button hole- front placket and collar
22	Top stitch B/H placket	46	Button attach
23	Sew button placket		

4.5 Data collection and analysis for critical factor

Identification of critical factors which hampers the production process are vital issues for increasing outputs of the production system. During data collection and observation of case company lot of problems are observed for reducing production target per day and highly deviating the actual output of production from target output. Firm productivity is an essential indicator of the strength of firms to stay in operation, expand, and compete in local and international markets and thereby contribute to employment, income, and generating essential foreign currency.

Even though they are a lot of reason for production loss, the researcher identified and categorized the basic causes of losses in product of shirts with in fourteen sewing lines. Recorded data shows that a total of 174,776 and 389,700 shirts product were losses in 2018 and 2019 years respectively. The researcher investigates and analyzed three consecutive months' data for finding for critical factors which hinder the production process and screening out vital few causes of losses in production which are responsible for trivial many losses in production. Pareto analysis and cause and effect diagram was employed for identification of vital few causes of losses and amount of loss product associated with them.

4.5.1 Assumption made during critical factor identification process

- External factors including government policies and institutional mechanisms, political, social and economic conditions, the business climate, the availability of finance, power, water, transport, communications and raw materials contributions are neglected
- Demand and supply of raw materials and logistic issues are not included
- Bureaucracies both internal and external of the company are not included
- Leadership commitment factors are not included
- Layout type and design problem are not included
- Education level is also not included

The above assumptions are not the objectives of this research. Preliminary survey for starting critical factors identification journey is started with importance survey. When designing survey questionnaire, 'Levels of Importance' questions used to assess what is most important to case company and other related garment companies' critical success factors and causes of losses in production. These detailed types of importance questions can help the researcher to understand the problem of identifying critical factor of losses in production and causes for bottleneck operation, factors make the production system less effective, less smooth and highly deviates in output production from the target product.

Properly measuring level of importance will garner critical information that ensures to continue to provide what is expected and what are more critical factors and level of effects they have on production loss. The researcher prepared level of importance survey for the suggested causes of production loss and results for high number of bottleneck operation in production system prior to balancing the sewing line using rock well arena 14 software. A more appropriate scale rating importance in this questionnaire is: Not at all important, Slightly Important, Important, Fairly Important, and Very Important, 0 to 4 values an interval scale.

When the researcher designs these level of importance questions in its critical factor identification survey, assumed that the following are true:

- Respondents have long year experience and highly exposed to these factors of the researcher enquiring about.
- Respondents can understand the critical factors raised by the researcher easily and give clear and considered response.
- Respondents believe that the problem is critical problem and should be solved as soon as possible. The following possible causes variation in production process of the company are suggested to be analyzed their criticality during company overview and one month data record regarding losses in production and causes of WIP. For simplicity and convenience the expected causes of variation and critical factors are replaced by capital letter of A-T.

Data collection and analysis were started with raising the following questionnaires for the experts of the company and production managers. Based on the reports of the company and literatures written before the following basic causes of variation in production were prepared.

Table 4.2 Critical Factors and Their Representations

Expected Critical factors	Symbol replaced for
Quality Workmanship losses	A
Machine Break Down and longer repair time	B
Quality control work in process inventory	C
Cutting Quality Issue at cutting section	D
Cutting Supply (starving the super market)	E
Eclectic Power fluctuation	F
Top Fuse Supply	G
Mixing Size of different kinds of shirt parts in super market area	H
Absenteeism for both operator staffs	I
Change in Style of product	J

Disciplinary Issue of worker	K
Late of Sub Material	L
Worker Skill or having only limited skill	M
Change in Color for shirts	N
Follow Up/Lack of supervision	O
Lack of machine or attachment	P
Shading errors	Q
Wrong measurement or Supply From WS	R
Safety Issue regarding worker performance	S

Table 4.3 Importance Rating and Their Value

Importance rating	Replaced symbol	Value
Not at all important	NI	0
Slightly Important	SI	1
Important	I	2
Fairly Important	FI	3
Very Important	VI	4

4.6 Data Collection for Simulation Model Analysis

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 preparatory and assembly line. After observing all operations or tasks which are done on the lines; then defining individual work elements to each workstations 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 and 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, GSD, line layout and operation breakdowns and production plans considered.

The cycle time required to complete a task in each work station depends on a lot of factors such as the task by itself, operator skill, properties of fabric, design and style of shirts and sub b materials, working environment, sewing machines status, quality level of product, hours of the day and psychology of the operator [54].

It’s not expected that operators and machines will work all working times of the shift without some interruptions. Therefore allowances of two types are allocated i.e. machine allowances and personal allowances like fatigue and delay allowances. Here under this research paper allowances of the above types are not included because of they are equally added on all operations and does not have any value for line balancing. For this research standard times were not taken into account, but the distributions of the collected time for each operation considered. Because process time of operations is variable because of different reasons and so a distribution of each process time is the best way to represent real system of shirt production process. Using predetermined standard times would decrease the model's authenticity for realistic applications due to their rigidity.

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

- Production output of the company per year, line, per shift and per hour
- Total no of tasks (operations) performed under each part of shirt production
- Processing time for each operation and number of machine and operator required for each operation
- Working hours per shift
- Process flow layout
- Expected critical factors and their importance in determining smooth flow of production system
- Product loosed per year and reasons of production loss.
- Frequencies of occurrence for each critical factors of losses in product and their associated quantity of product loosed
- Skill level operators have

All processing times of each operation were found to be probabilistic in nature rather than deterministic. The variation in processing times with different reasons and the random arrivals from day to day according to market demand caused randomness in the observations. Sometimes workers are going to other workstations for random motions, machine break downs, operators turn over and other unknown reasons makes the processing time data collection difficult. On the other hand operators move to other part of transportation table to pick up the WIP if helpers and WS are not around. This makes difficult and complex the data collection process. Because of these reasons the process of data collection follows the activity rather than the worker. The second strategy was to get the data over several one-day activities that had influenced the quality of the data because of the change in the station conditions and the change of the labor force size.

Seq. no.	operation names in each part of shirt	Observed cycle time in seconds										
		O_1	O_2	O_3	O_4	O_5	O_6	O_7	O_8	O_9	O_{10}	Aver.
Collar section												
1	Mark lining	10	11	15	10	12	10	11	11	12	14	10.77
2	Collar run-stitch	31	33	32	31	37	32	33	36	37	34	33.54
3	Collar turn and iron	14	15	14	14	17	15	15	16	17	15	15.17
4	Collar top-stitch	22	24	23	22	26	23	23	25	26	24	23.83
5	Collar band hem	22	24	23	23	27	23	24	26	27	25	24.43
6	Collar attach to band	34	37	35	34	40	35	36	39	41	37	36.66
7	Collar trimming and making	26	28	27	26	31	27	28	30	31	29	28.27
8	Collar band Centre stitch	21	23	22	21	25	22	22	24	25	23	22.91
Cuff section												
9	Cuff hem	27	30	28	28	33	29	29	32	33	30	29.79
10	Run stich cuff	34	37	35	34	40	35	36	39	41	37	36.66
11	Turn cuff	15	16	15	15	18	15	16	17	18	16	16.04
12	Iron cuff	19	21	20	19	23	20	20	22	23	21	20.81
13	Top stitch cuff	35	38	36	36	42	37	38	41	43	39	38.49
Pocket section												
14	Mark pocket	12	13	12	12	14	12	13	14	14	13	12.83
15	Pocket mouth iron	15	16	15	15	18	15	16	17	18	16	16.18
16	Hem pocket	19	21	20	19	23	20	20	22	23	21	20.94
17	Crease pocket	22	24	23	22	27	23	24	26	27	24	24.20
18	Trim pocket	22	24	23	22	26	23	23	25	27	24	23.97
Front section												
19	Mark front for pocket position	8	9	8	8	9	8	8	9	10	9	8.62
20	Form button hole placket	49	54	51	50	59	51	52	57	59	54	53.62
21	Crease button hole placket	11	12	11	11	13	11	11	12	13	12	11.73

22	Top stitch B/H placket	15	16	15	15	18	15	16	17	18	16	16.13
23	Sew button placket	20	21	20	20	23	20	21	23	24	21	21.31
24	Attach pocket (1 pocket)	38	41	39	38	45	40	40	44	46	42	41.24
25	Sew label at placket	30	33	31	30	36	31	32	34	36	33	32.58
Back section												
26	Join upper yoke panel	20	22	21	20	24	21	22	23	24	22	22.09
27	Attach back yoke with back panel	8	9	9	9	10	9	9	10	10	9	9.17
28	Pack yoke top stitch	20	22	21	20	24	21	21	23	24	22	21.77
Sleeve section												
29	Cut sleeve at placket position	25	28	26	26	31	27	27	29	31	28	27.82
30	Notch sleeve	21	23	22	22	26	22	23	25	26	24	23.37
31	Iron upper and lower sleeve placket	22	24	29	30	26	23	23	25	26	24	25.2
32	Attach plackets	38	41	39	36	45	40	44	44	46	42	41.5
33	Close lower placket	36	40	33	39	47	38	39	42	44	40	39.8
34	Close upper placket	55	59	61	55	65	57	58	63	66	60	59.9
Assembly process												
35	Set front and back and mark neck for collar	27	34	28	27	32	35	29	31	33	29	30.5
36	Shoulder attach	37	45	42	42	49	43	44	47	50	45	44.4
37	Shoulder top stitch	24	26	24	24	28	25	32	27	29	26	26.5
38	Sleeve attach	38	41	39	50	45	40	40	44	46	42	42.5
39	Top stitch armhole	30	32	37	39	36	31	32	34	36	33	34
40	Side seam	35	33	37	36	42	44	38	41	43	39	38.8
41	Collar attach	40	43	41	44	48	50	42	46	48	44	44.6
42	Collar close and insert label	33	36	42	33	39	34	35	38	40	36	36.6

43	Cuff attach and close	47	51	53	48	56	49	50	54	57	52	51.7
44	Bottom hem	39	42	40	39	47	44	41	45	47	43	42.7
45	Button hole- front placket and collar	26	23	22	21	25	28	31	24	25	23	24.8
46	Button attach	28	23	22	21	25	29	22	24	25	23	24.2
Total		20.3	22.0	21.4	20.9	24.2	21.7	21.8	23.3	24.4	22.3	21.76

Table 4.4 Operations and Observations of Processing Time

4.7 Arena Input Analyzer for Determining Best Theoretical Distribution of Each Processing Time

The following table shows that theoretical distribution, proper expressions and square errors using arena input analyzer from Rockwell arena 14 version software. The Input Analyzer is 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 also 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 determining the underlying best theoretical distribution for a set of probabilistic data, usually it involves to calculate goodness of fit test. These tests are 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. There are four different methods for conducting this comparison: Graphic approach, Chi-square test, Kolmogorov– Smirnov test and square error.

The arena input Analyzer 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. Therefore, the collected data was processed in the Input Analyzer tool built in Arena, and the results are used to set the type of probability distribution function and its value to be used 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 [56].

The following figure shows distribution for Attach back yoke with back panel operation from back section of the shirt production process.

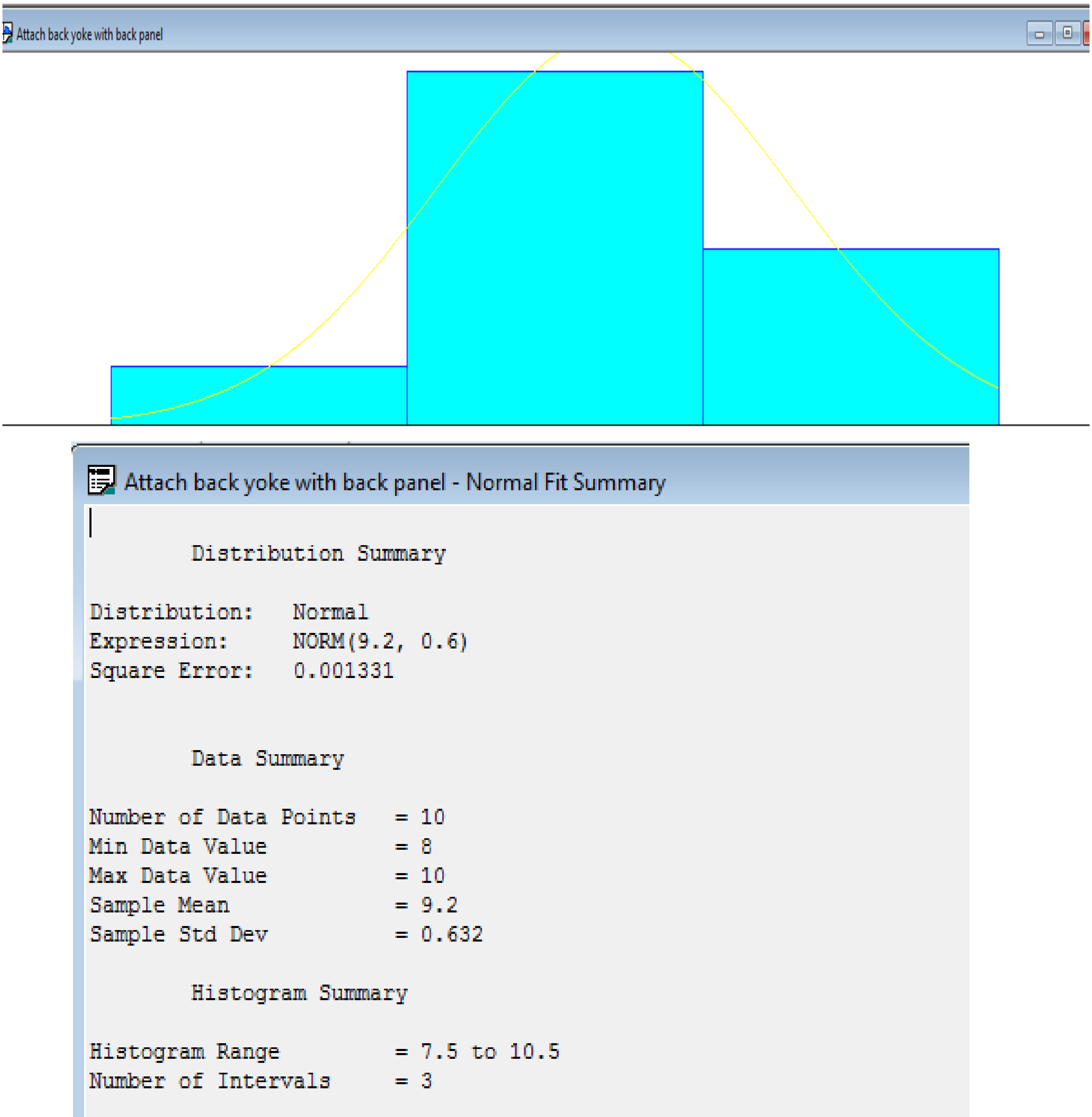


Figure 4.4 Theoretical Distribution Summary for Attach Back Yoke with Back Panel

Table 4. 5 Theoretical Distribution for Operations and Square Errors

Op. no	Operation description	Distribution	Expression	Sqr. error
1	Mark lining	Beta	29.5 + 7 * BETA(0.642, 0.808)	0.031540
2	Collar run-stitch	Uniform	UNIF(30.5, 37.5)	0.037143
3	Collar turn and iron	Lognormal	13.5 + LOGN(1.74, 1.44)	0.023540
4	Collar top-stitch	Erlang	21.5 + ERLA(1.15, 2)	0.018424
5	Collar band hem	Lognormal	21.5 + LOGN(3.02, 2.44)	0.025036
6	Collar attach to band	Beta	33.5 + 8 * BETA(0.917, 1.23)	0.024732
7	Collar trimming and making	Weibull	25.5 + WEIB(3.11, 1.55)	0.026150
8	Collar band Centre stitch	Erlang	20.5 + ERLA(1.15, 2)	0.018424
9	Cuff hem	Uniform	UNIF(26.5, 33.5)	0.037143
10	Run stich cuff	Beta	33.5 + 8 * BETA(0.917, 1.23)	0.024732
11	Turn cuff	Exponential	15 + EXPO(1.1)	0.055845
12	Iron cuff	Erlang	18.5 + ERLA(1.15, 2)	0.018424
13	Top stitch cuff	Gamma	34.5 + GAMM(2.06, 1.94)	0.026261
14	Mark pocket	Beta	11.5 + 3 * BETA(0.897, 1.02)	0.000941
15	Pocket mouth iron	Beta	14.5 + 4 * BETA(0.897, 1.02)	0.000941
16	Hem pocket	Erlang	18.5 + ERLA(1.15, 2)	0.018424
17	Crease pocket	Beta	21.5 + 6 * BETA(0.692, 0.846)	0.052115
18	Trim pocket	Erlang	21.5 + ERLA(1.2, 2)	0.005686
19	Mark front for pocket position	Beta	7.5 + 3 * BETA(0.897, 1.02)	0.000941
20	Form button hole placket	Gamma	48.5 + GAMM(3.02, 1.69)	0.072707
21	Crease button hole placket	Beta	10.5 + 3 * BETA(0.897, 1.02)	0.000941
22	Top stitch B/H placket	Uniform	UNIF(14.5, 18.5)	0.050000
23	Sew button placket	Exponential	19.5 + EXPO(1.8)	0.040625

24	Attach pocket (1 pocket)	Beta	37.5 + 9 * BETA(0.897, 1.02)	0.000941
25	Sew label at placket	Triangular	TRIA(29.5, 30, 36.5)	0.049653
26	Join upper yoke panel	Beta	19.5 + 5 * BETA(0.642, 0.808)	0.031540
27	Attach back yoke with back panel	Normal	NORM(9.2, 0.6)	0.001331
28	Pack yoke top stitch	Erlang	19.5 + ERLA(1.15, 2)	0.018424
29	Cut sleeve at placket position	Gamma	24.5 + GAMM(1.38, 2.39)	0.031165
30	Notch sleeve	Lognormal	20.5 + LOGN(3.02, 2.44)	0.025036
31	Iron upper and lower sleeve placket	Erlang	21.5 + ERLA(1.85, 2)	0.029698
32	Attach plackets	Beta	35.5 + 11 * BETA(1.2, 1.04)	0.027688
33	Close lower placket	Triangular	TRIA(32.5, 39.4, 47.5)	0.060950
34	Close upper placket	Beta	54.5 + 12 * BETA(1.2, 1.04)	0.027688
35	Set front and back and mark neck for collar	Weibull	20.5 + WEIB(4.78, 1.55)	0.028655
36	Shoulder attach	Normal	NORM(44.4, 3.58)	0.059715
37	Shoulder top stitch	Beta	36.5 + 14 * BETA(1.2, 1.04)	0.027688
38	Sleeve attach	Gamma	37.5 + GAMM(2.96, 1.69)	0.029303
39	Top stitch armhole	Uniform	UNIF(29.5, 39.5)	0.040000
40	Side seam	Erlang	32.5 + ERLA(3.15, 2)	0.031096
41	Collar attach	Exponential	39.5 + EXPO(5.1)	0.064367
42	Collar close and insert label	Beta	32.5 + 10 * BETA(0.648, 0.932)	0.027658
43	Cuff attach and close	Uniform	UNIF(46.5, 57.5	0.009091
44	Bottom hem	Weibull	38.5 + WEIB(4.56, 1.35)	0.044454
45	Button hole- front placket and collar	Exponential	20.5 + EXPO(4.3)	0.049975
46	Button attach	Erlang	20.5 + ERLA(1.85, 2)	0.029698

Assumptions during modelling and running the simulation model

- The assembly line is never starved; there is continuous supply of material from cutting section. There is no fabric loss since all cut panel bundles will ready in advance before production started.
- Set-up times and machine cleaning time are not taken into consideration. Because in a real system the setup process in garment manufacturing usually accomplished at the beginning in trial production.
- All process times for sewing operations and manual operations includes insignificant breakdowns like the detachment of sewing thread.
- Eight (8) hours working per shift time does not include lunch and breaks times.
- Sewing machines are available within eight hour working time and electric power and other utilities are available at all times.
- The operator works without any delay time and interruption; the operator's performance and skill stay constant throughout the entire process time. Allowance time for both operator and machines are neglected.
- Material and part on process transportations are performed by water spiders (operators who are not assigned for tasks under this analysis)
- No change in the product model and style: The product stays exactly the same during the whole production process. Also, material and trimmings as well as accessories do not change.
- Shirt main assembly line and the component production lines (preparatory section) considered as one system
- Operations in cutting room and at finishing process are not included.
- Processed parts which are decided to be reworked by quality checkers in line inspections are processed by other operators and machines which are out of the basic work stations (i.e. preparatory and assembly sections).
- As per quality checkers expert estimation the rejection rate of the existing production system considered to be 15% during mode formulation.

Sewing Machines used in case company and their application area

- Single Needle Lock Stitch: Collar and Cuff making, Pocket hemming and pocket attach, Yoke attach, Shoulder attach, Sleeve placket make, Sleeve attach, bottom hem, Main label attach, top stitches etc.

- Single Needle Lock Stitch (Edge cutter): Collar run stitch and Collar attach to collar band
- Double Needle Lock Stitch: Collar and Cuff Top Stitch and Armhole Top Stitch
- Multi Needle Chain Stitch (i.e. Kansai Optional): Front placket make and attach
- Feed off the Arm (optional): Side seam and under arm
- Button Stitching Machine: Attaching button to front placket and cuff
- Button Holing Machine: Making buttonholes.

Non-Sewing Machines

- **Fusing machine** for collar and cuff
- **Iron** for folding and pressing front pocket and sleeve plackets.
- **Collar and cuff turning machine:** For collar and cuff turn and iron

Table 4. 6 Operations, Number of Machines and Operators Required for Each Tasks

Seq.no.	Operation description	Resource name	No. of oper.	No. of m/c
1	Mark lining	Helper for mark lining	1	-
2	Collar run-stitch	SNL for collar run stitch	1	1
3	Collar turn and iron	helper with IRN for collar turn	1	-
4	Collar top-stitch	SNLS for top stitch	1	1
5	Collar band hem	DNL for collar band hem	1	1
6	Collar attach to band	SNL VT for collar attach to band	1	1
7	Collar trimming and making	helper for collar trimming	1	1
8	Collar band Centre stitch	SNL for collar band center	1	1
9	Cuff hem	DNL for cuff hem	1	1
10	Run stich cuff	SNL for run stitch cuff	1	1
11	Turn cuff	helper for turn cuff	1	1
12	Iron cuff	IRN for cuff	1	1
13	Top stitch cuff	SNL auto	1	1
14	Mark pocket	helper for pocket marking	1	1

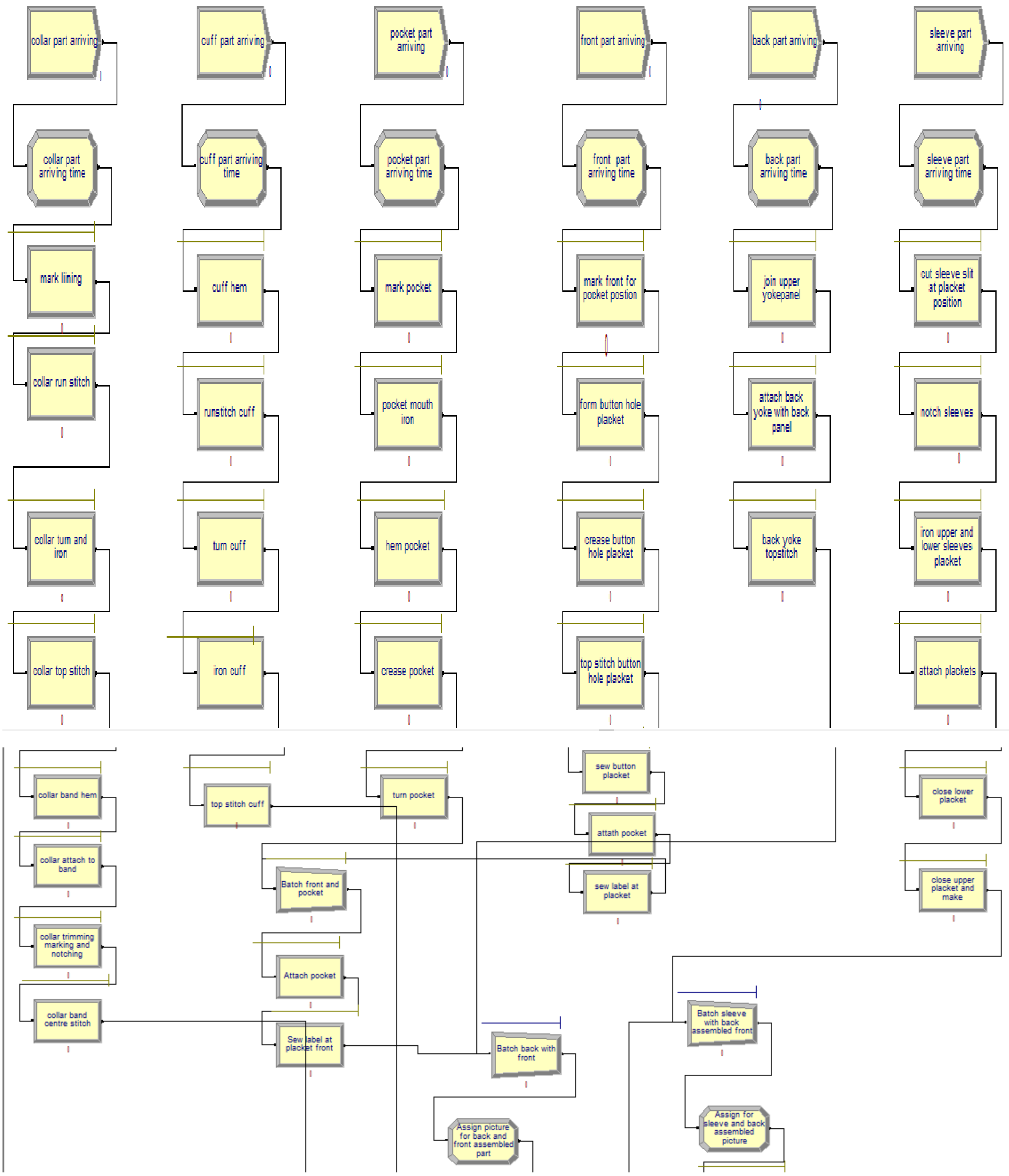
15	Pocket mouth iron	IRN for pocket mouth	1	1
16	Hem pocket	SNL for pocket	1	1
17	Crease pocket	helper for crease pocket	1	-
18	Turn pocket	helper for turn pocket	1	1
19	Mark front for pocket position	helper for mark front pocket position	1	-
20	Form button hole placket	BH for forming button hole placket	1	1
21	Crease button hole placket	helper for crease button hole placket	1	1
22	Top stitch B/H placket	DNL for top stitch button hole placket	1	1
23	Sew button placket	SNL for sew button placket	1	1
24	Attach pocket (1 pocket)	pocket attaching machine	1	1
25	Sew label at placket	label attaching machine	1	1
26	Join upper yoke panel	upper yoke attaching machine	1	1
27	Attach back yoke with back panel	SNLS for attaching back yoke	1	1
28	Pack yoke top stitch	SNLS for back yoke top stitch	1	1
29	Cut sleeve at placket position	cutter for sleeve slit at placket position	1	1
30	Notch sleeve	notching sleeve machine	1	1
31	Iron upper and lower sleeve placket	iron upper and lower sleeves placket machine	1	1
32	Attach plackets	SNL for placket attaching	1	1
33	Close lower placket	close lower placket machine	1	1
34	Close upper placket	close upper placket and make machine	1	1
35	Set front and back and mark neck for collar	Resource 11	1	1
36	Shoulder attach	Resource 12	1	1
37	Shoulder top stitch	Resource 13	1	1

38	Sleeve attach	JukiMH380U	1	1
39	Top stitch armhole	Resource 14	1	1
40	Side seam	Juki MS-1261, Resource 15	1	1
41	Collar attach	SNLS, for collar attaching	1	1
42	Collar close and insert label	SNLSM	1	1
43	Cuff attach and close	SNLSM	1	1
44	Bottom hem	SNLSM	1	1
45	Button hole- front placket and collar	Juki LBH 1790-S	1	1
46	Button attach	JUKI LBH	1	1

4.8 Simulation Model Formulation

The simulation model was built using Arena® version 14.0 simulation software. The construction period of the model is based on the existing shirts line process flow production diagram which highlighted during observation. Sewing machines are organized according to the production process flow, but the number of machines which are used for each operation are determined by the line balancing algorithm. During straight line production each operator uses only one machine. The objective of model formulation or development is to determine which components of the system should be included in the model and how the model should flow to imitate the real system. The model development was started with the declaration of the entity, the location of the workstations, generating path network and resources, declaration of the arrival and processing programming. Logic flow describes the way by which the entity acts during its journey in the simulation model. It was easy to observe the route the entity follows during the model building stage. The animation part of the Arena was very helpful in ensuring. The following model depicts the current model of men's long sleeve shirt assembly line system. This model picture shows that the two parts of long sleeve shirt processing operations or sections are merged together. In previous researches which are done by arena simulation software most of the models are designed separately because of the arena14.0 software was student version and it was allowed only for training purpose. Arena14.0 version of student version is limited with only 150 entities only and number of modules and others were also restricted. This arena14.0 software is licensed software which enable us to model both of preparatory section and assembly section to model in the same model window by using different assembly modules like, processing modules, batch modules match modules and others.

Assembly line simulation model for mens long sleeve shirt production by Tadesse F.



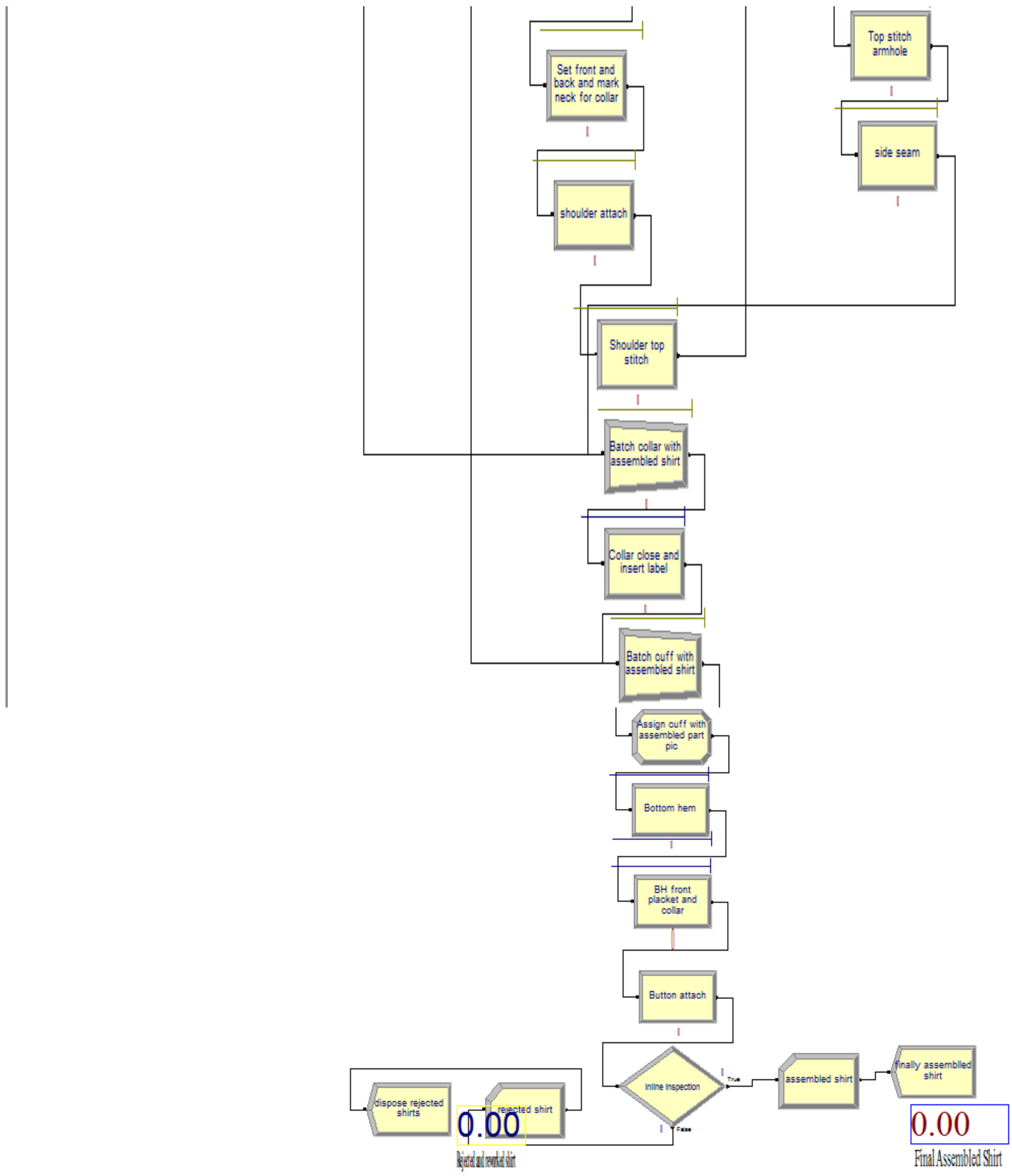
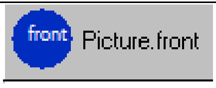
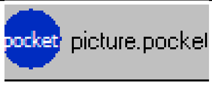
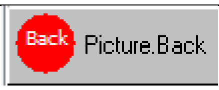
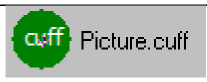


Figure 4.5 Simulation Model for the Existing System of Assembly Lines

4.9 Model Verification

During test run model working smoothly without any errors or warnings under different settings of the inputs by altering the arrival times. The animation of the processes observed by assigning different pictures for each entity (picture entity for collar, front, back, pocket, cuff and sleeve parts of shirt) the path was correct. Entities at batching and matching module are properly batched, leads single output. It can be said this model verified and represent the real system.

Table 4.7 Assigned Pictures for Entities flow in the simulation model

Entity name	**Picture assigned for the entities**
Collar part	
Front part	
Pocket part	
Sleeve part	
Back part	
Cuff part	

4.10 Model Validation

Validation of the model reliability can be by comparing the output of the real system the company currently producing and the model output of the existing system by developing model, a test run with ten replications was done and the output value checked. The output of the current real system varies from 288 shirts to 316 shirts at fourth and tenth replication respectively. The average output for eight hour shift in the current system from the model or category overview shows that 355 pcs of shirt out of this these 54 pcs are rejected shirts. When we compare the data gathered from the company at which output product per shift was 306pcs. The model is absolutely validated.

4:45:49PM **User Specified** May 31, 2021

Assembly line simulation model for full long sleeve shirt production process Replications: 10

Replication 1 Start Time: 0.00 Stop Time: 480.00 Time Units: Minutes

Counter

Count	Value
assembled shirt	303.00
number of rejectd shirts	52.0000

Replication 10 Start Time: 0.00 Stop Time: 480.00 Time Units: Minutes

Counter

Count	Value
assembled shirt	316.00
number of rejectd shirts	39.0000

Figure 4.6 User define preliminary simulation model output for model validation

Thus, the output value according to the model is realistic value. The test run was operating without problems; hence, the production line in the model run smoothly without interruptions. The assumption was made that the model is a realistic approach to the data basis of each operation. It can be said this model represents the real system and is said to be verified and validated. The decision made to use the model as basis of further analysis and propose productivity improvement model.

4.11 Calculation of replication number

In order to determine the number of replications, first the mean and standard deviation of the first ten replication calculated for preparation and assembly lines then standard error of the data calculated using [54] Eqn. 4.1

Multiple replications of simulation model are performed by changing the random number streams that are used by the model and re- running the simulation. The aim is to produce multiple samples in order to obtain a better estimate of mean performance.

$$\text{Standard error} = t_1 - \frac{\alpha}{2}, \left(\frac{n-1}{\sqrt{n}}\right) * s \ldots\ldots\ldots\ldots \text{eqn. } 4.1$$

Where,

t_1= t probability distribution value for 1- α/2 from table

n-1= degrees of freedom

s = standard deviation of the replication means

n = number of observations in the sample

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

$$S = \sqrt{\frac{\sum_{1}^{n} xi - x}{n-1}} \text{ ....eqn. 4.1}$$

Where,

s = standard deviation of sample

xi bar = the replication average

x bar = average of the replication averages

n = number of replications

Considering the first 10 replications, the standard deviation and half width value shown below on table 4.8.

Table 4. 8 Mean, standard deviation and half width for the first 10 replication

Replication number	Arena simulation output report
1	303
2	305
3	301
4	288
5	296
6	302
7	301
8	288
9	312
10	316
Mean	301
Standard deviation	9
Half width	6.43

Average of average replication result or final output in after ten replications is equal to 301 shirts produced or assembled at eight hour shift of production time. Standard deviation measures the amount of variability or dispersion of the replication results from the mean. The half width statistic is used to help in determining the reliability of the results from the replication. In other word half width is a sampling error introduced in taking sample. Therefore, the value of half width can be simply determined by using the standard error. Considering a 95% confidence level and n=9 samples the value of t can be read from t probability distribution table, hence t (at 95%, 9) = 2.262 [68].

Half width of assembly model = $2.262 * \frac{1}{\sqrt{10}} * 9$ = **6.43**

Set half width =h, solve for n = $t_{2n-1,1-\partial/2} * s_2/h_2$ replace t by z, corresponding normal critical value n ≅ $t_{2n-1,1-\partial/2} * s_2/h_2$

n ≅$n_o*(h_o/h)$ approximated replications are needed for more accurate simulation output result.

Where,

✓ n = number of observations in the sample = 10

✓ h = half width = 6.43

n_o is the number of initial replications we had and ho is the half width. If error level from the initial sample of 10 replications is not quite satisfying, the initial half width can be reduced thus greater precision level can be achieved. Assume half width for assembly line to be 3.2 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:

$1.96^2 * \frac{92}{3.22} = \frac{311.16}{10.24} = 30.38$ approximately 30 number of replications are required for better decision making process.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Critical Factor Identification Results and Analysis

The following table summarizes a total data collected from different expertise in a given company for assessing importance of each critical factors in the production system to be analyzed. For analysis of the importance for each factor twenty expert individuals were asked by using questioner type of data collection from production(cutting, sewing and presentation), engineering and maintenance, industrial engineering ,operator recruitment & development quality assurance, garment technician and planning. Over 72% of respondents are participated for each importance rating questions. Sample of twenty five individuals is selected because of the goal of this survey is to identify the importance of investigating those expected critical factors and the relationship they have with bottleneck operation. In parallel to identifications.

Table 5. 1 Expected critical factors and importance rating value

Expected critical factors In symbols	Importance rating and frequencies recorded under each rating						Values: NI= 0, SI= 1, I= 2 FI= 3 and VI= 4
	NI	SI	I	FI	VI	Total	No. of valid survey
A	-	-	2	3	20	2*2+ 3*3 + 20*4 = 93	25
B	-	-	5	9	10	5*2 + 9*3 + 10*4 = 77	24
C	1	-	7	6	11	7*2 + 6*3 + 11*4 = 100	25
D	-	-	3	10	12	3*2 + 10*3 + 12*4 = 84	25
E	-	-	-	11	14	11*3 + 14*4 = 89	25
F	-	-	5	10	9	5*2 + 10*3 + 9*4 = 76	24
G	2	4	5	3	4	4*1 + 5*2 +3*3 + 4*4 = 39	18
H	2	1	10	5	6	1*1 + 10*2 + 5*3 + 6*4 = 60	24
I	-	-	5	9	10	5*2 + 9*3 + 10*4 = 77	24
J	1	2	2	10	8	2*1 + 2*2 + 10*3 + 8*4 = 68	23
K	-	1	-	10	10	1*1 + 10*3 + 10*4 = 71	21
L	-	-	15	2	8	15*2 + 2*3 + 8*4 = 68	25
M	-	-	-	-	22	22*4 = 88	22
N	20	1	-	-	2	20*0 + 1*1 + 2*4 = 9	23
O	-	-	4	8	12	4*2 + 8*3 + 12*4 = 80	24
P	-	1	2	10	9	1*1 + 2*2 + 10*3 + 9*4 = 71	22

Q	5	11	2	-	1	11*1 + 2*3 + 1*4 = 21	19
R	-	1	10	10	3	1*1 + 10*2 + 10*3 + 3*4 = 63	24
S	-	5	4	10	3	5*1 + 4*2 + 10*3 + 3*4 = 55	22

From the above importance rating identification survey analysis conclusion can be made by list of maximum importance rating value to minimum value as follows. As the result shows from the expected critical factors critical factor C, A, E, M and D are the top five critical by having total importance value of 100, 93, 89, 88 and 84 respectively.

Table 5. 2 Expected critical factors importance assessment value and rank

Expected critical factor	Value	Rank
C, Quality control work in process inventory	100	1
A, Quality Workmanship losses	93	2
E, Cutting Supply (starving the super market)	89	3
M, Worker Skill or having only limited skill	88	4
D, Cutting Quality Issue at cutting section	84	5
O, Follow Up/Lack of supervision	80	6
I, Absenteeism for both operator staffs	77	7
B, Machine Break Down and longer repair time	77	8
F, Eclectic Power fluctuation	76	9
K ,Disciplinary Issue of worker	71	10
P, Lack of machine or attachment	71	11
J, Change in Style of product	68	12
L, Late of Sub Material	68	13
R, Wrong measurement or Supply From WS	63	14
H, Mixing Size of different kinds of shirt parts in super market area	60	15
S, Safety Issue regarding worker performance	55	16
G, Top Fuse Supply	39	17
Q, Shading errors	21	18
N, Change in Color for shirts	9	19

Table 5. 3 Expected factors and their associated losses

Expected critical factors	Losses associated with each critical cause in pcs.	Frequency of occurrence within three months
A	3824	190
B	2737	136
C	2133	106
D	886	44
E	684	34
F	564	28
G	443	22
H	403	20
I	322	16
J	242	12
K	161	8
L	201	10
M	242	12
N	523	26
O	966	48
P	926	46
Q	886	44
R	926	46
S	443	22
Total	17,509	870

5.2 Critical factor identification based on their associated losses

Pareto Analysis is generally very powerful and essential technique required for solving problems like errors, defects, etc. It is one of the simplest, easiest, and very effective tools that are used in identifying effective and essential solutions to problems. Pareto Analysis can also be used very effectively and clearly in various situations where the 80/20 rule does not apply. The 80/20 rule simply means that usually, 80 percent of problems or defects occurred due to 20 percent fundamental causes.

Table 5. 4 List of expected critical factors and effect in descending order

Expected critical factors	Losses associated with each critical cause in pcs.	Percentage of Occurrence and effect	Cumulative percentage
A	3824	22%	22%
B	2737	16%	38%
C	2133	12%	50%
O	966	6%	55%
R	926	5%	61%
P	926	5%	66%
Q	886	5%	71%
D	886	5%	76%
E	684	4%	80%
F	564	3%	83%
N	523	3%	86%
G	443	3%	89%
S	443	3%	91%
H	403	2%	94%
I	322	2%	95%
M	242	1%	97%
J	242	1%	98%
L	201	1%	99%
K	161	1%	100%
Total	17,509	100%	100%

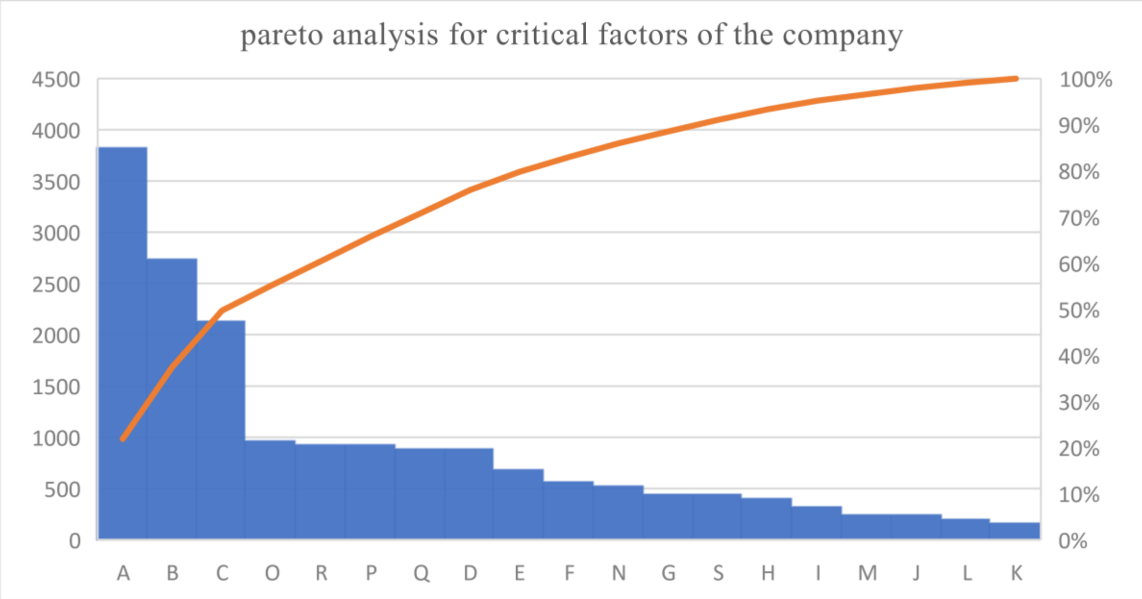


Figure 5. 1 Pareto analysis for identification of critical few factors

5.3 Simulation Model Output Analysis

Simulation Output Analysis is the analysis of data generated a simulation run in order to analyzing 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. Analyzing the current assembly line performance of the company is one of the specific objectives of this research. Output analysis is also used for understanding the initial performance of system and identifications problems, obstacles, wastes, resources utilizations, bottleneck operations and 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 analyzed to propose different scenarios for productivity improvement through line balancing. Scenarios of different integrations are proposed for better productivity in terms resource utilization, reducing wastes of processing time, takt time, average making span time for each entity and other optimum utilization.

5.4 Existing System Analysis Based on the Simulation Model Results

For the simplification and better analyzing mechanism the researcher breaks down the garment manufacturing basically sewing section of the system into the following structures.

Table 5. 5 Basic contents of the simulation model output reports

Entities	Processes (number)		Resources		Queues		Overall system output	
	preparatory	assembly	m/c	Oper.	waiting time	#.waiting	Assembled shirt	Reworked shirt
Collar part	O# (1_8)	O#35__O#46	Name and qty. Of m/c	Operator required for each m/c	Average waiting time at each process in system within eight hours for 30 days or 30 replications	Average number waiting of entities, processes in each processing work stations	Average number of finally assembled shirts and passes through inline quality inspection within 480 minutes and 30 replications running	Average number of reworked and rejected shirt in 480 minutes based on 15% rejection rate.
Cuff part	O# (9_13)							
Pocket part	O# (14_18)							
Front part	O#(19_25)							
Back part	O#(26_28)							
Sleeve part	O#(29_34)							

Based on the output of simulation model results /report with 30 replications the output, WIP values, resource utilization, productivity per operator, productivity per machine, lead time, waiting time in queue, takt time and line efficiency discussed in table 5.6 below.

Table 5. 6 Existing assembly line simulation model output report

Section of shirt	No. in	No. out	WIP average	Total resource
Collar part	1034	557	250	8
Cuff part	1095	770	166	5
Pocket part	910	457	246	7
Front part	896	417	258	7
Back part	1459	778	367	3
Sleeve part	864	**387**	249	6
Assembled shirt	387	301	80	11
Overall output		355		46

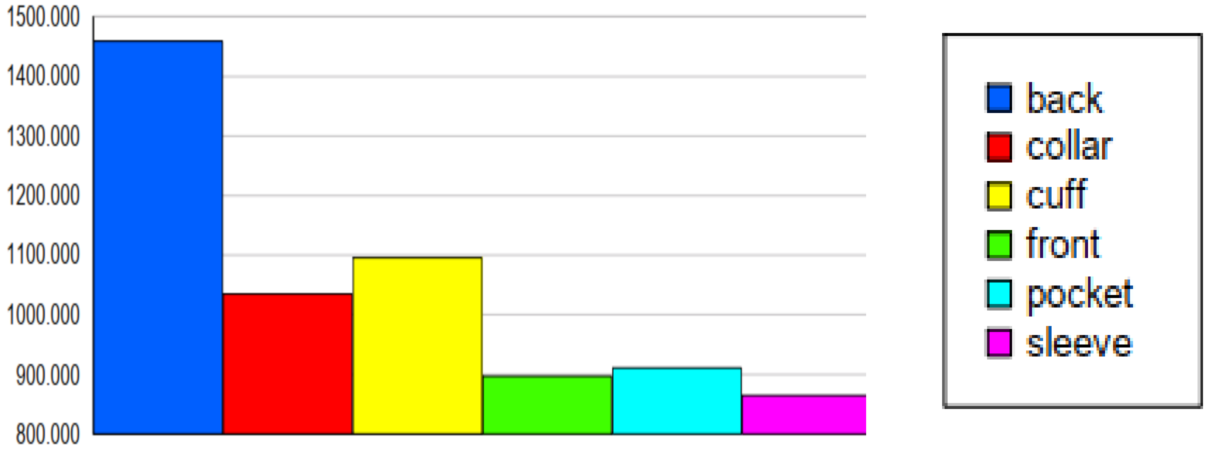


Figure 5. 2 Graphical expressions of entities entering to the system

As it is observed from table 5.6 preparatory sections have different productivity levels both in machine and labor productivity, but the productivity of the company becomes in decreasing order and the productivity of assembly section is 30. But the final assembled shirt product depends on the minimum number of result as we observe from table 5.5 the sleeve part is the minimum value i.e. 387 sleeves per shift. The maximum product as overall efficiency become less than 387 shirts per shift i.e. 355 shirts per shift because of the preparatory section is an input for the assembly section. The overall productivity of the company in current system is 7shirts/machine/operator.

5:17:11PM **Category Overview** June 1, 2021

Values Across All Replications

Assembly line simulation model for full long sleeve shirt production process done by

Replications: 30 Time Units: Minutes

Key Performance Indicators

System

	Average
Number Out	350

5:17:11PM **Category Overview** June 1, 2021

Values Across All Replications

Assembly line simulation model for full long sleeve shirt production process done by

Replications: 30 Time Units: Minutes

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
assembled shirt	297.90	2.73	282.00	314.00
number of rejectd shirts	52.1333	2.62	37.0000	68.0000

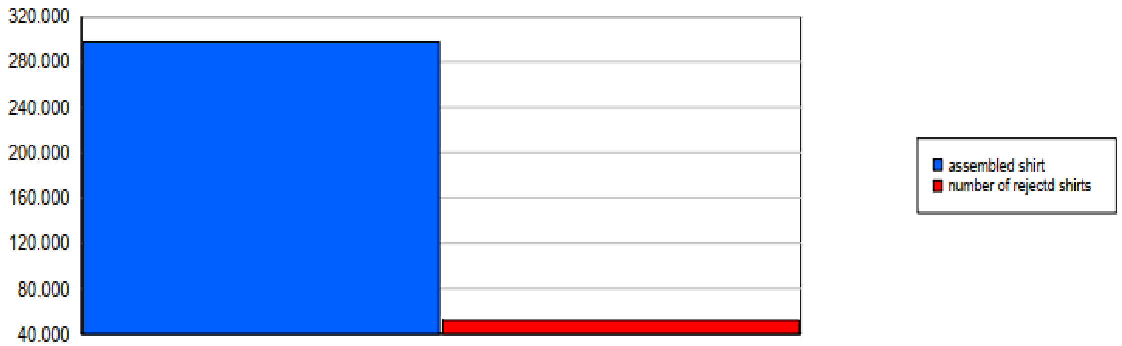


Figure 5. 3 Category overview for existing system

Takt time: Takt time calculation is based on the production quantity a company produces per day both finally passes the inline inspection and reworked and rejected products and standard working time of operation. Takt time (min) = Working minutes/daily production. Factory planned production is 417pcs/day. Takt time for assembly section planned to be 480 min/417pcs =1.15min/pcs. That means every 1.15 min one unit needs to be produced. The Takt time needs to be adapted to the output targets per time. The existing system of the company takt time is 480minutes/301pcs = 1.6minutes/pcs which is in higher deviation with the planned time. To fulfill the planned output quantity, the operational time at each operation for the production of one unit shall be equal to takt time. If the cycle times of the operations are equal to Takt time, the production runs smoothly, if not the line needs to be balanced.

5.5 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. So, identifying bottleneck operations and removing them is a very significant task to get the highest capacity production.

The simulation model ran by 30 replication lengths for the default results of category overview to count finally assembled shirt, rejected and reworked shirts per shift. The following figure shows that the average of 30 replication results.

5.5.1 Resource utilization for the 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 sin they are inputs the processing company.

Table 5. 7 Resource utilization rate for existing assembly line system

5:17:11PM **Category Overview** June 1, 2021

Values Across All Replications

Assembly line simulation model for full long sleeve shirt production process done by

Replications: 30 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
BH for forming button hole placket	0.9997	0.00	0.9996	0.9997	0.00	1.0000
close lower placket machine	0.7747	0.00	0.7705	0.7804	0.00	1.0000
close upper placket and make machine	0.9945	0.00	0.9938	0.9949	0.00	1.0000
cutter for sleeve slit at placket position	0.5404	0.00	0.5374	0.5463	0.00	1.0000
DNL for collar band hem	0.4083	0.00	0.4059	0.4112	0.00	1.0000
DNL for cuffhem	0.5833	0.00	0.5797	0.5864	0.00	1.0000
DNL for top stitch button hole placket	0.3075	0.00	0.3045	0.3104	0.00	1.0000
helper for collar trimming	0.4715	0.00	0.4683	0.4739	0.00	1.0000
helper for crease pocket	0.4707	0.00	0.4670	0.4741	0.00	1.0000
helper for creasebbutton hole placket	0.2219	0.00	0.2200	0.2243	0.00	1.0000
helper for mark front pocket position	0.1732	0.00	0.1721	0.1743	0.00	1.0000
Helper for mark lining	0.5435	0.00	0.5405	0.5465	0.00	1.0000
helper for pocket marking	0.2510	0.00	0.2494	0.2527	0.00	1.0000
Helper for mark lining	0.5435	0.00	0.5405	0.5465	0.00	1.0000
helper for pocket marking	0.2510	0.00	0.2494	0.2527	0.00	1.0000
helper for turn cuff	0.3131	0.00	0.3118	0.3160	0.00	1.0000
helper for turn pocket	0.4644	0.00	0.4602	0.4669	0.00	1.0000
helper with IRN for collar turn	0.2540	0.00	0.2510	0.2571	0.00	1.0000
IRN for cuff	0.4044	0.00	0.4011	0.4068	0.00	1.0000
IRN for pocket mouth	0.3185	0.00	0.3165	0.3205	0.00	1.0000
iron upper and lower sleeves placket machine	0.4899	0.00	0.4856	0.4930	0.00	1.0000
JUKI LBH	0.5966	0.00	0.5875	0.6066	0.00	1.0000
label attaching machine	0.5943	0.00	0.5899	0.6005	0.00	1.0000
notching sleeve machine	0.4574	0.00	0.4532	0.4620	0.00	1.0000
pocket attaching machine	0.7753	0.00	0.7690	0.7822	0.00	1.0000
Resource 11	0.4757	0.00	0.4707	0.4800	0.00	1.0000
Resource 12	0.8516	0.00	0.8470	0.8566	0.00	1.0000
Resource 13	0.8432	0.00	0.8315	0.8493	0.00	1.0000
Resource 14	0.6117	0.00	0.6084	0.6159	0.00	1.0000
Resource 15	0.6874	0.00	0.6808	0.6955	0.00	1.0000
Resource machine	0.7925	0.00	0.7888	0.7976	0.00	1.0000
Resource machine sew	0.6071	0.00	0.6043	0.6103	0.00	1.0000
SNL auto	0.7493	0.00	0.7448	0.7552	0.00	1.0000
SNL for collar band centre	0.3798	0.00	0.3767	0.3814	0.00	1.0000
SNL for collar run stitch	0.5663	0.00	0.5625	0.5703	0.00	1.0000

SNL for placket attaching	0.8044	0.00	0.7986	0.8092	0.00	1.0000
SNL for pocket	0.4045	0.00	0.4012	0.4080	0.00	1.0000
SNL for runstitch cuff	0.7189	0.00	0.7157	0.7223	0.00	1.0000
SNL for sew button placket	0.3961	0.00	0.3921	0.4000	0.00	1.0000
SNL VT for collar attch to band	0.6158	0.00	0.6127	0.6194	0.00	1.0000
SNLS for attaching back yoke	0.1789	0.00	0.1780	0.1799	0.00	1.0000
SNLS for back yoke top stitch	0.4241	0.00	0.4218	0.4266	0.00	1.0000
SNLS for top stitch	0.3968	0.00	0.3940	0.4007	0.00	1.0000
SNLSM	0.9926	0.00	0.9922	0.9930	0.00	1.0000
upper yoke attaching machine	0.4221	0.00	0.4199	0.4252	0.00	1.0000

Based on the table 5.7 resource utilization report the maximum utilization is 99.97% for BH for forming button placket machine and the least utilization 17.32% for human resource at mark front pocket position. From the above existing system resource utilization report, we can identify the top ten highly utilized resources as follow in table 5.8.

Table 5. 8 Top ten highly utilized resources in existing system (74% - 100%)

Seq.#	Resource name	Part of shirt and process number	Utilization rate (%)
1	BH for forming button hole placket	Front, O#20	0.9997
2	close upper placket and make m/c	Sleeve, O#34	0.9945
3	SNLSM	Assembly, O#42	0.9926
4	Resource 12	Assembly, O#36	0.8516
5	Resource 13	Assembly, O#37	0.8432
6	SNL for placket attaching	Sleeve, O#32	0.8044
7	Resource machine	Assembly, O#24	0.7925
8	pocket attaching machine	Front, O#15	0.7753
9	close lower placket m/c	Sleeve, O#33	0.7747
10	SNL auto	Cuff, O#13	0.7493

Table 5. 9 Top ten least utilized resource (<40%)

Seq#.	Resource name	Operation No.	Utilization
1	helper for mark front pocket position	19	0.1732
2	SNLS for attaching back yoke	27	0.1789
3	helper for crease button hole placket	21	0.2219
4	helper for pocket marking	14	0.2510
5	helper with IRN for collar turn	3	0.2540
6	DNL for top stitch button hole placket	22	0.3075
7	helper for turn cuff	11	0.3131
8	IRN for pocket mouth	15	0.3185
9	SNL for collar band center	8	0.3798
10	SNL for sew button placket	23	0.3961

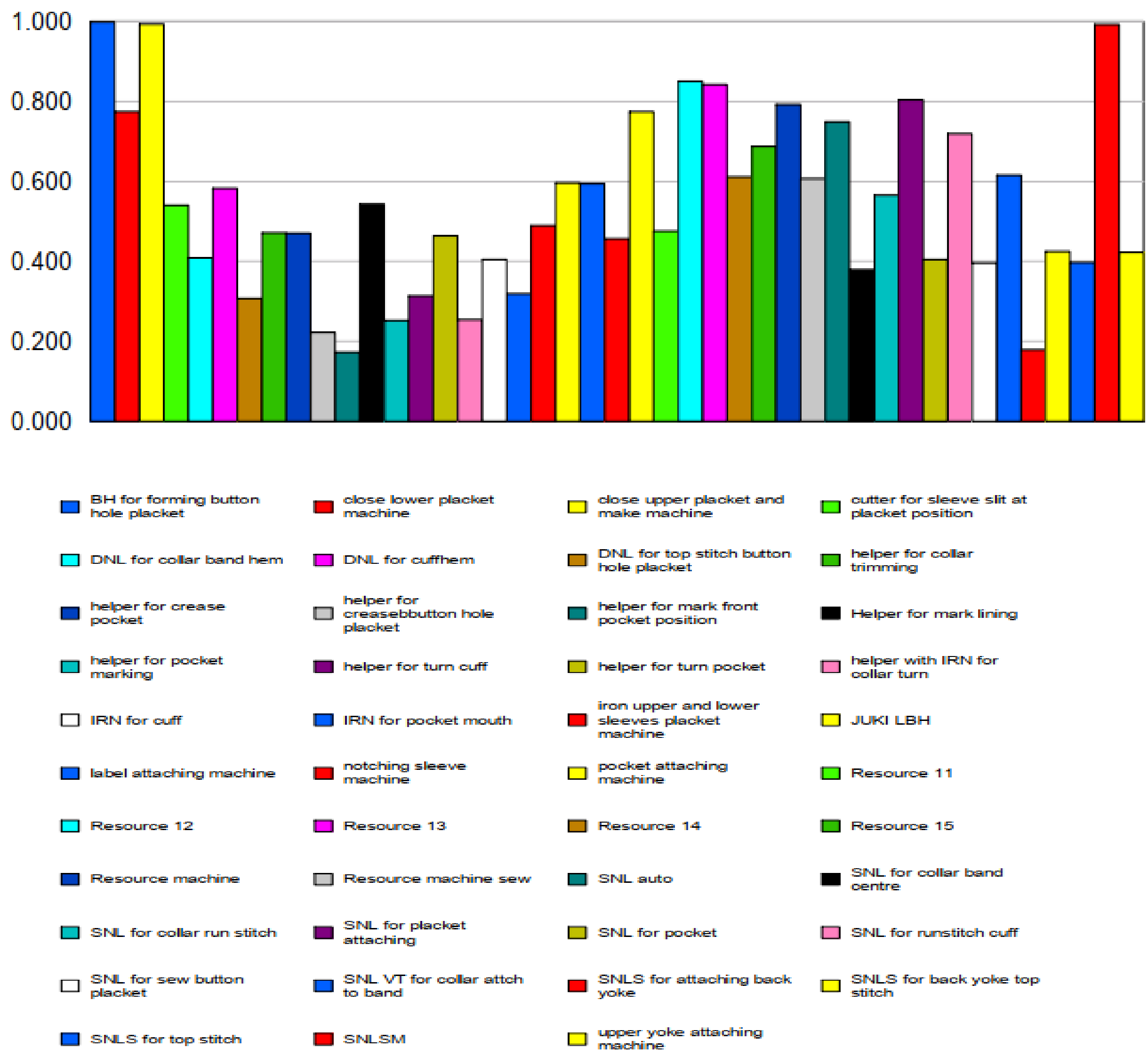


Figure 5. 4 Graphical expressions for resource utilization of existing system

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 (machines, operators and others) the work stations should be properly assigned. Assignments of operators to work station for balancing line is 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 above in table 5.8 and 5.9.

5.6 Bottleneck Operations Based on Different Processing Status of the Existing System

Table 5. 10 Bottleneck operations based on average waiting time

5:17:11PM **Category Overview** June 1, 2021

Values Across All Replications

Assembly line simulation model for full long sleeve shirt production process done by

Replications: 30 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel.Queue	0.00	0.00	0.00	0.00	0.00	0.00
attach plackets.Queue	7.7685	0.04	7.6009	8.0454	0.00	17.1225
Attach pocket.Queue	2.8760	0.02	2.7539	3.0559	0.00	8.1496
attath pocket.Queue	0.00028172	0.00	0.00000922	0.00053531	0.00	0.1110
back yoke topstitch.Queue	0.1774	0.01	0.1051	0.2699	0.00	1.1462
Batch back with front.Queue	0.2163	0.00	0.2139	0.2195	0.00	2.3661
Batch collar with assembled shirt.Queue	0.2399	0.00	0.2333	0.2531	0.00	2.3572
Batch cuff with assembled shirt.Queue	0.2576	0.00	0.2514	0.2688	0.00	2.8281
Batch front and pocket.Queue	0.2184	0.00	0.2157	0.2220	0.00	1.3939
Batch sleeve with back assembled front.Queue	0.2339	0.00	0.2272	0.2383	0.00	1.1078
BH front placket and collar.Queue	0.01740579	0.00	0.01238922	0.02399467	0.00	0.6734
Bottom hem.Queue	63.8934	0.23	62.9141	65.2899	0.00	126.32
Button attach.Queue	0.00172193	0.00	0.00	0.00442446	0.00	0.5349
close lower placket.Queue	0.06473621	0.01	0.04510894	0.1094	0.00	0.7059
close upper placket and make.Queue	42.5389	0.23	41.0869	44.2129	0.00	84.4501
collar attach to band.Queue	1.4679	0.03	1.2891	1.6380	0.00	4.2681
collar band centre stitch.Queue	0.00000737	0.00	0.00	0.00012651	0.00	0.06072260
collar band hem.Queue	0.00110355	0.00	0.00038305	0.00213563	0.00	0.3358
Collar close and insert label.Queue	63.2123	0.25	62.1666	64.8869	0.00	126.26
collar run stitch.Queue	0.7060	0.03	0.5355	0.8402	0.00	2.3003
collar top stitch.Queue	0.00012151	0.00	0.00	0.00058665	0.00	0.2308
collar trimming marking and notching.Queue	0.00004004	0.00	0.00	0.00021264	0.00	0.05099207
collar turn and iron.Queue	0.00000011	0.00	0.00	0.00000326	0.00	0.00156685
crease button hole placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
crease pocket.Queue	1.9697	0.03	1.7977	2.1158	0.00	4.9963
cuff hem.Queue	17.2252	0.02	17.1256	17.3926	0.00	35.1673
cut sleeve slit at placket position.Queue	15.9646	0.02	15.8633	16.1393	0.00	32.9743
form button hole placket.Queue	33.4477	0.28	31.3578	34.1958	0.00	68.3059
hem pocket.Queue	2.5381	0.02	2.4535	2.6637	0.00	5.7773
iron cuff.Queue	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. 11 List of bottleneck operations and their average waiting time in minutes

Seq. no.	Operations description	Oper. No.	Waiting time (minutes)
1	Bottom hem. Queue	44	63.8934
2	Collar close and insert label. Queue	42	63.2123
3	Close upper placket and make. Queue	34	42.00
4	Form button whole placket. Queue	20	33.447
5	Cuff hem. Queue	9	17.22
6	Mark lining. Queue	1	15.997
7	Cut sleeve slit at placket. Queue	29	15.964
8	Join upper yoke panel. Queue	26	12.457
9	Attach placket. Queue	32	7.76
10	Mark pocket. Queue	14	7.41

From table 5.11 the bottom hem operation 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. 12 Bottleneck operations based on average number waiting

5:17:11PM **Category Overview** June 1, 2021

Values Across All Replications

Assembly line simulation model for full long sleeve shirt production process done by

Replications: 30 Time Units: Minutes

Queue

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel.Queue	0.00	0.00	0.00	0.00	0.00	0.00
attach plackets.Queue	9.0633	0.05	8.8677	9.3863	0.00	25.0000
Attach pocket.Queue	3.2771	0.03	3.1326	3.4824	0.00	12.0000
attath pocket.Queue	0.00031452	0.00	0.00001027	0.00059888	0.00	1.0000
back yoke topstitch.Queue	0.2069	0.02	0.1226	0.3149	0.00	4.0000
Batch back with front.Queue	0.4994	0.00	0.4937	0.5059	0.00	2.0000
Batch collar with assembled shirt.Queue	0.4958	0.00	0.4811	0.5220	0.00	2.0000
Batch cuff with assembled shirt.Queue	0.5009	0.00	0.4907	0.5219	0.00	2.0000
Batch front and pocket.Queue	0.4980	0.00	0.4917	0.5051	0.00	2.0000
Batch sleeve with back assembled front.Queue	0.4984	0.00	0.4838	0.5084	0.00	2.0000
BH front placket and collar.Queue	0.01273905	0.00	0.00903380	0.01764608	0.00	1.0000
Bottom hem.Queue	61.6400	0.19	60.7975	62.7819	0.00	124.00

attach back yoke with back panel.Queue	0.00	0.00	0.00	0.00	0.00	0.00
attach plackets.Queue	9.0633	0.05	8.8677	9.3863	0.00	25.0000
Attach pocket.Queue	3.2771	0.03	3.1326	3.4824	0.00	12.0000
attath pocket.Queue	0.00031452	0.00	0.00001027	0.00059888	0.00	1.0000
back yoke topstitch.Queue	0.2069	0.02	0.1226	0.3149	0.00	4.0000
Batch back with front.Queue	0.4994	0.00	0.4937	0.5059	0.00	2.0000
Batch collar with assembled shirt.Queue	0.4958	0.00	0.4811	0.5220	0.00	2.0000
Batch cuff with assembled shirt.Queue	0.5009	0.00	0.4907	0.5219	0.00	2.0000
Batch front and pocket.Queue	0.4980	0.00	0.4917	0.5051	0.00	2.0000
Batch sleeve with back assembled front.Queue	0.4984	0.00	0.4838	0.5084	0.00	2.0000
BH front placket and collar.Queue	0.01273905	0.00	0.00903380	0.01764608	0.00	1.0000
Bottom hem.Queue	61.6400	0.19	60.7975	62.7819	0.00	124.00

The following operations have maximum number of waiting time in queue assembly lines.

Table 5. 13 Operations and their maximum number waiting in queue

Seq.no	Operation description	Oper.no	Averg. No. waiting in queue
1	Collar close and insert label. Queue	42	65.29
2	Bottom hem. Queue	44	61.64
3	Close upper placket and make	34	49.62
4	Form buttonhole placket. Queue	20	39.844
5	Cuff hem. Queue	9	20.13
6	Cut sleeve slit at placket position. Queue	29	18.65

5.7 Operator skill matrix for developing alternative simulation models

Before line balancing operation takes place designing operator skill matrix is mandatory to rotate and assigning operators to work stations depend on the skill level they have. For developing skill matric of operators Harvey balls and excel sheets are integrated together to design training level operators have and skill gap they need to train. Operator skill matrix used to know whether assembly line balancing designer have sufficient operators at the right skill level or not prior to assigning to work stations. Harvey balls are used to represent skill levels operators have at the time the assembly line balancing take place. Harvey balls have four quadrants to represent different skills levels operators have.

Table 5. 14 Harvey balls and their interpretations

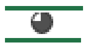
Harvey balls	Skill level
○	Training is required
◔	Started training
◑	Trained, can work with the supervision of coach
◕	Fully trained, can work without supervision of coach
●	Fully trained and can able to train others

5.8 Alternative Model Development Based on Different Scenarios

Scenarios of different alternatives are rotating operators, based on their skill and machine type which can be used for two or more operations with the same machine type. The previous assembly line balancing by simulation modelling done without building operator skill matrix, but here under this paper operator skill matrix is developed to be used as source of information for assigning operators to different work stations for reducing cycle times of operations, minimizing number of WIP and increasing productivity of the assembly lines without affecting activity precedence.

Based on the operator skill matrix provided under table 5.14 the following scenarios are prepared for the ultimate goal of increasing productivity of the case company.

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

As it is observed from skill matrix operation number 19 and 3 can be merged together in order to be done with resource, skill matrix tells information that operator number 19 has skill to operate operation number 3 with skill matrix symbol  this means that, operator number 19 can operate operation number 3 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.

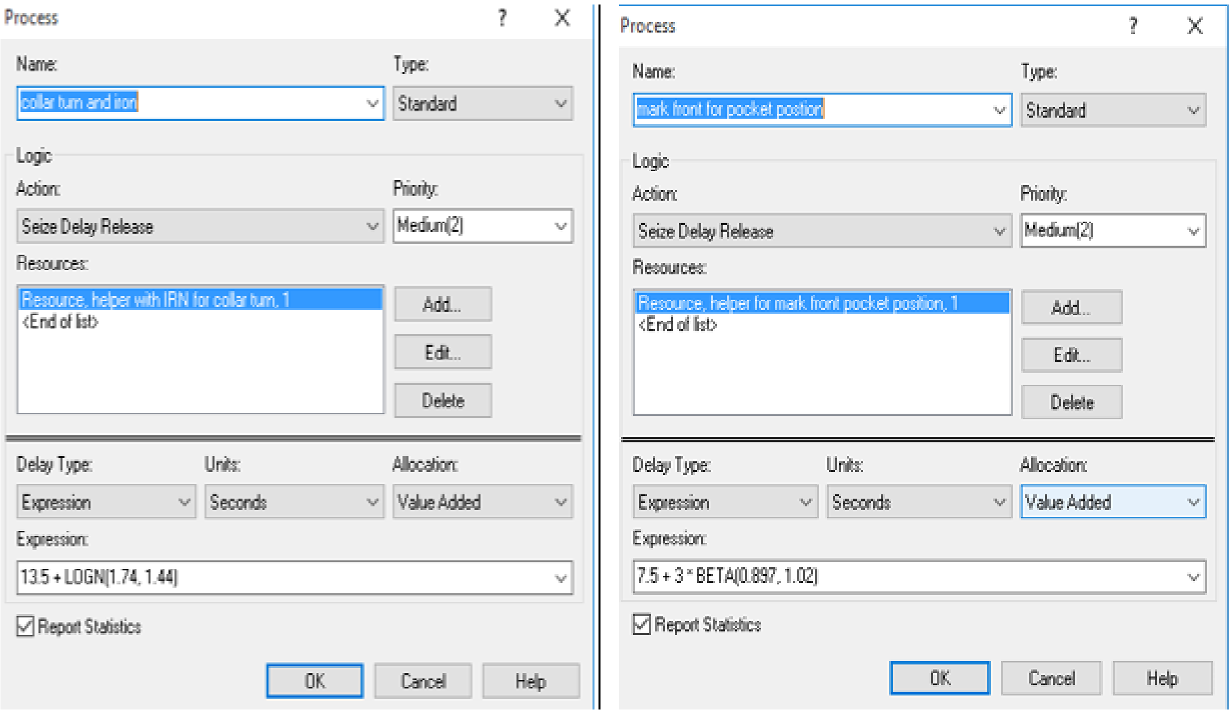
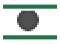


Figure 5. 5 Merged operations based on the skill matrix operators have

As it is observed from the above figure5.4 the operations are merged together to be undertaken by operator number 19.

Other possible alternative for merging operations is, merging operation number 14 and 15 at the pocket part of the shirt. As it is observed from resource utilization table 5.5 both resources are idle 75% and 69% of the processing time the simulation model runs. Skill matrix shows that operator number 14 can operate operation number 15 with full of four quadrant skill level .

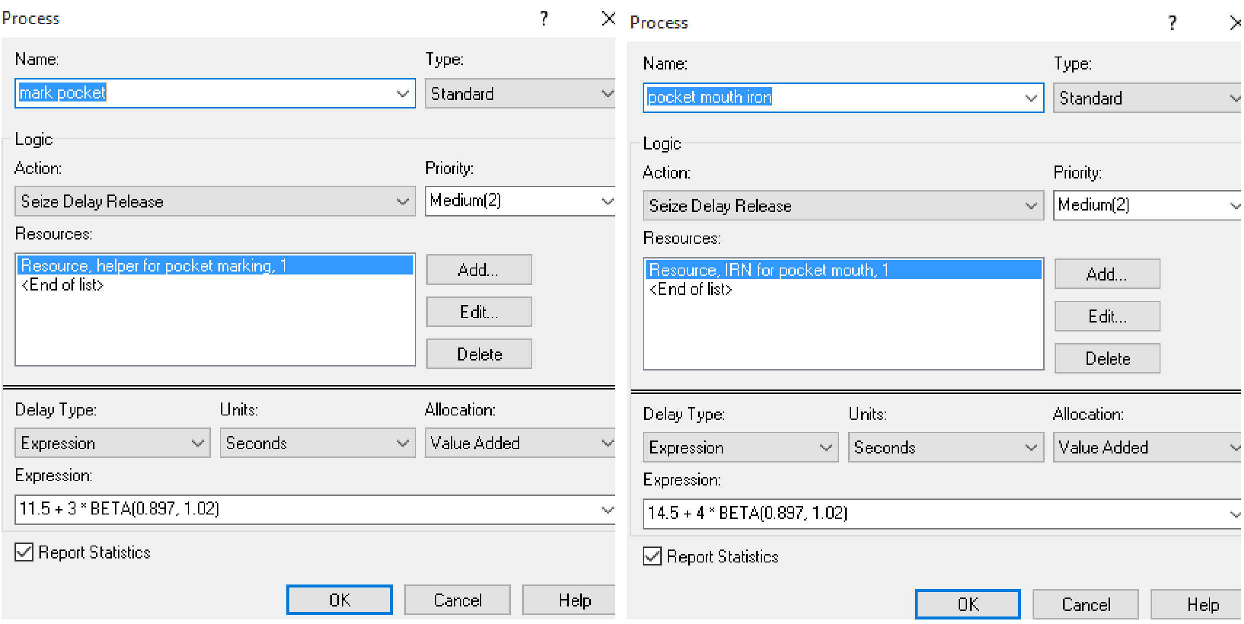
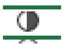


Figure 5. 6 Merged operations for scenario I

Other possible alternative for merging operations with more idle resource is, merging operation number 27 and 23 since those operations required the same machine, single needle lock stich machine (SNLM) and operator number 27 can perform operation number 23 with skill matrix of  i.e. can operate with 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 (front and back part) respectively.

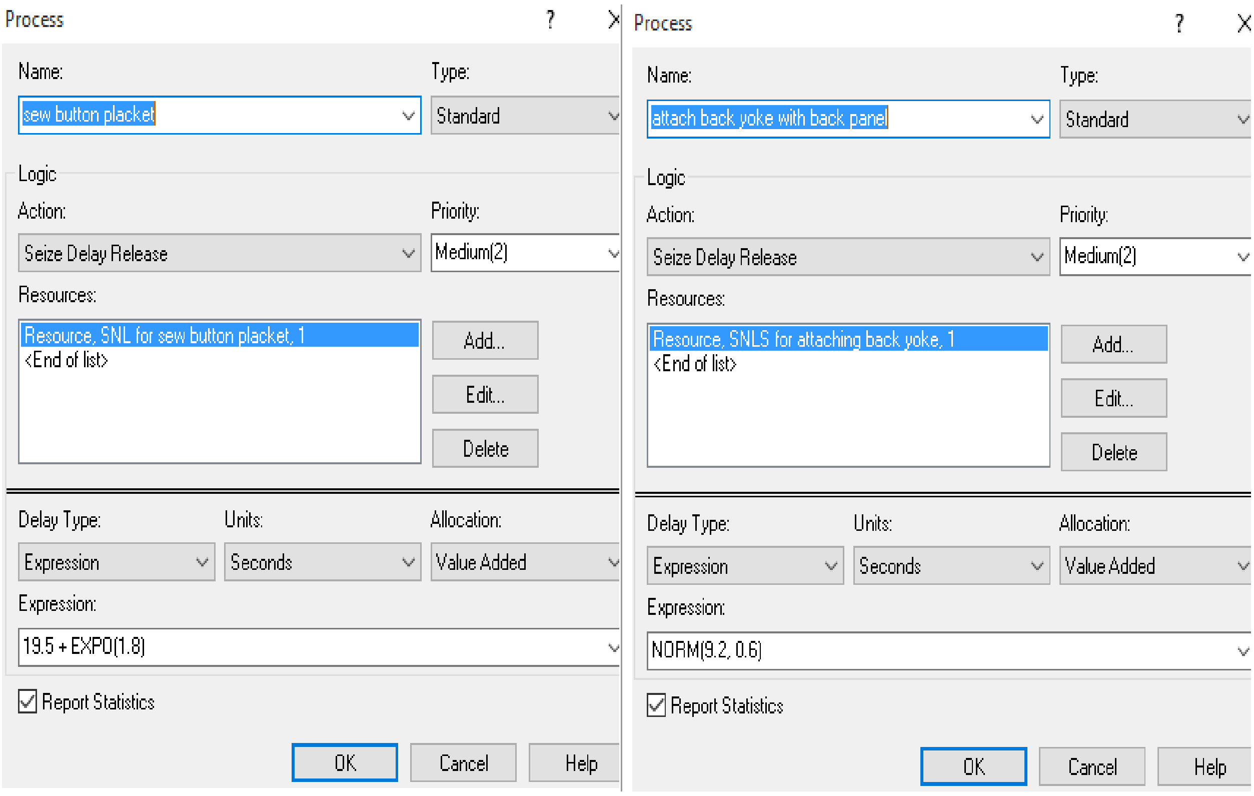


Figure 5. 7 Merged operations for scenario II

Under scenario one operator number 3, 15 and 23 are reduced in addition to reducing number of operator 1 SNL and 1 IRN machines are reduced. As it is observed from table 5.9 operation number 44, 42, 34, 20, 9 and 29 have high amount of number waiting in queue (WIP) therefore these work stations need additional resources. From skill matrix operator number 23 can be rotated to work station 44 operator 15 to work station 34 and operator 3 to work station 29. The above statements yield to be investigated as two scenarios as one modelling because both of them gives the same output except slight change in resource utilization those don't have any contribution for improvement.

Flow process chart for scenario II and II

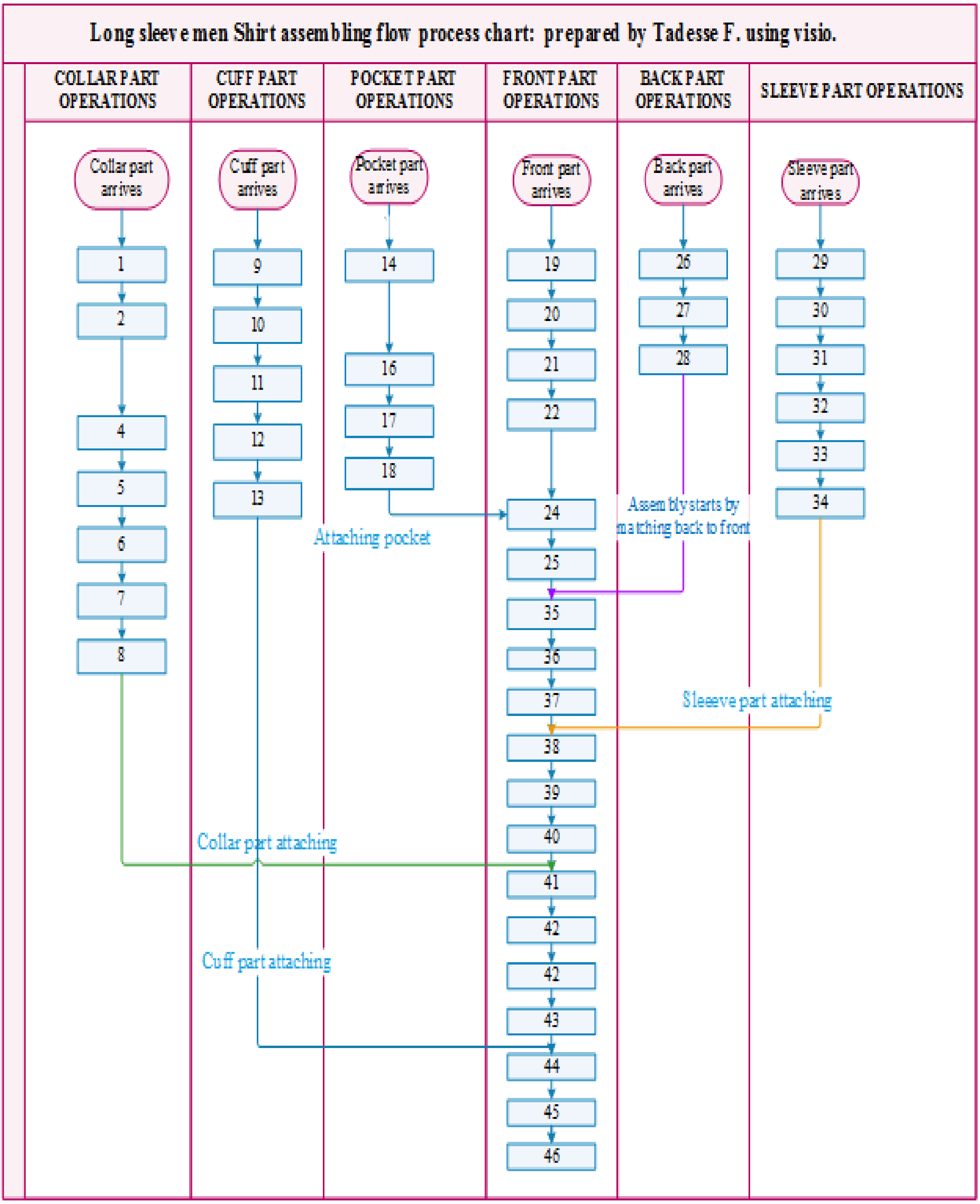


Figure 5. 8 Process flow charts for scenario I and II

11:56:01PM **User Specified** June 7, 2021

Assembly line simulation model for full long sleeve shirt Replications: 30

Replication 1 Start Time: 0.00 Stop Time: 480.00 Time Units: Minutes

Counter

Count	Value
assembled shirt	438.00
number of rejectd shirts	89.0000

Figure 5. 9 User defined output for improved system

5.9 Comparison of existing system output and two scenarios developed

Table 5. 15 Number of Resource and Work Station at Existing System and Scenarios

Scenarios	No. m/c	No. of operator	No. of work station
Existing system	42	46	46
Scenario I	39	43	43
Scenario II	42	46	43

Table 5. 16 Statistical Output Comparison for Existing System and scenarios

Scenarios	Output		Max. WIP		productivity		Takt time (min/pcs)
	Assembled pcs.	Rejected shirt/day	Waiting time in	Number waiting in pcs.	m/c	operator	
Existing system	301	55	64	65	7	7	1.6
Scenario I	438	88	42.23	49.33	11	10	1.095
Scenario II	438	88	42.33	51.22	10.4	9.52	1.095
Company plan	417					10	1.15

Figure 5. 10 Comparison of Basic Statistical Outputs

One of the basic aims in simulation modelling with different scenarios is to increase resource utilization in parallel increasing number of output products.

The following table 5.18 compares resource utilizations of assembly line balancing with different scenarios.

Table 5. 17 Resource Utilization at Different Simulation Modelling State

Seq#.	Resource name	Utilization		
		Existing	Scenario I	Scenario II
1	helper for mark front pocket position	0.1732	0.4223	0.422
2	SNLS for attaching back yoke	0.1789	0.5932	0.58
3	helper for crease button hole placket	0.2219	0.2217	0.333
4	helper for pocket marking	0.2510	0.5292	0.66
6	DNL for top stitch button hole placket	0.3075	0.3255	0.30
7	helper for turn cuff	0.3131	0.33	0.37
9	SNL for collar band center	0.3798	0.3801	0.27

Table 5. 18 Samples of Resource utilization in scenario I

11:35:48PM **Category Overview** June 7, 2021

Values Across All Replications

Assembly line simulation model for full long sleeve shirt

Replications: 30 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
BH for forming button hole placket	0.9991	0.00	0.9966	1.0000	0.00	1.0000
close lower placket machine	0.7742	0.00	0.7699	0.7797	0.00	1.0000
close upper placket and make machine	0.9948	0.00	0.9930	0.9956	0.00	1.0000
cutter for sleeve slit at placket	0.4753	0.01	0.4451	0.5065	0.00	1.0000
DNL for collar band hem	0.4084	0.00	0.4063	0.4120	0.00	1.0000
DNL for cuffhem	0.5835	0.00	0.5804	0.5860	0.00	1.0000
DNL for top stitch button hole placket	0.3255	0.00	0.3232	0.3279	0.00	1.0000
helper for collar trimming	0.4715	0.00	0.4692	0.4741	0.00	1.0000
helper for crease pocket	0.4710	0.00	0.4678	0.4743	0.00	1.0000
helper for creasebbutton hole	0.2217	0.00	0.2201	0.2234	0.00	1.0000
helper for mark front pocket position and IRN	0.4222	0.01	0.3905	0.4641	0.00	1.0000
Helper for mark lining	0.5438	0.00	0.5411	0.5470	0.00	1.0000
helper for pocket marking	0.5292	0.00	0.5276	0.5304	0.00	1.0000
helper for turn cuff	0.3133	0.00	0.3120	0.3150	0.00	1.0000
helper for turn pocket	0.4648	0.00	0.4621	0.4681	0.00	1.0000
iron upper and lower sleeves placket machine	0.4900	0.00	0.4864	0.4938	0.00	1.0000
JUKI LBH	0.8958	0.00	0.8881	0.9028	0.00	1.0000
label attaching machine	0.5938	0.00	0.5892	0.5992	0.00	1.0000
notching sleeve machine	0.4569	0.00	0.4532	0.4607	0.00	1.0000
pocket attaching machine	0.7751	0.00	0.7708	0.7817	0.00	1.0000
Resource 11	0.4767	0.00	0.4730	0.4796	0.00	1.0000
Resource 12	0.8515	0.00	0.8447	0.8564	0.00	1.0000
Resource 13	0.8434	0.00	0.8369	0.8490	0.00	1.0000
Resource 14	0.6114	0.00	0.6060	0.6147	0.00	1.0000
Resource 15	0.6870	0.00	0.6802	0.6943	0.00	1.0000
Resource machine	0.7926	0.00	0.7853	0.7974	0.00	1.0000
Resource machine sew	0.6073	0.00	0.6039	0.6107	0.00	1.0000
SNL auto	0.7475	0.00	0.7422	0.7523	0.00	1.0000

Table 5. 19 Samples of Waiting time in queue for scenario I

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel and sew button placket.Queue	5.0402	0.02	4.9212	5.1482	0.00	11.0674
attach plackets.Queue	8.0904	0.17	7.2244	9.2722	0.00	20.2051
Attach pocket.Queue	2.0737	0.02	1.9226	2.1415	0.00	5.9559
attath pocket.Queue	0.00000067	0.00	0.00	0.00000956	0.00	0.00510700
back yoke topstitch.Queue	0.00003515	0.00	0.00	0.00019528	0.00	0.0990
Batch back with front.Queue	0.2159	0.00	0.2121	0.2194	0.00	2.5520
Batch collar with assembled shirt.Queue	0.2402	0.00	0.2276	0.2510	0.00	2.4024
Batch cuff with assembled shirt.Queue	0.2249	0.00	0.2143	0.2314	0.00	4.1339
Batch front and pocket.Queue	0.2184	0.00	0.2149	0.2221	0.00	1.4624
Batch sleeve with back assembled front.Queue	0.2332	0.00	0.2276	0.2404	0.00	1.1082
BH front placket and collar.Queue	2.5670	0.09	1.9862	3.0615	0.00	8.7918
Bottom hem.Queue	1.5193	0.17	0.7421	2.5967	0.00	15.0054
Button attach.Queue	2.7576	0.10	2.1562	3.2970	0.00	8.7152
close lower placket.Queue	0.05660931	0.01	0.03848102	0.1085	0.00	0.9121
close upper placket and make.Queue	42.2310	0.26	40.2934	43.8984	0.00	85.6640
collar attach to band.Queue	1.4493	0.03	1.3145	1.5836	0.00	3.9864
collar band centre stitch.Queue	0.00000642	0.00	0.00	0.00005233	0.00	0.02511992
collar band hem.Queue	0.00119827	0.00	0.00005976	0.00363062	0.00	0.6223
Collar close and insert label.Queue	0.01801384	0.00	0.01190859	0.02221303	0.00	0.4040
collar run stitch.Queue	0.7173	0.03	0.5821	0.8720	0.00	2.5044
collar top stitch.Queue	0.00001517	0.00	0.00	0.00015329	0.00	0.04800509

CHAPTER SIX
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Productivity enhancement with shorter lead time is a primary request for textile and garment industry in order to stay alive in competitive fashion market. The profit earnings and for maximum market share of garment products largely depends on productivity improvement of the both resource on utilization and human resource available on hand. Garment industries are labor intensive and needs most of sewing machines and non-sewing machines which performs very complex and progressive operations.

In this research assembly line balancing of operation in swing line of men long sleeve shirt was done by arena simulation software. For examining the current system performance of the case company and developing different scenarios of simulation model by identifying critical factors of production and assignments of operators and machines based on operator skill level was the first aim. Random assembly line balancing and modelling a simulation model without screening principal of critical factors of production and operator skill matrix leads to confusion in monitoring and only one time improvement programs. As the result of the company report shows that the variance between monthly target and actual monthly product is maximum 174,776 and 389,700 shirts product were losses in 2018 and 2019 years respectively. On the other side actual and target productivity of the company was 7 and 9 pcs of shirts per day respectively.

The methodology applied to solve the problem of higher takt time and low productivity of machines and labors was identification of critical factors of production and associated losses in production based on the frequency of occurrence in three months. Analysis result shows that absenteeism or turn over, quality workmanship losses, machine break down and longer repair time, quality control work in process inventory, cutting quality issue at cutting section, wrong measurement or supply from WS, lack of machine or attachment, shading errors are the critical few the company needs to work on and which are causes for 80% of losses in production. The second approach focuses on developing operator kill matrix for greater insight and reasonable and assignments of operators to work stations during balancing assembly lines. Operators of the case company are categorized under, training is required, started training trained and can work with the supervision of coach, fully trained and can work without supervision of coach, fully trained and can able to train others.

Final analysis (developing ALB simulation model) with 30 number of replication and 480 minutes replication length shows that the current production system performance of 355 pcs of shirts per day. Out of 355 pcs of shirt 301 pcs passed inline inspection and 54 pcs of shirts fails in line inspection. Bottom hem. Queue, Collar close and insert label. Queue, Close upper placket and make. Queue, Form button whole placket. Queue, Cuff hem. Queue, Mark lining. Queue and Cut sleeve slit at placket. Queue with 63.8934, 63.2123, 42.00, 33.447, 17.22, 15.997, 15.964 minutes of average waiting time respectively. Operation with maximum WIP inventories were identified as collar close and insert label, Bottom hem. Queue, Close upper placket and make, Form buttonhole placket. Queue, Cuff hem. Queue, cut sleeve slit at placket position. Queue with average inventories 65.29, 61.64, 49.62, 39.844, 20.13, and 18.65 respectively. Highly utilized resource and least utilized resource was identified as BH for forming button hole placket, close upper placket and make m/c, and SNLS for attaching back yoke and helper for mark front pocket position, 99.97%, 99.45% and 17.89%, 17.32% respectively.

Other approach was developing alternative models for productivity improvement by balancing sewing lines based on operator skill level. The result of the simulation model report shows that the final assembled shirt which passes inline inspection was increased to 438 pcs per day by re assigning operators and merging two operations which can be performed parallels and not affecting precedence of operations. Productivity of machines improved from 7 pcs per day to 11 pcs, operator productivity 7 pcs to 10 pcs per day. Takt time improved from 1.6 to 1.095 minute/pcs which is lower than company target plan 1.6. The least utilization of resources improved from 17.89% to 59.32%.

The cost benefit analysis of the research shows that this research can contribute total sales income of 69,851,740ETB, this is estimation benefit which included cost of production and expenses over the year.

6.2 Recommendations

- The company losses good opportunities of optimum utilization of resources because of unbalanced assembly line designs and operator assignment
- The case company and other similar companies need to implement critical factor of success/loss identification process
- Implementation of operator skill level based simulation assembly line balancing method is recommended for greater insight and easily monitoring, examining the performance of the production system in the current and prediction of long year's performances of the system.
- Company also recommended to implement comprehensive and updatable operator skill matrix for easy and valuable balancing operation

- The basic focus of the company should be on solving problems of critical factors of production the 20% vital few

6.3 Future Study Area

1. Automation of ALB system in garment manufacturing industries
2. Further analysis of critical factors production and operator turn overs in Ethiopian garment manufacturing industries
3. Alternative layout design of assembly lines in garment manufacturing industries

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APPENDIX A: CRITICAL FACTOR ANALYSIS SURVEY AND OPERATOR SKILL MATRIC QUESTIONER

Table A-1: Questioner and Respondents

Number of questions raised	25
Number of respondents	25
Copies of paper distributed	125
Respondent role in the case companies	Production manager and supervisors
Number of valid responses	78%

Table A- 2 Production Report in 2018 and 2019

Sewing line (SL_1- SL_{14})	**2018 records for both actual and target out put**		**2019 records for both actual and target out put**	
	Target output on average(pcs)	Actual output on average(pcs)	Target output on average(pcs)	Actual output on average(pcs)
SL_1	134086	109600	122100	111300
SL_2	128220	116500	122100	106200
SL_3	138600	129400	121200	114900
SL_4	111000	100000	133800	94800
SL_5	113100	98800	121200	116400
SL_6	96600	75400	110400	91800
SL_7	104700	51700	121200	114900
SL_8	146400	134800	117300	30900
SL_9	135900	97300	120300	93600
SL_{10}	111300	90700	151200	120300
SL_{11}	11970	106000	122100	101400
SL_{12}	104700	91300	120300	80400
SL_{13}	141900	121900	145800	108000
SL_{14}	97800	78100	154200	108600
Total	1,576,276	1,401,500	1,783,200	1,393,500

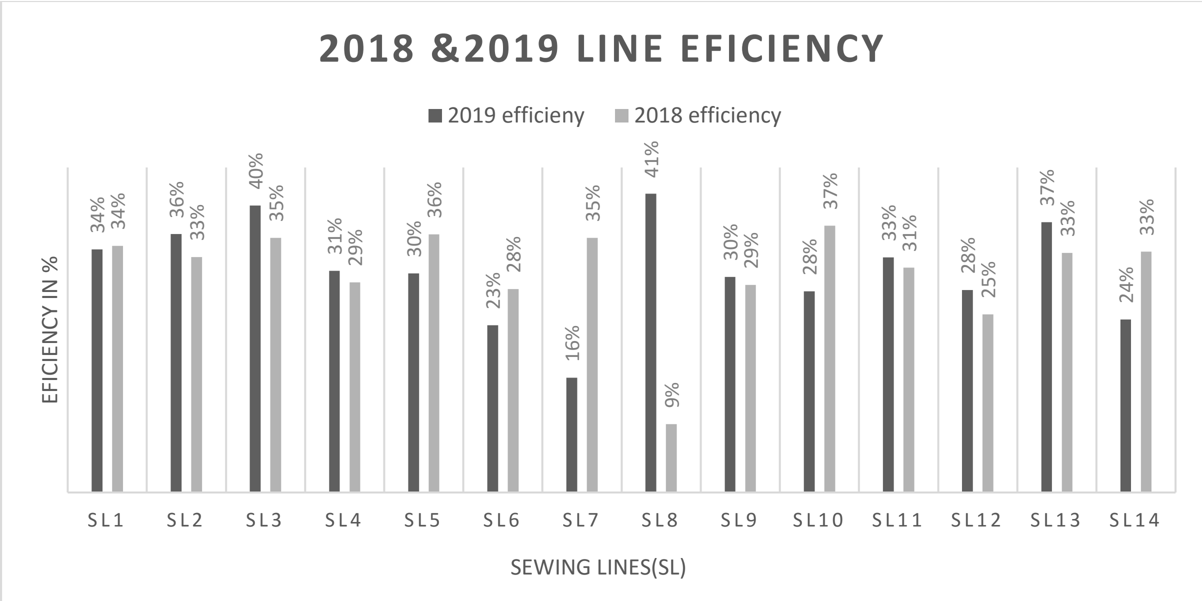


Figure A-1 Sewing Line Efficiencies in 2018 and 2019 year

Table A-3 data for operator skill level

	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	41	42	43	44	45	46
1	4	2	0	1	0	1	1	1	0	1	2	0	0	2	1	1	3	2	2	3	1	0	2	0	4	0	1	3	3	3	0	1	0	1	2	1	1	1	1	2	2	1	2	2	0	1
2	2	4	0	0	1	1	1	1	2	2	0	1	2	1	0	2	1	0	1	2	1	0	1	0	0	0	0	0	0	1	0	0	0	0	2	0	0	1	2	0	0	0	0	0	1	2
3	3	1	4	0	1	2	3	2	1	0	1	2	1	3	1	2	3	1	1	0	2	2	0	2	2	1	0	0	3	0	0	2	2	2	1	0	2	1	0	1	3	0	4	0	1	0
4	1	1	2	4	1	3	1	0	1	2	1	2	2	2	3	1	0	2	2	0	0	1	2	0	0	0	1	0	0	1	0	0	0	0	0	1	0	1	3	0	0	1	0	1	1	4
5	1	1	0	1	4	1	0	1	0	0	1	0	1	3	0	2	2	0	4	0	1	0	0	3	1	1	0	0	0	0	4	0	0	3	3	1	2	1	0	3	0	0	2	2	1	0
6	1	1	1	0	0	4	0	1	0	0	0	4	0	0	2	3	0	0	2	4	3	1	1	0	3	0	2	1	0	0	0	2	2	0	0	1	0	0	4	0	1	2	0	0	1	2
7	2	1	1	1	0	0	4	0	2	0	2	0	2	1	0	0	2	2	0	0	0	0	0	1	0	4	0	3	3	2	0	0	0	2	0	0	0	1	0	3	0	0	2	3	2	0
8	3	1	1	0	0	0		4	0	0	0	0	0	2	0	0	0	2	3	3	2	2	2	3	2	1	0	0	0	0	0	0	1	0	0	1	3	1	3	0	1	3	0	0	1	0
9	2	1	1	2	2	0	2	1	4	0	0	2	2	0	2	1	2	0	0	0	0	0	3	3	0	0	1	1	0	1	2	2	0	0	0	0	3	0	0	0	1	3	2	0	1	3
10	1	1	1	0	0	0	2	1		4	0	0	0	2	0	3	1	4	2	4	2	2	0	0	3	3	0	3	2	0	0	0	0	2	3	1	3	1	1	1	0	1	2	0	1	0
11	1	1	1	1	1	3	0	0	2	0	4	0	0	1	0	0	0	0	0	0	0	0	2	1	1	0	1	0	0	3	3	4	3	0	0	0	0	1	0	2	3	0	0	1	0	0
12	3	1	3	0	0	0	0	0	0	0	0	4	0	0	4	3	2	2	0	3	2	2	1	0	1	1	0	4	2	0	0	0	0	3	2	1	2	1	1	2	0	2	2	0	1	0
13	2	1	0	1	1	0	2	0	2	0	0	0	4	0	0	0	0	0	3	0	0	0	0	1	0	0	2	0	0	2	2	2	3	0	0	1	3	0	1	1	3	0	2	0	1	1
14	2	1	3	0	0	2	0	4	0	4	0	0	0	4	4	2	0	2	0	2	2	1	1	2	1	2	0	1	2	0	0	1	0	2	2	0	0	4	0	2	0	4	2	3	1	1
15	1	1	0	0	0	0	3	0	2	0	0	3	0	2	4	0	3	1	1	0	0	1	1	0	0	1	1	3	0	0	2	0	4	3	2	1	3	1	1	0	1	0	0	0	3	1
16	1	1	0	0	1	2	0	3	0	4	3	0	0	0	0	4	0	2	0	1	3	1	0	2	1	0	0	0	2	2	2	2	0	0	2	1	3	0	1	2	0	3	2	0	1	1
17	1	1	0	3	0	0	2	0	1	0	0	0	3	0	3	0	4	0	2	2	0	0	1	3	0	2	2	1	0	0	0	1	3	2	0	0	2	1	1	2	1	3	2	0	1	2
18	2	1	0	0	0	0	2	2	0	2	0	0	0	2	0	3	0	4	0	0	2	1	0	0	3	3	2	0	2	3	0	0	0	0	2	1	0	1	2	0	1	0	2	0	1	1
19	2	1	3	3	2	0	0	0	2	0	2	1	0	0	3	3	2	2	4	3	0	2	1	2	0	0	0	2	0	0	3	3	2	3	2	1	3	0	1	1	1	2	0	3	1	2
20	2	1	0	0	0	1	0	3	0	3	0	0	3	0	0	0	0	2	0	4	3	0	0	0	0	2	3	0	3	0	0	0	0	0	1	1	3	3	0	0	1	0	2	0	3	1

21	2	1	1	3	2	0	3	1	2	0	2	3	0	3	1	0	2	2	3	0	3	4	1	1	3	1	0	2	0	3	0	3	1	2	2	0	3	1	1	2	1	2	2	3	1	1
22	2	1	0	1	2	0	0	1	0	1	0	0	0	0	0	1	2	2	0	0	0	3	0	1	0	0	3	0	4	0	4	0	0	0	2	1	3	1	1	2	2	0	0	0	1	1
23	2	1	3	0	0	1	0	1	3	4	1	1	1	1	1	1	2	1	1	1	1	1	4	0	2	2	0	3	0	2	0	2	1	0	3	1	0	0	1	0	1	0	2	1	1	1
24	2	1	1	0	1	1	2	1	1	2	1	1	1	0	1	1	1	1	1	1	1	1	1	3	0	0	4	0	0	0	3	0	0	0	2	1	3	1	3	2	1	2	0	3	1	0
25	2	1	0	0	1	0	2	1	4	0	2	1	2	1	1	0	0	1	1	1	1	1	1	1	3	0	0	1	2	2	2	0	0	3	2	3	3	1	1	0	0	0	2	1	1	1
26	2	1	1	1	0	1	1	1	0	0	1	1	1	1	2	3	2	2	0	0	0	0	0	0	0	4	2	0	0	0	0	2	3	0	1	1	3	1	1	2	1	3	1	3	0	1
27	2	1	0	0	2	0	2	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	4	0	3	3	4	0	0	0	0	1	0	1	1	0	1	0	2	0	2	1
28	2	1	0	2	0	1	0	1	2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	0	0	0	3	0	3	0	1	3	1	1	2	0	3	0	3	0	1
29	2	1	0	0	2	0	2	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	3	0	3	0	0	0	2	1	3	1	1	0	1	0	3	0	1	1
30	2	1	3	3	2	3	2	1	0	3	0	1	0	0	3	0	3	2	0	0	0	0	0	1	3	3	0	0	3	3	1	0	0	0	0	3	3	0	1	2	1	1	2	1	0	1
31	2	1	0	0	0	0	2	1	2	0	1	0	4	2	0	0	2	0	2	1	1	2	3	1	0	0	3	4	3	0	3	0	0	2	3	1	1	1	1	0	1	3	1	1	3	1
32	2	1	3	0	3	2	2	0	0	3	1	0	0	0	0	4	0	3	2	3	1	3	0	1	1	3	0	0	2	0	0	4	0	0	0	1	3	4	1	0	0	0	2	1	0	1
33	2	3	0	1	1	2	2	1	2	3	3	2	2	2	4	2	2	0	0	0	0	0	1	1	0	0	2	0	2	0	0	0	4	0	0	0	0	1	1	1	1	0	2	1	1	1
34	2	1	3	0	1	0	2	1	1	0	0	3	0	2	2	2	3	2	2	2	2	2	2	1	2	2	2	2	3	2	2	2	2	4	0	1	2	0	1	3	1	2	2	2	0	1
35	2	2	0	0	2	2	2	1	2	1	1	0	1	0	0	0	0	0	1	0	3	0	0	1	0	3	0	0	2	0	0	0	0	0	4	1	0	1	1	2	1	0	2	1	0	1
36	2	1	0	0	1	1	2	2	1	0	1	1	1	4	0	2	3	3	2	2	0	4	3	1	2	0	4	0	3	4	3	0	2	0	0	4	3	1	1	0	1	0	1	1	0	1
37	2	1	1	0	1	2	2	1	0	3	1	0	2	0	3	0	0	0	0	0	2	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	4	1	1	2	1	4	0	3	0	0
38	2	1	2	2	1	1	2	1	2	0	3	4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2	4	1	0	0	0	3	1	2	0
39	2	1	0	0	1	2	2	1	2	1	1	0	1	1	1	1	4	1	3	0	1	3	1	1	2	1	1	1	1	4	1	0	1	1	3	1	1	1	4	2	1	0	0	3	0	3
40	2	1	0	0	1	2	2	2	1	3	3	0	0	1	1	3	2	0	1	1	3	3	3	1	1	2	1	3	1	3	0	2	3	0	3	0	1	0	3	3	1	2	3	2	3	0
41	2	2	3	0	3	0	2	1	2	0	1	1	1	1	2	0	4	1	1	2	0	0	0	1	0	1	3	1	0	0	0	0	0	0	0	0	1	0	1	0	3	0	0	3	0	0
42	2	1	0	2	1	0	2	1	0	2	0	0	2	1	1	3	0	0	3	0	2	2	2	1	2	0	1	3	2	2	2	2	2	2	2	2	2	2	1	2	4	4	1	1	4	1
43	2	1	3	0	1	1	2	2	2	0	1	2	1	1	0	0	1	2	1	3	0	4	1	1	0	3	1	0	0	0	0	0	2	0	1	0	1	0	0	0	1	1	4	1	1	1
44	2	3	0	0	1	2	2	1	2	3	1	1	3	3	3	3	3	3	1	0	1	0	0	1	3	0	3	3	1	0	3	3	0	2	1	2	1	0	1	0	1	1	1	3	1	
45	2	1	0	0	0	2	2	1	0	0	1	0	1	0	3	0	2	1	0	2	0	0	3	1	0	0	1	0	1	0	0	0	0	0	0	0	1	0	1	0	1	1	1	1	4	1
46	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	1	2	2	3	2	2	2	2	2	2	2	2	1	2	3	1	1	1	2	2	0	1	1	1	1	1	4

APPENDIX B: SIMULATION MODELLING ALB

Table B-1 processing cycle time observations

No.	operation	O_1	O_2	O_3	O_4	O_5	O_6	O_7	O_8	O_9	O_{10}
1	Mark lining	10	11	15	10	12	10	11	11	12	14
2	Collar run-stitch	31	33	32	31	37	32	33	36	37	34
3	Collar turn and iron	14	15	14	14	17	15	15	16	17	15
4	Collar top-stitch	22	24	23	22	26	23	23	25	26	24
5	Collar band hem	22	24	23	23	27	23	24	26	27	25
6	Collar attach to band	34	37	35	34	40	35	36	39	41	37
7	Collar trimming and making	26	28	27	26	31	27	28	30	31	29
8	Collar band Centre stitch	21	23	22	21	25	22	22	24	25	23
9	Cuff hem	27	30	28	28	33	29	29	32	33	30
10	Run stich cuff	34	37	35	34	40	35	36	39	41	37
11	Turn cuff	15	16	15	15	18	15	16	17	18	16
12	Iron cuff	19	21	20	19	23	20	20	22	23	21
13	Top stitch cuff	35	38	36	36	42	37	38	41	43	39
14	Mark pocket	12	13	12	12	14	12	13	14	14	13
15	Pocket mouth iron	15	16	15	15	18	15	16	17	18	16
16	Hem pocket	19	21	20	19	23	20	20	22	23	21
17	Crease pocket	22	24	23	22	27	23	24	26	27	24
18	Trim pocket	22	24	23	22	26	23	23	25	27	24
19	Mark front for pocket position	8	9	8	8	9	8	8	9	10	9
20	Form button hole placket	49	54	51	50	59	51	52	57	59	54
21	Crease button hole placket	11	12	11	11	13	11	11	12	13	12
22	Top stitch B/H placket	15	16	15	15	18	15	16	17	18	16
23	Sew button placket	20	21	20	20	23	20	21	23	24	21
24	Attach pocket (1 pocket)	38	41	39	38	45	40	40	44	46	42
25	Sew label at placket	30	33	31	30	36	31	32	34	36	33
26	Join upper yoke panel	20	22	21	20	24	21	22	23	24	22
27	Attach back yoke with back panel	8	9	9	9	10	9	9	10	10	9
28	Pack yoke top stitch	20	22	21	20	24	21	21	23	24	22
29	Cut sleeve at placket position	25	28	26	26	31	27	27	29	31	28

30	Notch sleeve	21	23	22	22	26	22	23	25	26	24
31	Iron upper and lower sleeve placket	22	24	29	30	26	23	23	25	26	24
32	Attach plackets	38	41	39	36	45	40	44	44	46	42
33	Close lower placket	36	40	33	39	47	38	39	42	44	40
34	Close upper placket	55	59	61	55	65	57	58	63	66	60
35	Set front and back and mark neck for collar	27	34	28	27	32	35	29	31	33	29
36	Shoulder attach	37	45	42	42	49	43	44	47	50	45
37	Shoulder top stitch	24	26	24	24	28	25	32	27	29	26
38	Sleeve attach	38	41	39	50	45	40	40	44	46	42
39	Top stitch armhole	30	32	37	39	36	31	32	34	36	33
40	Side seam	35	33	37	36	42	44	38	41	43	39
41	Collar attach	40	43	41	44	48	50	42	46	48	44
42	Collar close and insert label	33	36	42	33	39	34	35	38	40	36
43	Cuff attach and close	47	51	53	48	56	49	50	54	57	52
44	Bottom hem	39	42	40	39	47	44	41	45	47	43
45	Button hole- front placket and collar	26	23	22	21	25	28	31	24	25	23
46	Button attach	28	23	22	21	25	29	22	24	25	23

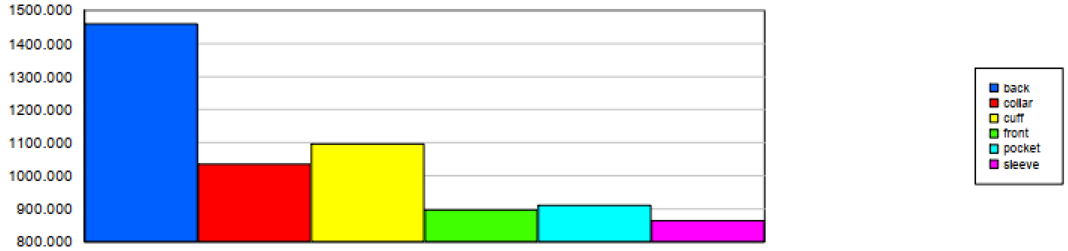
APPENDIX C: STATITISTICAL OUTPUT REPORT FOR EXISTING SYSTEM AND SCENARIOS DEVELOPPED

Table C-1 Entity Report

Entity

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
back	1459.17	1.89	1451.00	1472.00
collar	1034.77	0.19	1034.00	1036.00
cuff	1095.40	0.19	1095.00	1096.00
front	896.47	2.28	888.00	911.00
pocket	910.47	2.25	897.00	919.00
sleeve	864.73	1.91	853.00	872.00



Number Out	Average	Half Width	Minimum Average	Maximum Average
back	778.83	3.08	762.00	797.00
collar	557.37	1.88	545.00	565.00
cuff	770.30	0.70	767.00	776.00
front	417.30	1.61	410.00	426.00
pocket	457.70	1.84	449.00	467.00
sleeve	387.40	1.76	379.00	399.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
back	367.19	1.03	363.35	373.19	0.00	696.00
collar	250.90	0.69	247.87	255.21	0.00	489.00
cuff	166.94	0.43	164.93	169.61	0.00	328.00
front	258.16	0.97	254.31	265.24	0.00	490.00
pocket	246.45	0.77	242.93	250.32	0.00	464.00
sleeve	249.05	0.72	245.96	252.91	0.00	486.00

Table C-2 Process Report

Category Overview

Values Across All Replications

Assembly line simulation model for full long sleeve shirt production process done by

Replications: 30 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel	0.1534	0.00	0.1526	0.1542	0.1139	0.1967
attach plackets	0.6895	0.00	0.6845	0.6936	0.5917	0.7750
Attach pocket	0.6956	0.00	0.6920	0.6999	0.6250	0.7750
attath pocket	0.6951	0.00	0.6910	0.6982	0.6250	0.7750
back yoke topstitch	0.3635	0.00	0.3616	0.3657	0.3275	0.5984
BH front placket and collar	0.4137	0.00	0.4059	0.4221	0.3417	0.9802
Bottom hem	0.7116	0.00	0.7046	0.7173	0.6417	1.0381
Button attach	0.4035	0.00	0.3991	0.4069	0.3457	0.6933
close lower placket	0.6641	0.00	0.6604	0.6689	0.5424	0.7897
close upper placket and make	1.0146	0.00	1.0071	1.0209	0.9084	1.1083
collar attach to band	0.6158	0.00	0.6127	0.6194	0.5583	0.6916
collar band centre stitch	0.3798	0.00	0.3767	0.3814	0.3442	0.6221
collar band hem	0.4083	0.00	0.4059	0.4112	0.3604	0.8561
Collar close and insert label	0.6098	0.00	0.6063	0.6152	0.5417	0.7083
collar run stitch	0.5663	0.00	0.5625	0.5703	0.5083	0.6250
collar top stitch	0.3968	0.00	0.3940	0.4007	0.3609	0.6010
collar trimming marking and notching	0.4715	0.00	0.4683	0.4739	0.4251	0.6805
collar turn and iron	0.2540	0.00	0.2510	0.2571	0.2262	0.5569
crease button hole placket	0.1985	0.00	0.1969	0.1998	0.1750	0.2250
crease pocket	0.4035	0.00	0.4002	0.4064	0.3583	0.4583
cuff hem	0.5000	0.00	0.4969	0.5026	0.4417	0.5583
cut sleeve slit at placket position	0.4632	0.00	0.4606	0.4683	0.4133	0.7124
form button hole placket	0.8932	0.00	0.8865	0.8977	0.8134	1.4107
hem pocket	0.3467	0.00	0.3439	0.3497	0.3108	0.5472
iron cuff	0.3466	0.00	0.3438	0.3487	0.3108	0.5660
iron upper and lower sleeves placket	0.4199	0.00	0.4162	0.4225	0.3625	0.6931
join upper yokepanel	0.3618	0.00	0.3599	0.3645	0.3250	0.4083
mark front for pocket postion	0.1485	0.00	0.1475	0.1494	0.1250	0.1750
mark liining	0.5435	0.00	0.5405	0.5465	0.4917	0.6083
mark pocket	0.2151	0.00	0.2138	0.2166	0.1917	0.2417
notch sleeves	0.3921	0.00	0.3884	0.3960	0.3443	0.8645
pocket mouth iron	0.2730	0.00	0.2713	0.2747	0.2417	0.3083
runstitch cuff	0.6162	0.00	0.6135	0.6191	0.5583	0.6917
Set front and back and mark neck for collar	0.4131	0.00	0.4093	0.4166	0.3418	0.6827
sew button placket	0.3547	0.00	0.3525	0.3575	0.3250	0.6287

Table C-3 Time Per entity Report

5:17:11PM **Category Overview** June 1, 2021

Values Across All Replications

Assembly line simulation model for full long sleeve shirt production process done by

Replications: 30 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel	0.1534	0.00	0.1526	0.1542	0.1139	0.1967
attach plackets	0.6895	0.00	0.6845	0.6936	0.5917	0.7750
Attach pocket	0.6956	0.00	0.6920	0.6999	0.6250	0.7750
attath pocket	0.6951	0.00	0.6910	0.6982	0.6250	0.7750
back yoke topstitch	0.3635	0.00	0.3616	0.3657	0.3275	0.5984
BH front placket and collar	0.4137	0.00	0.4059	0.4221	0.3417	0.9802
Bottom hem	0.7116	0.00	0.7046	0.7173	0.6417	1.0381
Button attach	0.4035	0.00	0.3991	0.4069	0.3457	0.6933
close lower placket	0.6641	0.00	0.6604	0.6689	0.5424	0.7897
close upper placket and make	1.0146	0.00	1.0071	1.0209	0.9084	1.1083
collar attach to band	0.6158	0.00	0.6127	0.6194	0.5583	0.6916
collar band centre stitch	0.3798	0.00	0.3767	0.3814	0.3442	0.6221
collar band hem	0.4083	0.00	0.4059	0.4112	0.3604	0.8561
Collar close and insert label	0.6098	0.00	0.6063	0.6152	0.5417	0.7083
collar run stitch	0.5663	0.00	0.5625	0.5703	0.5083	0.6250
collar top stitch	0.3968	0.00	0.3940	0.4007	0.3609	0.6010
Collar close and insert label	0.6098	0.00	0.6063	0.6152	0.5417	0.7083
collar run stitch	0.5663	0.00	0.5625	0.5703	0.5083	0.6250
collar top stitch	0.3968	0.00	0.3940	0.4007	0.3609	0.6010
collar trimming marking and notching	0.4715	0.00	0.4683	0.4739	0.4251	0.6805
collar turn and iron	0.2540	0.00	0.2510	0.2571	0.2262	0.5569
crease button hole placket	0.1985	0.00	0.1969	0.1998	0.1750	0.2250
crease pocket	0.4035	0.00	0.4002	0.4064	0.3583	0.4583
cuff hem	0.5000	0.00	0.4969	0.5026	0.4417	0.5583
cut sleeve slit at placket position	0.4632	0.00	0.4606	0.4683	0.4133	0.7124
form button hole placket	0.8932	0.00	0.8865	0.8977	0.8134	1.4107
hem pocket	0.3467	0.00	0.3439	0.3497	0.3108	0.5472
iron cuff	0.3466	0.00	0.3438	0.3487	0.3108	0.5660
iron upper and lower sleeves placket	0.4199	0.00	0.4162	0.4225	0.3625	0.6931
join upper yokepanel	0.3618	0.00	0.3599	0.3645	0.3250	0.4083
mark front for pocket postion	0.1485	0.00	0.1475	0.1494	0.1250	0.1750
mark liining	0.5435	0.00	0.5405	0.5465	0.4917	0.6083
mark pocket	0.2151	0.00	0.2138	0.2166	0.1917	0.2417
notch sleeves	0.3921	0.00	0.3884	0.3960	0.3443	0.8645
pocket mouth iron	0.2730	0.00	0.2713	0.2747	0.2417	0.3083
runstitch cuff	0.6162	0.00	0.6135	0.6191	0.5583	0.6917
Set front and back and mark neck for collar	0.4131	0.00	0.4093	0.4166	0.3418	0.6827
sew button placket	0.3547	0.00	0.3525	0.3575	0.3250	0.6287

sew label at placket	0.5335	0.00	0.5311	0.5353	0.4917	0.6073
Sew label at placket front	0.5333	0.00	0.5312	0.5360	0.4919	0.6077
shoulder attach	0.7397	0.00	0.7352	0.7449	0.5017	0.9726
Shoulder top stitch	0.7327	0.00	0.7217	0.7377	0.6084	0.8416
side seam	0.6466	0.00	0.6420	0.6520	0.5485	1.1214
Top stitch armhole	0.5749	0.00	0.5717	0.5785	0.4917	0.6583
top stitch button hole placket	0.2752	0.00	0.2731	0.2768	0.2417	0.3083
top stitch cuff	0.6423	0.00	0.6384	0.6474	0.5799	1.0195
turn cuff	0.2683	0.00	0.2673	0.2709	0.2500	0.4144
turn pocket	0.3981	0.00	0.3945	0.4002	0.3610	0.6749

Table C-4 Waiting time Report

Process

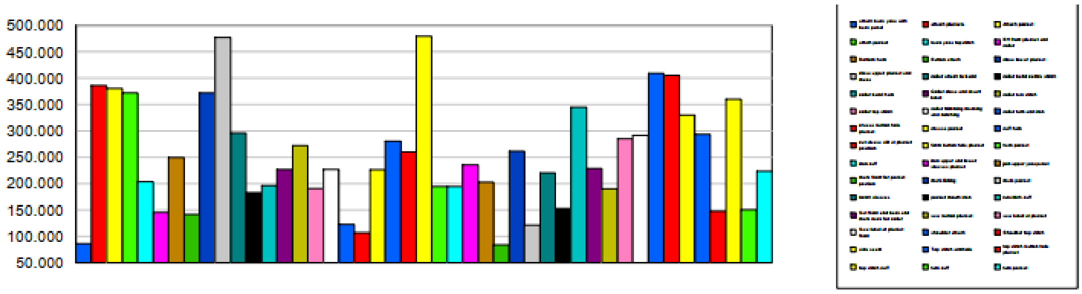
Time per Entity

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel	0.00	0.00	0.00	0.00	0.00	0.00
attach plackets	7.7685	0.04	7.6009	8.0454	0.00	17.1225
Attach pocket	2.8778	0.02	2.7539	3.0615	0.00	8.1496
attath pocket	0.00028203	0.00	0.00000923	0.00053531	0.00	0.1110
back yoke topstitch	0.1774	0.01	0.1051	0.2699	0.00	1.1462
BH front placket and collar	0.01732510	0.00	0.01238922	0.02406284	0.00	0.6734
Bottom hem	63.7973	0.23	62.7631	65.2899	0.00	126.32
Button attach	0.00167449	0.00	0.00	0.00442446	0.00	0.5349
close lower placket	0.06473621	0.01	0.04510894	0.1094	0.00	0.7059
close upper placket and make	42.4542	0.23	40.9993	44.1267	0.00	84.1444
collar attach to band	1.4679	0.03	1.2891	1.6380	0.00	4.2681
collar band centre stitch	0.00000737	0.00	0.00	0.00012651	0.00	0.06072260
collar band hem	0.00110355	0.00	0.00038305	0.00213563	0.00	0.3358
Collar close and insert label	63.1594	0.24	62.1666	64.7398	0.00	126.26
collar run stitch	0.7060	0.03	0.5355	0.8402	0.00	2.3003
collar top stitch	0.00012151	0.00	0.00	0.00058665	0.00	0.2308
collar trimming marking and notching	0.00004004	0.00	0.00	0.00021264	0.00	0.05099207
crease button hole placket	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
crease pocket	1.9697	0.03	1.7977	2.1158	0.00	4.9963
cuff hem	17.2560	0.02	17.1562	17.4236	0.00	35.1673
cut sleeve slit at placket position	15.9931	0.02	15.8916	16.1681	0.00	32.9743
form button hole placket	33.4123	0.28	31.3195	34.1605	0.00	68.3059
hem pocket	2.5381	0.02	2.4535	2.6637	0.00	5.7773
iron cuff	0.00	0.00	0.00	0.00	0.00	0.00
iron upper and lower sleeves placket	0.02438212	0.00	0.01768504	0.03063487	0.00	0.4787
join upper yokepanel	12.4801	0.02	12.4069	12.5864	0.00	25.5736
mark front for pocket postion	5.1199	0.01	5.0786	5.1663	0.00	10.5865
mark liining	16.0303	0.02	15.9384	16.1223	0.00	32.7877
mark pocket	7.4265	0.01	7.3744	7.4839	0.00	15.1369
notch sleeves	0.00546599	0.00	0.00336828	0.01089997	0.00	0.4629
pocket mouth iron	1.9927	0.02	1.9042	2.0620	0.00	4.6148
runstitch cuff	4.0097	0.03	3.8692	4.1845	0.00	8.9602
Set front and back and mark neck for collar	0.02241862	0.00	0.01950032	0.02699690	0.00	0.3824
sew button placket	0.00	0.00	0.00	0.00	0.00	0.00

sew label at placket	0.00	0.00	0.00	0.00	0.00	0.00
Sew label at placket front	0.00	0.00	0.00	0.00	0.00	0.00
shoulder attach	6.4759	0.04	6.2278	6.6601	0.00	14.5349
Shoulder top stitch	0.2264	0.02	0.1212	0.3348	0.00	1.6872
side seam	0.00845312	0.00	0.00530340	0.01163814	0.00	0.4856
Top stitch armhole	0.00008472	0.00	0.00	0.00020304	0.00	0.04155766
top stitch button hole placket	0.00	0.00	0.00	0.00	0.00	0.00
top stitch cuff	0.9404	0.03	0.7650	1.1149	0.00	3.1313
turn cuff	0.00	0.00	0.00	0.00	0.00	0.00
turn pocket	0.0949	0.01	0.05157780	0.1606	0.00	0.7979

Table C-5 Accumulated Time Report

sew label at placket	285.04	0.45	282.72	287.75
Sew label at placket front	291.34	0.30	290.05	292.97
shoulder attach	408.69	0.45	406.55	411.17
Shoulder top stitch	404.69	0.68	399.11	407.69
side seam	329.77	0.53	326.78	333.83
Top stitch armhole	293.51	0.39	291.59	295.64
top stitch button hole placket	147.55	0.22	146.17	148.92
top stitch cuff	359.67	0.45	357.49	362.52
turn cuff	150.27	0.16	149.67	151.68
turn pocket	222.92	0.26	220.90	224.13



collar band centre stitch	182.31	0.19	180.82	183.06
collar band hem	195.99	0.23	194.83	197.36
Collar close and insert label	226.45	0.30	225.20	228.22
collar run stitch	271.82	0.29	269.98	273.72
collar top stitch	190.48	0.28	189.13	192.35
collar trimming marking and notching	226.31	0.25	224.80	227.48
collar turn and iron	121.92	0.23	120.50	123.41
crease button hole placket	106.49	0.21	105.53	107.65
crease pocket	225.94	0.33	224.14	227.59
cuff hem	279.99	0.29	278.27	281.46
cut sleeve slit at placket position	259.38	0.36	257.94	262.22
form button hole placket	479.40	0.11	478.90	479.84
hem pocket	194.15	0.28	192.57	195.83
iron cuff	194.12	0.26	192.55	195.26
iron upper and lower sleeves placket	235.14	0.34	233.07	236.63
join upper yokepanel	202.60	0.25	201.56	204.11
mark front for pocket postion	83.1574	0.11	82.6214	83.6520
mark liining	260.88	0.26	259.43	262.30
mark pocket	120.46	0.15	119.72	121.29
notch sleeves	219.57	0.38	217.52	221.77
pocket mouth iron	152.88	0.16	151.93	153.83
runstitch cuff	345.09	0.27	343.56	346.72
Set front and back and mark neck for collar	228.30	0.43	225.93	230.38
sew button placket	190.05	0.38	188.22	191.96

Table C-6 Entities Entering at Each Processes Report

5:17:11PM **Category Overview** June 1, 2021

Values Across All Replications

Assembly line simulation model for full long sleeve shirt production process done by

Replications: 30 Time Units: Minutes

Process

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
attach back yoke with back panel	560.00	0.00	560.00	560.00
attach plackets	560.00	0.00	560.00	560.00
Attach pocket	546.93	0.32	546.00	549.00
attath pocket	535.77	0.63	533.00	540.00
back yoke topstitch	560.00	0.00	560.00	560.00
BH front placket and collar	350.87	0.55	348.00	353.00
Bottom hem	465.40	0.19	465.00	466.00
Button attach	350.47	0.53	347.00	353.00
close lower placket	560.00	0.00	560.00	560.00
close upper placket and make	560.00	0.00	560.00	560.00
collar attach to band	480.00	0.00	480.00	480.00
collar band centre stitch	480.00	0.00	480.00	480.00
collar band hem	480.00	0.00	480.00	480.00
Collar close and insert label	494.77	0.19	494.00	496.00
collar run stitch	480.00	0.00	480.00	480.00
collar top stitch	480.00	0.00	480.00	480.00
collar trimming marking and notching	480.00	0.00	480.00	480.00
collar turn and iron	480.00	0.00	480.00	480.00
crease button hole placket	536.70	0.65	534.00	541.00
crease pocket	560.00	0.00	560.00	560.00
cuff hem	630.00	0.00	630.00	630.00
cut sleeve slit at placket position	630.00	0.00	630.00	630.00
form button hole placket	560.00	0.00	560.00	560.00
hem pocket	560.00	0.00	560.00	560.00
iron cuff	560.00	0.00	560.00	560.00
iron upper and lower sleeves placket	560.00	0.00	560.00	560.00
join upper yokepanel	630.00	0.00	630.00	630.00
mark front for pocket postion	630.00	0.00	630.00	630.00
mark liining	540.00	0.00	540.00	540.00
mark pocket	630.00	0.00	630.00	630.00
notch sleeves	560.00	0.00	560.00	560.00
pocket mouth iron	560.00	0.00	560.00	560.00
runstitch cuff	560.00	0.00	560.00	560.00
Set front and back and mark neck for collar	552.90	0.23	552.00	554.00
sew button placket	536.17	0.67	534.00	540.00

sew label at placket	535.13	0.67	533.00	539.00
Sew label at placket front	546.60	0.36	545.00	549.00
shoulder attach	552.67	0.20	552.00	554.00
Shoulder top stitch	552.53	0.21	552.00	554.00
side seam	510.50	0.29	509.00	512.00
Top stitch armhole	511.00	0.31	509.00	512.00
top stitch button hole placket	536.50	0.70	534.00	541.00
top stitch cuff	560.00	0.00	560.00	560.00
turn cuff	560.00	0.00	560.00	560.00
turn pocket	560.00	0.00	560.00	560.00

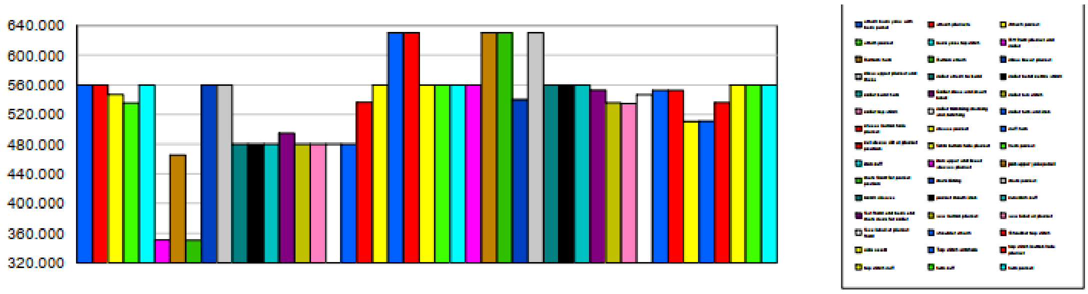


Table C-7 Number out Report

Number Out	Average	Half Width	Minimum Average	Maximum Average
attach back yoke with back panel	560.00	0.00	560.00	560.00
attach plackets	560.00	0.00	560.00	560.00
Attach pocket	546.60	0.36	545.00	549.00
attath pocket	535.13	0.67	533.00	539.00
back yoke topstitch	560.00	0.00	560.00	560.00
BH front placket and collar	350.47	0.53	347.00	353.00
Bottom hem	350.87	0.55	348.00	353.00
Button attach	350.03	0.50	347.00	353.00
close lower placket	560.00	0.00	560.00	560.00
close upper placket and make	470.07	0.51	467.00	473.00
collar attach to band	480.00	0.00	480.00	480.00
collar band centre stitch	480.00	0.00	480.00	480.00
collar band hem	480.00	0.00	480.00	480.00
Collar close and insert label	371.37	0.25	370.00	373.00
collar run stitch	480.00	0.00	480.00	480.00
collar top stitch	480.00	0.00	480.00	480.00
collar trimming marking and notching	480.00	0.00	480.00	480.00
collar turn and iron	480.00	0.00	480.00	480.00
crease button hole placket	536.50	0.70	534.00	541.00
crease pocket	560.00	0.00	560.00	560.00
cuff hem	560.00	0.00	560.00	560.00
cut sleeve slit at placket position	560.00	0.00	560.00	560.00
form button hole placket	536.70	0.65	534.00	541.00
hem pocket	560.00	0.00	560.00	560.00
iron cuff	560.00	0.00	560.00	560.00

iron upper and lower sleeves placket	560.00	0.00	560.00	560.00
join upper yokepanel	560.00	0.00	560.00	560.00
mark front for pocket postion	560.00	0.00	560.00	560.00
mark liining	480.00	0.00	480.00	480.00
mark pocket	560.00	0.00	560.00	560.00
notch sleeves	560.00	0.00	560.00	560.00
pocket mouth iron	560.00	0.00	560.00	560.00
runstitch cuff	560.00	0.00	560.00	560.00
Set front and back and mark neck for collar	552.67	0.20	552.00	554.00
sew button placket	535.77	0.63	533.00	540.00
sew label at placket	534.30	0.69	532.00	538.00
Sew label at placket front	546.27	0.37	545.00	548.00
shoulder attach	552.53	0.21	552.00	554.00
Shoulder top stitch	552.37	0.18	552.00	553.00
side seam	510.03	0.30	509.00	512.00
Top stitch armhole	510.50	0.29	509.00	512.00
top stitch button hole placket	536.17	0.67	534.00	540.00
top stitch cuff	560.00	0.00	560.00	560.00
turn cuff	560.00	0.00	560.00	560.00
turn pc				

5:17:11PM **Category Overview** June 1, 2021

Values Across All Replications

Assembly line simulation model for full long sleeve shirt production process done by

Replications: 30 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel.Queue	0.00	0.00	0.00	0.00	0.00	0.00
attach plackets.Queue	7.7685	0.04	7.6009	8.0454	0.00	17.1225
Attach pocket.Queue	2.8760	0.02	2.7539	3.0559	0.00	8.1496
attath pocket.Queue	0.00028172	0.00	0.00000922	0.00053531	0.00	0.1110
back yoke topstitch.Queue	0.1774	0.01	0.1051	0.2699	0.00	1.1462
Batch back with front.Queue	0.2163	0.00	0.2139	0.2195	0.00	2.3661
Batch collar with assembled shirt.Queue	0.2399	0.00	0.2333	0.2531	0.00	2.3572
Batch cuff with assembled shirt.Queue	0.2576	0.00	0.2514	0.2688	0.00	2.8281
Batch front and pocket.Queue	0.2184	0.00	0.2157	0.2220	0.00	1.3939
Batch sleeve with back assembled front.Queue	0.2339	0.00	0.2272	0.2383	0.00	1.1078
BH front placket and collar.Queue	0.01740579	0.00	0.01238922	0.02399467	0.00	0.6734
Bottom hem.Queue	63.8934	0.23	62.9141	65.2899	0.00	126.32
collar.Queue						
Bottom hem.Queue	63.8934	0.23	62.9141	65.2899	0.00	126.32
Button attach.Queue	0.00172193	0.00	0.00	0.00442446	0.00	0.5349
close lower placket.Queue	0.06473621	0.01	0.04510894	0.1094	0.00	0.7059
close upper placket and make.Queue	42.5389	0.23	41.0869	44.2129	0.00	84.4501
collar attach to band.Queue	1.4679	0.03	1.2891	1.6380	0.00	4.2681
collar band centre stitch.Queue	0.00000737	0.00	0.00	0.00012651	0.00	0.06072260

Table C-8 Queue Report

collar band hem.Queue	0.00110355	0.00	0.00038305	0.00213563	0.00	0.3358
Collar close and insert label.Queue	63.2123	0.25	62.1666	64.8869	0.00	126.26
collar run stitch.Queue	0.7060	0.03	0.5355	0.8402	0.00	2.3003
collar top stitch.Queue	0.00012151	0.00	0.00	0.00058665	0.00	0.2308
collar trimming marking and notching.Queue	0.00004004	0.00	0.00	0.00021264	0.00	0.05099207
collar turn and iron.Queue	0.00000011	0.00	0.00	0.00000326	0.00	0.00156685
crease button hole placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
crease pocket.Queue	1.9697	0.03	1.7977	2.1158	0.00	4.9963
cuff hem.Queue	17.2252	0.02	17.1256	17.3926	0.00	35.1673
cut sleeve slit at placket position.Queue	15.9646	0.02	15.8633	16.1393	0.00	32.9743
form button hole placket.Queue	33.4477	0.28	31.3578	34.1958	0.00	68.3059
hem pocket.Queue	2.5381	0.02	2.4535	2.6637	0.00	5.7773
iron cuff.Queue	0.00	0.00	0.00	0.00	0.00	0.00
iron upper and lower sleeves placket.Queue	0.02438212	0.00	0.01768504	0.03063487	0.00	0.4787
join upper yokepanel.Queue	12.4578	0.02	12.3847	12.5640	0.00	25.5736
mark front for pocket postion.Queue	5.1108	0.01	5.0696	5.1571	0.00	10.5865
mark liining.Queue	15.9970	0.02	15.9053	16.0887	0.00	32.7877
mark pocket.Queue	7.4132	0.01	7.3612	7.4706	0.00	15.1369
notch sleeves.Queue	0.00546599	0.00	0.00336828	0.01089997	0.00	0.4629
pocket mouth iron.Queue	1.9927	0.02	1.9042	2.0620	0.00	4.6148
runstitch cuff.Queue	4.0097	0.03	3.8692	4.1845	0.00	8.9602
Set front and back and mark neck for collar.Queue	0.02240957	0.00	0.01950032	0.02699690	0.00	0.3824
sew button placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Sew label at placket front.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	6.4744	0.04	6.2278	6.6601	0.00	14.5349
Shoulder top stitch.Queue	0.2263	0.02	0.1212	0.3342	0.00	1.6872
side seam.Queue	0.00844626	0.00	0.00529305	0.01163814	0.00	0.4856
Top stitch armhole.Queue	0.00008464	0.00	0.00	0.00020304	0.00	0.04155766
top stitch button hole placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
top stitch cuff.Queue	0.9404	0.03	0.7650	1.1149	0.00	3.1313
turn cuff.Queue	0.00	0.00	0.00	0.00	0.00	0.00
turn pocket.Queue	0.0949	0.01	0.05157780	0.1606	0.00	0.7979

Table C:9 Number Waiting Report For Queue

Queue

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel.Queue	0.00	0.00	0.00	0.00	0.00	0.00
attach plackets.Queue	9.0633	0.05	8.8677	9.3863	0.00	25.0000
Attach pocket.Queue	3.2771	0.03	3.1326	3.4824	0.00	12.0000
attath pocket.Queue	0.00031452	0.00	0.00001027	0.00059888	0.00	1.0000
back yoke topstitch.Queue	0.2069	0.02	0.1226	0.3149	0.00	4.0000
Batch back with front.Queue	0.4994	0.00	0.4937	0.5059	0.00	2.0000
Batch collar with assembled shirt.Queue	0.4958	0.00	0.4811	0.5220	0.00	2.0000
Batch cuff with assembled shirt.Queue	0.5009	0.00	0.4907	0.5219	0.00	2.0000
Batch front and pocket.Queue	0.4980	0.00	0.4917	0.5051	0.00	2.0000
Batch sleeve with back assembled front.Queue	0.4984	0.00	0.4838	0.5084	0.00	2.0000
BH front placket and collar.Queue	0.01273905	0.00	0.00903380	0.01764608	0.00	1.0000
Bottom hem.Queue	61.6400	0.19	60.7975	62.7819	0.00	124.00
Button attach.Queue	0.00125772	0.00	0.00	0.00322617	0.00	1.0000
close lower placket.Queue	0.07552557	0.01	0.05262709	0.1276	0.00	1.0000
close upper placket and make.Queue	49.6282	0.26	48.0651	51.4783	0.00	101.00
collar attach to band.Queue	1.4679	0.03	1.2891	1.6380	0.00	7.0000
collar band centre stitch.Queue	0.00000737	0.00	0.00	0.00012651	0.00	1.0000
collar band hem.Queue	0.00110355	0.00	0.00038305	0.00213563	0.00	1.0000
Collar close and insert label.Queue	65.2987	0.21	64.3944	66.5698	0.00	129.00
collar run stitch.Queue	0.7060	0.03	0.5355	0.8402	0.00	5.0000
collar top stitch.Queue	0.00012151	0.00	0.00	0.00058665	0.00	1.0000
collar trimming marking and notching.Queue	0.00004004	0.00	0.00	0.00021264	0.00	1.0000
collar turn and iron.Queue	0.00000011	0.00	0.00	0.00000326	0.00	1.0000
crease button hole placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
crease pocket.Queue	2.2979	0.04	2.0973	2.4685	0.00	13.0000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
iron upper and lower sleeves placket.Queue	0.02844580	0.00	0.02063254	0.03574068	0.00	2.0000
join upper yokepanel.Queue	14.5601	0.02	14.4747	14.6841	0.00	69.0000
mark front for pocket postion.Queue	5.9732	0.01	5.9251	6.0274	0.00	69.0000
mark liining.Queue	16.0303	0.02	15.9384	16.1223	0.00	59.0000
mark pocket.Queue	8.6642	0.01	8.6034	8.7312	0.00	69.0000
Match sleeve with back and front.Queue2	0.00	0.00	0.00	0.00	0.00	0.00
notch sleeves.Queue	0.00637699	0.00	0.00392966	0.01271664	0.00	1.0000
pocket mouth iron.Queue	2.3248	0.02	2.2216	2.4057	0.00	17.0000
runstitch cuff.Queue	4.6779	0.04	4.5140	4.8820	0.00	15.0000
Set front and back and mark neck for collar.Queue	0.02581348	0.00	0.02246599	0.03110268	0.00	1.0000
sew button placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Sew label at placket front.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	7.4545	0.04	7.1750	7.6591	0.00	20.0000
Shoulder top stitch.Queue	0.2605	0.02	0.1394	0.3857	0.00	3.0000
side seam.Queue	0.00898281	0.00	0.00564592	0.01236553	0.00	1.0000
Top stitch armhole.Queue	0.00009009	0.00	0.00	0.00021658	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	1.0971	0.04	0.8924	1.3008	0.00	5.0000
turn cuff.Queue	0.00	0.00	0.00	0.00	0.00	0.00
turn pocket.Queue	0.1107	0.01	0.06017410	0.1874	0.00	2.0000

Table C-10 Resource Detail Report

Resource Detail Summary

Usage

	Inst Util	Num Busy	Num Sched	Num Seized	Sched Util
BH for forming	1.00	1.00	1.00	535.00	1.00
close lower	0.78	0.78	1.00	560.00	0.78
close upper	0.99	0.99	1.00	470.00	0.99
cutter for	0.55	0.55	1.00	561.00	0.55
DNL for collar	0.41	0.41	1.00	480.00	0.41
DNL for	0.59	0.59	1.00	561.00	0.59
DNL for top	0.30	0.30	1.00	534.00	0.30
helper for	0.47	0.47	1.00	480.00	0.47
helper for	0.47	0.47	1.00	560.00	0.47
helper for	0.22	0.22	1.00	534.00	0.22
helper for	0.17	0.17	1.00	561.00	0.17
Helper for	0.55	0.55	1.00	481.00	0.55
helper for	0.25	0.25	1.00	561.00	0.25
helper for turn	0.31	0.31	1.00	560.00	0.31
helper for turn	0.46	0.46	1.00	560.00	0.46
helper with	0.26	0.26	1.00	480.00	0.26
IRN for cuff	0.40	0.40	1.00	560.00	0.40
IRN for pocket	0.32	0.32	1.00	560.00	0.32
iron upper and	0.49	0.49	1.00	560.00	0.49
JUKI LBH	0.60	0.60	1.00	706.00	0.60
label attaching	0.59	0.59	1.00	533.00	0.59
notching	0.46	0.46	1.00	560.00	0.46
pocket	0.77	0.77	1.00	533.00	0.77
Resource 11	0.48	0.48	1.00	552.00	0.48
Resource 12	0.85	0.85	1.00	552.00	0.85
Resource 13	0.84	0.84	1.00	552.00	0.84
Resource 14	0.61	0.61	1.00	510.00	0.61
Resource 15	0.68	0.68	1.00	510.00	0.68
Resource	0.79	0.79	1.00	546.00	0.79
Resource	0.61	0.61	1.00	545.00	0.61
Resource	0.79	0.79	1.00	546.00	0.79
Resource	0.61	0.61	1.00	545.00	0.61
SNL auto	0.75	0.75	1.00	560.00	0.75
SNL for collar	0.38	0.38	1.00	480.00	0.38
SNL for collar	0.57	0.57	1.00	480.00	0.57
SNL for	0.80	0.80	1.00	560.00	0.80
SNL for pocket	0.40	0.40	1.00	560.00	0.40
SNL for	0.72	0.72	1.00	560.00	0.72
SNL for sew	0.40	0.40	1.00	534.00	0.40
SNL VT for	0.62	0.62	1.00	480.00	0.62
SNLS for	0.18	0.18	1.00	560.00	0.18
SNLS for back	0.42	0.42	1.00	560.00	0.42
SNLS for top	0.40	0.40	1.00	480.00	0.40
SNLSM	0.99	0.99	1.00	726.00	0.99
upper yoke	0.42	0.42	1.00	561.00	0.42

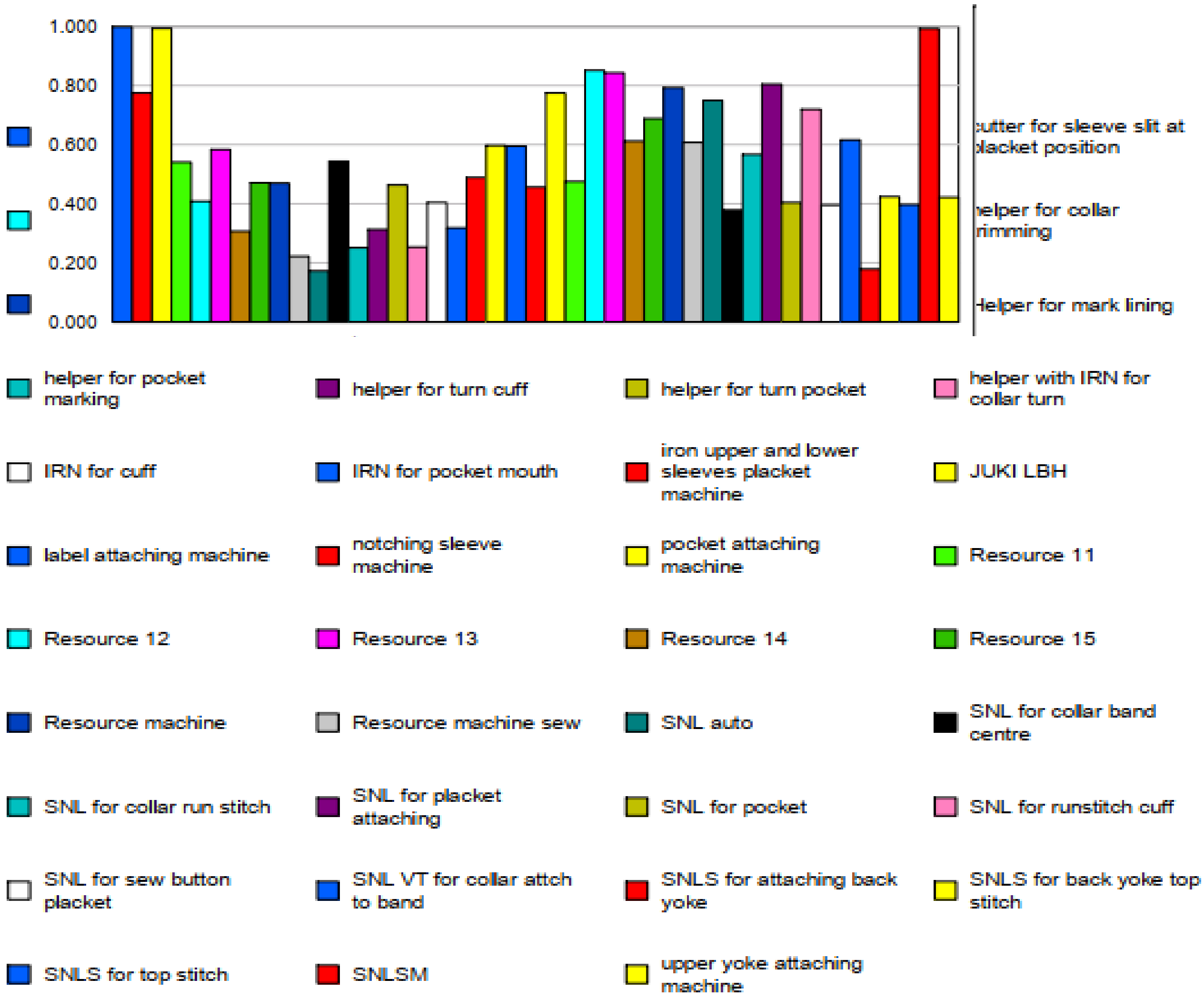


Table C-11 User Defined Report or Counter

5:17:11PM **Category Overview** June 1, 2021

Values Across All Replications

Assembly line simulation model for full long sleeve shirt production process done by

Replications: 30 Time Units: Minutes

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
assembled shirt	297.90	2.73	282.00	314.00
number of rejectd shirts	52.1333	2.62	37.0000	68.0000

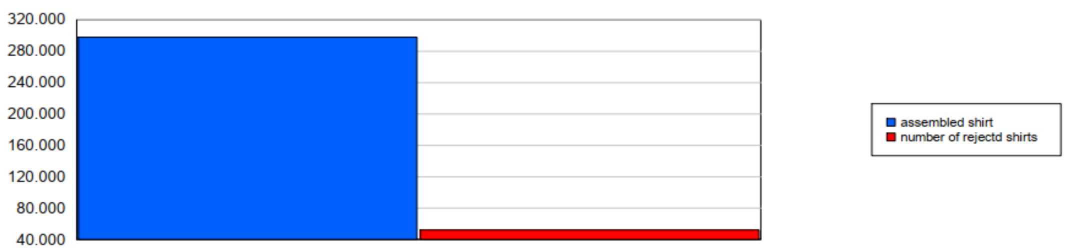


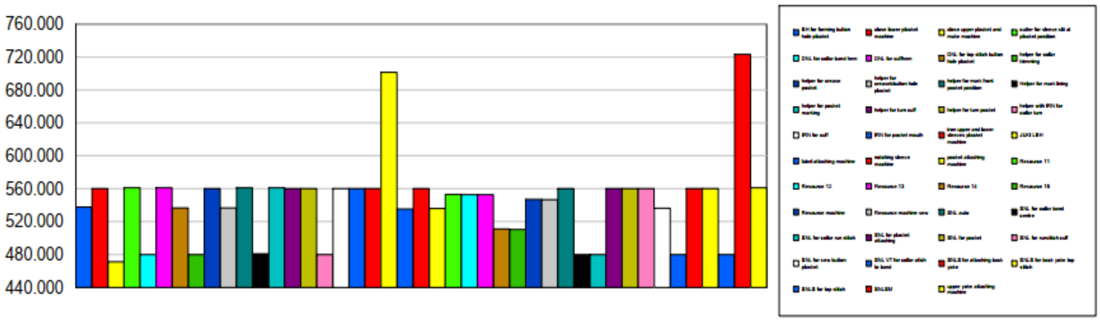
Table C-12 Resource Number Seized Report

Resource

Usage

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
BH for forming button hole placket	537.70	0.65	535.00	542.00
close lower placket machine	560.00	0.00	560.00	560.00
close upper placket and make machine	471.07	0.51	468.00	474.00
cutter for sleeve slit at placket position	561.00	0.00	561.00	561.00
DNL for collar band hem	480.00	0.00	480.00	480.00
DNL for cuffhem	561.00	0.00	561.00	561.00
DNL for top stitch button hole placket	536.50	0.70	534.00	541.00
helper for collar trimming	480.00	0.00	480.00	480.00
helper for crease pocket	560.00	0.00	560.00	560.00
helper for creasebbutton hole placket	536.70	0.65	534.00	541.00
helper for mark front pocket	561.00	0.00	561.00	561.00
helper for pocket marking	561.00	0.00	561.00	561.00
helper for turn cuff	560.00	0.00	560.00	560.00
helper for turn pocket	560.00	0.00	560.00	560.00
helper with IRN for collar turn	480.00	0.00	480.00	480.00
IRN for cuff	560.00	0.00	560.00	560.00
IRN for pocket mouth	560.00	0.00	560.00	560.00
iron upper and lower sleeves placket machine	560.00	0.00	560.00	560.00
JUKI LBH	701.30	1.06	695.00	706.00
label attaching machine	535.13	0.67	533.00	539.00
notching sleeve machine	560.00	0.00	560.00	560.00
pocket attaching machine	535.77	0.63	533.00	540.00
Resource 11	552.90	0.23	552.00	554.00
Resource 12	552.67	0.20	552.00	554.00
Resource 13	552.53	0.21	552.00	554.00
Resource 14	511.00	0.31	509.00	512.00
Resource 15	510.50	0.29	509.00	512.00
Resource machine	546.93	0.32	546.00	549.00
Resource machine sew	546.60	0.36	545.00	549.00
SNL auto	560.00	0.00	560.00	560.00
SNL for collar band centre	480.00	0.00	480.00	480.00
SNL for collar run stitch	480.00	0.00	480.00	480.00

SNL for placket attaching	560.00	0.00	560.00	560.00
SNL for pocket	560.00	0.00	560.00	560.00
SNL for runstitch cuff	560.00	0.00	560.00	560.00
SNL for sew button placket	536.17	0.67	534.00	540.00
SNL VT for collar attch to band	480.00	0.00	480.00	480.00
SNLS for attaching back yoke	560.00	0.00	560.00	560.00
SNLS for back yoke top stitch	560.00	0.00	560.00	560.00
SNLS for top stitch	480.00	0.00	480.00	480.00
SNLSM	723.23	0.74	719.00	727.00
upper yoke attaching machine	561.00	0.00	561.00	561.00



APPENDIX D: FINAL SELECTED SCENARIO SIMULATION MODEL STATISTICS REPORT

Table D-1 Final Improved System Output

11:56:01PM **User Specified** June 7, 2021

Assembly line simulation model for full long sleeve shirt Replications: 30

Replication 1 Start Time: 0.00 Stop Time: 480.00 Time Units: Minutes

Counter

Count	Value
assembled shirt	438.00
number of rejectd shirts	89.0000

Table D-2 Entity Report for New Model

Replications: 30 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
cuff	20.4842	0.03	20.2249	20.5767	5.2006	95.5890

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
cuff	0.6260	0.01	0.5685	0.6730	0.00002410	6.7231

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
cuff	185.80	0.66	181.88	189.38	1.0842	1169.25

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
cuff	0.00	0.00	0.00	0.00	0.00	0.00

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
cuff	0.00	0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
cuff	64.9336	0.28	63.8248	66.8161	3.7896	141.31

Other

Table D-4 processes status report

Assembly line simulation model for full long sleeve shirt

Replications: 30 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel and sew button placket	0.5085	0.00	0.5051	0.5106	0.4783	0.9004
attach plackets	0.6899	0.00	0.6845	0.6956	0.5917	0.7750
Attach pocket	0.6960	0.00	0.6898	0.6988	0.6250	0.7750
attath pocket	0.6952	0.00	0.6907	0.6995	0.6250	0.7750
back yoke topstitch	0.3633	0.00	0.3607	0.3653	0.3275	0.5809
BH front placket and collar	0.4128	0.00	0.4067	0.4183	0.3417	1.0174
Button attach	0.4035	0.00	0.3997	0.4077	0.3457	0.6985
close lower placket	0.6636	0.00	0.6599	0.6684	0.5422	0.7901
close upper placket and make	1.0148	0.00	1.0103	1.0204	0.9084	1.1083
collar attach to band	0.6161	0.00	0.6120	0.6202	0.5583	0.6916
collar band centre stitch	0.3801	0.00	0.3776	0.3830	0.3442	0.5680
collar band hem	0.4084	0.00	0.4063	0.4120	0.3608	1.1620
Collar close and insert label	0.6100	0.00	0.6053	0.6130	0.5417	0.7083
collar run stitch	0.5669	0.00	0.5639	0.5705	0.5083	0.6250
collar top stitch	0.3965	0.00	0.3940	0.3983	0.3609	0.6131
collar trimming marking and notching	0.4715	0.00	0.4692	0.4741	0.4250	0.6384
crease button hole placket	0.1985	0.00	0.1974	0.1994	0.1750	0.2250
crease pocket	0.4038	0.00	0.4010	0.4066	0.3583	0.4583
cut sleeve slit at placket position	0.4074	0.01	0.3815	0.4342	0.00004122	5.1093
form button hole placket	0.8938	0.00	0.8884	0.8987	0.8134	1.4626
hem pocket	0.3468	0.00	0.3447	0.3485	0.3108	0.5326
iron cuff	0.3467	0.00	0.3448	0.3505	0.3109	0.6159
iron upper and lower sleeves placket	0.4200	0.00	0.4169	0.4233	0.3625	0.7264
join upper yokepanel	0.3622	0.00	0.3601	0.3639	0.3250	0.4083
mark front for pocket postion and collar turn and iron	0.3619	0.01	0.3347	0.3978	0.00003648	3.4206
mark liining	0.5438	0.00	0.5411	0.5470	0.4917	0.6083
mark pocket and pocket mouth iron	0.4536	0.00	0.4522	0.4547	0.4300	0.4800
notch sleeves	0.3916	0.00	0.3885	0.3949	0.3449	1.0040
runstitch cuff	0.6163	0.00	0.6130	0.6187	0.5583	0.6916
Set front and back and mark neck for collar	0.4140	0.00	0.4106	0.4164	0.3417	0.6963
sew label at placket	0.5333	0.00	0.5317	0.5359	0.4919	0.6078
Sew label at placket front	0.5337	0.00	0.5313	0.5361	0.4919	0.6074
shoulder attach	0.7396	0.00	0.7332	0.7445	0.5157	0.9871
Shoulder top stitch	0.7329	0.00	0.7277	0.7377	0.6084	0.8417
side seam	0.6462	0.00	0.6399	0.6534	0.5485	1.1545
Top stitch armhole	0.5747	0.00	0.5690	0.5777	0.4917	0.6583
top stitch button hole placket	0.2916	0.00	0.2908	0.2927	0.2750	0.3083
top stitch cuff	0.6407	0.00	0.6362	0.6449	0.5799	0.9658
turn cuff	0.2686	0.00	0.2675	0.2700	0.2500	0.4918
turn pocket	0.3984	0.00	0.3961	0.4012	0.3609	0.6503

Table D-5 Waiting Time Report

Time per Entity

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel and sew button placket	5.0402	0.02	4.9212	5.1482	0.00	11.0674
attach plackets	8.0904	0.17	7.2244	9.2722	0.00	20.2051
Attach pocket	2.0750	0.02	1.9226	2.1443	0.00	5.9559
attath pocket	0.00000067	0.00	0.00	0.00000958	0.00	0.00510700
back yoke topstitch	0.00003515	0.00	0.00	0.00019528	0.00	0.0990
BH front placket and collar	2.5672	0.09	1.9862	3.0615	0.00	8.7918
Bottom hem	1.5193	0.17	0.7421	2.5967	0.00	15.0054
Button attach	2.7583	0.10	2.1562	3.2995	0.00	8.7152
close lower placket	0.05660931	0.01	0.03848102	0.1085	0.00	0.9121
close upper placket and make	42.1459	0.26	40.2068	43.8090	0.00	85.3063
collar attach to band	1.4493	0.03	1.3145	1.5836	0.00	3.9864
collar band centre stitch	0.00000642	0.00	0.00	0.00005233	0.00	0.02511992
collar band hem	0.00119827	0.00	0.00005976	0.00363062	0.00	0.6223
Collar close and insert label	0.01801792	0.00	0.01190859	0.02221303	0.00	0.4040
collar run stitch	0.7173	0.03	0.5821	0.8720	0.00	2.5044
collar top stitch	0.00001517	0.00	0.00	0.00015329	0.00	0.04800509
collar trimming marking and notching	0.00002897	0.00	0.00	0.00016671	0.00	0.07115071
crease button hole placket	0.00	0.00	0.00	0.00	0.00	0.00
crease pocket	0.00584332	0.00	0.00466685	0.00762602	0.00	0.1930
cuff hem	17.2566	0.02	17.1536	17.3761	0.00	35.1804
cut sleeve slit at placket position	14.0465	0.25	12.6288	15.1532	0.00	38.2069
form button hole placket	26.3678	0.41	24.3010	28.5283	0.00	58.2589
hem pocket	0.00010944	0.00	0.00	0.00032705	0.00	0.0920
iron cuff	0.00000056	0.00	0.00	0.00001684	0.00	0.00943203
iron upper and lower sleeves placket	0.5583	0.04	0.3452	0.7412	0.00	3.4167
join upper yokepanel	12.4948	0.02	12.4007	12.5768	0.00	25.5699
mark front for pocket postion and collar turn and iron	12.5492	0.21	11.7548	14.0587	0.00	33.6228
mark liining	16.0403	0.02	15.9567	16.1161	0.00	32.8487
mark pocket and pocket mouth iron	15.6488	0.01	15.5927	15.6793	0.00	31.6245
notch sleeves	1.2837	0.10	0.9019	1.8572	0.00	8.9689
runstitch cuff	4.0038	0.03	3.8583	4.2063	0.00	9.2199
Set front and back and mark neck for collar	0.00134655	0.00	0.00065417	0.00289363	0.00	0.2685
sew label at placket	0.00	0.00	0.00	0.00	0.00	0.00
Sew label at placket front	0.00	0.00	0.00	0.00	0.00	0.00
shoulder attach	4.2790	0.04	4.0674	4.4918	0.00	10.2765
Shoulder top stitch	0.2189	0.02	0.1393	0.3922	0.00	1.8978
side seam	0.00805345	0.00	0.00537188	0.01235320	0.00	0.4150
Top stitch armhole	0.00009819	0.00	0.00001187	0.00025321	0.00	0.04737450
top stitch button hole placket	0.00	0.00	0.00	0.00	0.00	0.00
top stitch cuff	0.8939	0.03	0.6682	1.0349	0.00	3.4134
turn cuff	0.00	0.00	0.00	0.00	0.00	0.00
turn pocket	0.00662326	0.00	0.00417786	0.00848096	0.00	0.2471

Table D-6 Time per Entity Report

Process

Time per Entity

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel and sew button placket	5.5487	0.02	5.4283	5.6584	0.4784	11.5780
attach plackets	8.7803	0.17	7.9125	9.9678	0.5939	20.9445
Attach pocket	2.7710	0.02	2.6130	2.8411	0.6250	6.6371
attath pocket	0.6952	0.00	0.6907	0.6995	0.6250	0.7750
back yoke topstitch	0.3633	0.00	0.3607	0.3654	0.3275	0.5809
BH front placket and collar	2.9801	0.09	2.3978	3.4755	0.3417	9.2455
Bottom hem	2.1454	0.18	1.3418	3.2577	0.00066018	15.6434
Button attach	3.1619	0.10	2.5584	3.7033	0.3462	9.1582
close lower placket	0.7202	0.01	0.7003	0.7745	0.5449	1.5356
close upper placket and make	43.1607	0.27	41.2199	44.8286	0.9192	86.3130
collar attach to band	2.0654	0.03	1.9292	2.2029	0.5584	4.5559
collar band centre stitch	0.3802	0.00	0.3776	0.3830	0.3442	0.5680
collar band hem	0.4096	0.00	0.4069	0.4156	0.3608	1.1620
Collar close and insert label	0.6280	0.00	0.6218	0.6341	0.5417	1.0045
collar run stitch	1.2843	0.03	1.1479	1.4419	0.5084	3.1148
collar top stitch	0.3966	0.00	0.3940	0.3984	0.3609	0.6131
collar trimming marking and notching	0.4715	0.00	0.4692	0.4742	0.4250	0.6384
crease button hole placket	0.1985	0.00	0.1974	0.1994	0.1750	0.2250
crease pocket	0.4096	0.00	0.4060	0.4142	0.3583	0.6312
cuff hem	17.7567	0.02	17.6511	17.8784	0.4422	35.6802
cut sleeve slit at placket position	14.4538	0.25	13.0103	15.5873	0.00440072	38.4659
form button hole placket	27.2616	0.41	25.1895	29.4250	0.8283	59.1428
hem pocket	0.3469	0.00	0.3448	0.3487	0.3108	0.5326
iron cuff	0.3467	0.00	0.3448	0.3505	0.3109	0.6159
iron upper and lower sleeves placket	0.9783	0.04	0.7623	1.1613	0.3626	3.8070
join upper yokepanel	12.8570	0.02	12.7615	12.9405	0.3250	25.9688
mark front for pocket postion and collar turn and iron	12.9110	0.22	12.0895	14.4565	0.00108776	34.6607
mark liining	16.5841	0.02	16.4978	16.6612	0.4918	33.3596
mark pocket and pocket mouth iron	16.1024	0.01	16.0449	16.1334	0.4301	32.0595
notch sleeves	1.6753	0.10	1.2955	2.2499	0.3453	9.3171
runstitch cuff	4.6201	0.03	4.4714	4.8249	0.5586	9.7857
Set front and back and mark neck for collar	0.4154	0.00	0.4113	0.4192	0.3417	0.6963
sew label at placket	0.5333	0.00	0.5317	0.5359	0.4919	0.6078
Sew label at placket front	0.5337	0.00	0.5313	0.5361	0.4919	0.6074
shoulder attach	5.0186	0.04	4.8045	5.2352	0.5514	11.0392
Shoulder top stitch	0.9518	0.02	0.8703	1.1288	0.6084	2.6532
side seam	0.6542	0.00	0.6471	0.6611	0.5485	1.1545
Top stitch armhole	0.5748	0.00	0.5692	0.5777	0.4917	0.6841
top stitch button hole placket	0.2916	0.00	0.2908	0.2927	0.2750	0.3083
top stitch cuff	1.5346	0.03	1.3044	1.6782	0.5809	4.0431
turn cuff	0.2686	0.00	0.2675	0.2700	0.2500	0.4918
turn pocket	0.4050	0.00	0.4006	0.4090	0.3609	0.6503

shoulder attach	408.65	0.56	405.46	411.06

Process

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
attach back yoke with back panel and sew button placket	284.74	0.25	282.87	285.95
attach plackets	386.32	0.54	383.32	389.51
Attach pocket	380.35	0.48	376.96	382.23
attath pocket	371.73	0.47	369.91	374.65
back yoke topstitch	203.45	0.22	201.99	204.59
BH front placket and collar	217.54	0.51	214.36	220.47
Button attach	212.40	0.45	209.64	214.88
close lower placket	371.62	0.40	369.56	374.28
close upper placket and make	476.91	0.15	476.14	477.78
collar attach to band	295.74	0.37	293.78	297.67
collar band centre stitch	182.47	0.25	181.26	183.83
collar band hem	196.05	0.27	195.02	197.75
Collar close and insert label	301.76	0.37	299.61	303.43
collar run stitch	272.13	0.31	270.66	273.82
collar top stitch	190.34	0.20	189.11	191.17
collar trimming marking and notching	226.30	0.22	225.21	227.59
crease button hole placket	106.38	0.14	105.63	107.24
crease pocket	226.10	0.28	224.56	227.67
cuff hem	280.07	0.31	278.60	281.26
cut sleeve slit at placket position	228.13	3.03	213.64	243.13
form button hole placket	479.16	0.20	477.84	479.95
hem pocket	194.19	0.21	193.04	195.14
iron cuff	194.18	0.29	193.07	196.26
iron upper and lower sleeves placket	235.18	0.38	233.47	237.03
join upper yokepanel	202.81	0.20	201.65	203.77
mark front for pocket postion and collar turn and iron	202.64	3.50	187.42	222.78
mark liining	261.02	0.26	259.72	262.55
mark pocket and pocket mouth iron	254.00	0.12	253.25	254.61
notch sleeves	219.30	0.33	217.55	221.12
runstitch cuff	345.10	0.29	343.29	346.45
Set front and back and mark neck for collar	228.82	0.30	227.06	230.20
sew label at placket	284.83	0.42	282.43	287.61
Sew label at placket front	291.43	0.32	289.89	293.13

Table D-7 Accumulated Time Report

Table D-8 Number in to the Process Report

Process

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
attach back yoke with back panel and sew button placket	560.00	0.00	560.00	560.00
attach plackets	560.00	0.00	560.00	560.00
Attach pocket	546.80	0.33	545.00	549.00
attath pocket	535.43	0.62	532.00	539.00
back yoke topstitch	560.00	0.00	560.00	560.00
BH front placket and collar	527.00	0.00	527.00	527.00
Bottom hem	527.00	0.00	527.00	527.00
Button attach	526.93	0.09	526.00	527.00
close lower placket	560.00	0.00	560.00	560.00
close upper placket and make	560.00	0.00	560.00	560.00
collar attach to band	480.00	0.00	480.00	480.00
collar band centre stitch	480.00	0.00	480.00	480.00
collar band hem	480.00	0.00	480.00	480.00
Collar close and insert label	494.77	0.16	494.00	495.00
collar run stitch	480.00	0.00	480.00	480.00
collar top stitch	480.00	0.00	480.00	480.00
collar trimming marking and notching	480.00	0.00	480.00	480.00
crease button hole placket	536.10	0.62	532.00	540.00
crease pocket	560.00	0.00	560.00	560.00
cuff hem	630.00	0.00	630.00	630.00
cut sleeve slit at placket position	630.00	0.00	630.00	630.00
form button hole placket	560.00	0.00	560.00	560.00
hem pocket	560.00	0.00	560.00	560.00
iron cuff	560.00	0.00	560.00	560.00
iron upper and lower sleeves placket	560.00	0.00	560.00	560.00
join upper yokepanel	630.00	0.00	630.00	630.00
mark front for pocket postion and collar turn and iron	630.00	0.00	630.00	630.00
mark liining	540.00	0.00	540.00	540.00
mark pocket and pocket mouth iron	630.00	0.00	630.00	630.00
notch sleeves	560.00	0.00	560.00	560.00
runstitch cuff	560.00	0.00	560.00	560.00
Set front and back and mark neck for collar	552.80	0.21	552.00	554.00
sew label at placket	534.70	0.63	531.00	538.00
Sew label at placket front	546.47	0.29	545.00	548.00
shoulder attach	552.70	0.20	552.00	554.00
Shoulder top stitch	552.50	0.19	552.00	553.00
side seam	510.47	0.25	509.00	511.00
Top stitch armhole	510.87	0.31	509.00	512.00
top stitch button hole placket	535.90	0.63	532.00	540.00
top stitch cuff	560.00	0.00	560.00	560.00
turn cuff	560.00	0.00	560.00	560.00
turn pocket	560.00	0.00	560.00	560.00

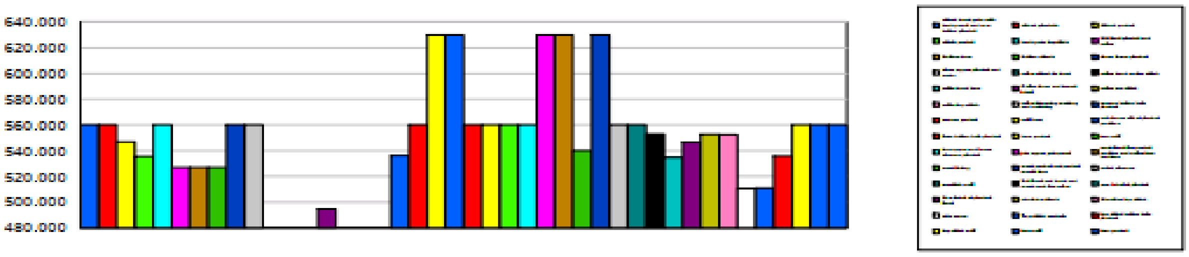


Table D-9 Process Number out Report

Number Out	Average	Half Width	Minimum Average	Maximum Average
attach back yoke with back panel and sew button placket	560.00	0.00	560.00	560.00
attach plackets	560.00	0.00	560.00	560.00
Attach pocket	546.47	0.29	545.00	548.00
attath pocket	534.70	0.63	531.00	538.00
back yoke topstitch	560.00	0.00	560.00	560.00
BH front placket and collar	526.93	0.09	526.00	527.00
Bottom hem	527.00	0.00	527.00	527.00
Button attach	526.33	0.58	519.00	527.00
close lower placket	560.00	0.00	560.00	560.00
close upper placket and make	469.97	0.51	467.00	472.00
collar attach to band	480.00	0.00	480.00	480.00
collar band centre stitch	480.00	0.00	480.00	480.00
collar band hem	480.00	0.00	480.00	480.00
Collar close and insert label	494.67	0.18	494.00	495.00
collar run stitch	480.00	0.00	480.00	480.00
collar top stitch	480.00	0.00	480.00	480.00
collar trimming marking and notching	480.00	0.00	480.00	480.00
crease button hole placket	535.90	0.63	532.00	540.00
crease pocket	560.00	0.00	560.00	560.00
cuff hem	560.00	0.00	560.00	560.00
cut sleeve slit at placket position	560.00	0.00	560.00	560.00
form button hole placket	536.10	0.62	532.00	540.00
hem pocket	560.00	0.00	560.00	560.00
iron cuff	560.00	0.00	560.00	560.00
iron upper and lower sleeves placket	560.00	0.00	560.00	560.00
join upper yokepanel	560.00	0.00	560.00	560.00
mark front for pocket postion and collar turn and iron	560.00	0.00	560.00	560.00
mark liining	480.00	0.00	480.00	480.00
mark pocket and pocket mouth iron	560.00	0.00	560.00	560.00
notch sleeves	560.00	0.00	560.00	560.00
runstitch cuff	560.00	0.00	560.00	560.00
Set front and back and mark neck for collar	552.70	0.20	552.00	554.00
sew label at placket	534.07	0.63	530.00	538.00
Sew label at placket front	546.10	0.36	544.00	548.00
shoulder attach	552.50	0.19	552.00	553.00
Shoulder top stitch	552.30	0.20	551.00	553.00
side seam	510.13	0.29	509.00	511.00
Top stitch armhole	510.47	0.25	509.00	511.00
top stitch button hole placket	535.43	0.62	532.00	539.00
top stitch cuff	560.00	0.00	560.00	560.00
turn cuff	560.00	0.00	560.00	560.00
turn pocket	560.00	0.00	560.00	560.00

Table D-10 Waiting Time or Queue Report

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel and sew button placket.Queue	5.0402	0.02	4.9212	5.1482	0.00	11.0674
attach plackets.Queue	8.0904	0.17	7.2244	9.2722	0.00	20.2051
Attach pocket.Queue	2.0737	0.02	1.9226	2.1415	0.00	5.9559
attath pocket.Queue	0.00000067	0.00	0.00	0.00000956	0.00	0.00510700
back yoke topstitch.Queue	0.00003515	0.00	0.00	0.00019528	0.00	0.0990
Batch back with front.Queue	0.2159	0.00	0.2121	0.2194	0.00	2.5520
Batch collar with assembled shirt.Queue	0.2402	0.00	0.2276	0.2510	0.00	2.4024
Batch cuff with assembled shirt.Queue	0.2249	0.00	0.2143	0.2314	0.00	4.1339
Batch front and pocket.Queue	0.2184	0.00	0.2149	0.2221	0.00	1.4624
Batch sleeve with back assembled front.Queue	0.2332	0.00	0.2276	0.2404	0.00	1.1082
BH front placket and collar.Queue	2.5670	0.09	1.9862	3.0615	0.00	8.7918
Bottom hem.Queue	1.5193	0.17	0.7421	2.5967	0.00	15.0054
Button attach.Queue	2.7576	0.10	2.1562	3.2970	0.00	8.7152
close lower placket.Queue	0.05660931	0.01	0.03848102	0.1085	0.00	0.9121
close upper placket and make.Queue	42.2310	0.26	40.2934	43.8984	0.00	85.6640
collar attach to band.Queue	1.4493	0.03	1.3145	1.5836	0.00	3.9864
collar band centre stitch.Queue	0.00000642	0.00	0.00	0.00005233	0.00	0.02511992
collar band hem.Queue	0.00119827	0.00	0.00005976	0.00363062	0.00	0.6223
Collar close and insert label.Queue	0.01801384	0.00	0.01190859	0.02221303	0.00	0.4040
collar run stitch.Queue	0.7173	0.03	0.5821	0.8720	0.00	2.5044
collar top stitch.Queue	0.00001517	0.00	0.00	0.00015329	0.00	0.04800509
collar trimming marking and notching.Queue	0.00002897	0.00	0.00	0.00016671	0.00	0.07115071
crease button hole placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
crease pocket.Queue	0.00584332	0.00	0.00466685	0.00762602	0.00	0.1930
cuff hem.Queue	17.2259	0.02	17.1230	17.3452	0.00	35.1804
cut sleeve slit at placket position.Queue	14.0214	0.25	12.6063	15.1261	0.00	38.2069
form button hole placket.Queue	26.3970	0.41	24.3345	28.5505	0.00	58.2589
hem pocket.Queue	0.00010944	0.00	0.00	0.00032705	0.00	0.0920
iron cuff.Queue	0.00000056	0.00	0.00	0.00001684	0.00	0.00943203
iron upper and lower sleeves placket.Queue	0.5583	0.04	0.3452	0.7412	0.00	3.4167
join upper yokepanel.Queue	12.4725	0.02	12.3786	12.5544	0.00	25.5699
mark front for pocket postion and collar turn and iron.Queue	12.5268	0.21	11.7339	14.0336	0.00	33.6228
mark liining.Queue	16.0069	0.02	15.9236	16.0826	0.00	32.8487
mark pocket and pocket mouth iron.Queue	15.6209	0.01	15.5649	15.6513	0.00	31.6245
notch sleeves.Queue	1.2837	0.10	0.9019	1.8572	0.00	8.9689
runstitch cuff.Queue	4.0038	0.03	3.8583	4.2063	0.00	9.2199
Set front and back and mark neck for collar.Queue	0.00134627	0.00	0.00065417	0.00289363	0.00	0.2685
Sew label at placket front.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	4.2775	0.04	4.0674	4.4918	0.00	10.2765
Shoulder top stitch.Queue	0.2188	0.02	0.1393	0.3914	0.00	1.8978
side seam.Queue	0.00804835	0.00	0.00536137	0.01235320	0.00	0.4150
Top stitch armhole.Queue	0.00009810	0.00	0.00001187	0.00025321	0.00	0.04737450
top stitch button hole placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
top stitch cuff.Queue	0.8939	0.03	0.6682	1.0349	0.00	3.4134
turn cuff.Queue	0.00	0.00	0.00	0.00	0.00	0.00
turn pocket.Queue	0.00662326	0.00	0.00417786	0.00848096	0.00	0.2471

Table D-11 Number Waiting Report

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
attach back yoke with back panel and sew button placket.Queue	5.8802	0.02	5.7414	6.0062	0.00	23.0000
attach plackets.Queue	9.4388	0.20	8.4285	10.8176	0.00	29.0000
Attach pocket.Queue	2.3623	0.02	2.1870	2.4391	0.00	9.0000
attath pocket.Queue	0.00000075	0.00	0.00	0.00001064	0.00	1.0000
back yoke topstitch.Queue	0.00004101	0.00	0.00	0.00022783	0.00	1.0000
Batch back with front.Queue	0.4983	0.00	0.4897	0.5056	0.00	2.0000
Batch collar with assembled shirt.Queue	0.4961	0.00	0.4694	0.5193	0.00	2.0000
Batch cuff with assembled shirt.Queue	0.4954	0.00	0.4715	0.5114	0.00	2.0000
Batch front and pocket.Queue	0.4981	0.00	0.4898	0.5058	0.00	2.0000
Batch sleeve with back assembled front.Queue	0.4971	0.00	0.4856	0.5134	0.00	2.0000
BH front placket and collar.Queue	2.8184	0.10	2.1806	3.3613	0.00	13.0000
Bottom hem.Queue	1.6681	0.19	0.8147	2.8510	0.00	18.0000
Button attach.Queue	3.0264	0.11	2.3673	3.6144	0.00	13.0000
close lower placket.Queue	0.06604419	0.01	0.04489452	0.1266	0.00	2.0000
close upper placket and make.Queue	49.3313	0.30	47.4070	51.2601	0.00	102.00
collar attach to band.Queue	1.4493	0.03	1.3145	1.5836	0.00	7.0000
collar band centre stitch.Queue	0.00000642	0.00	0.00	0.00005233	0.00	1.0000
collar band hem.Queue	0.00119827	0.00	0.00005976	0.00363062	0.00	1.0000
Collar close and insert label.Queue	0.01856853	0.00	0.01228073	0.02286091	0.00	1.0000
collar run stitch.Queue	0.7173	0.03	0.5821	0.8720	0.00	5.0000
collar top stitch.Queue	0.00001517	0.00	0.00	0.00015329	0.00	1.0000
collar trimming marking and notching.Queue	0.00002897	0.00	0.00	0.00016671	0.00	1.0000
crease button hole placket.Queue	0.00	0.00	0.00	0.00	0.00	0.00
crease pocket.Queue	0.00681721	0.00	0.00544465	0.00889702	0.00	1.0000
cuff hem.Queue	20.1327	0.03	20.0126	20.2721	0.00	69.0000
cut sleeve slit at placket position.Queue	16.3875	0.29	14.7336	17.6787	0.00	69.0000
form button hole placket.Queue	31.3603	0.47	28.9642	33.5616	0.00	70.0000
hem pocket.Queue	0.00012768	0.00	0.00	0.00038155	0.00	1.0000
iron cuff.Queue	0.00000066	0.00	0.00	0.00001965	0.00	1.0000
iron upper and lower sleeves placket.Queue	0.6514	0.05	0.4027	0.8647	0.00	8.0000
mark front for pocket postion and collar turn and iron.Queue	14.6407	0.25	13.7140	16.4018	0.00	69.0000
mark liining.Queue	16.0403	0.02	15.9567	16.1161	0.00	59.0000
mark pocket and pocket mouth iron.Queue	18.2569	0.01	18.1915	18.2925	0.00	69.0000
Match sleeve with back and front.Queue2	0.00	0.00	0.00	0.00	0.00	0.00
notch sleeves.Queue	1.4977	0.11	1.0522	2.1667	0.00	24.0000
runstitch cuff.Queue	4.6711	0.03	4.5014	4.9073	0.00	15.0000
Set front and back and mark neck for collar.Queue	0.00155033	0.00	0.00075366	0.00333370	0.00	1.0000
Sew label at placket front.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	4.9253	0.05	4.6775	5.1750	0.00	14.0000
Shoulder top stitch.Queue	0.2519	0.03	0.1602	0.4510	0.00	3.0000
side seam.Queue	0.00855965	0.00	0.00570762	0.01315102	0.00	1.0000
Top stitch armhole.Queue	0.00010444	0.00	0.00001264	0.00026957	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	1.0428	0.04	0.7796	1.2074	0.00	5.0000
turn cuff.Queue	0.00	0.00	0.00	0.00	0.00	0.00
turn pocket.Queue	0.00772713	0.00	0.00487417	0.00989445	0.00	1.0000

Table D-12 Resource Utilization Report

Resource

Usage

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
BH for forming button hole placket	0.9991	0.00	0.9966	1.0000
close lower placket machine	0.7742	0.00	0.7699	0.7797
close upper placket and make machine	0.9948	0.00	0.9930	0.9956
cutter for sleeve slit at placket position	0.4753	0.01	0.4451	0.5065
DNL for collar band hem	0.4084	0.00	0.4063	0.4120
DNL for cuffhem	0.5835	0.00	0.5804	0.5860
DNL for top stitch button hole placket	0.3255	0.00	0.3232	0.3279
helper for collar trimming	0.4715	0.00	0.4692	0.4741
helper for crease pocket	0.4710	0.00	0.4678	0.4743
helper for creasebbutton hole placket	0.2217	0.00	0.2201	0.2234
helper for mark front pocket position	0.00	0.00	0.00	0.00
helper for mark front pocket position and IRN	0.4222	0.01	0.3905	0.4641
Helper for mark lining	0.5438	0.00	0.5411	0.5470
helper for pocket marking	0.5292	0.00	0.5276	0.5304
helper for turn cuff	0.3133	0.00	0.3120	0.3150
helper for turn pocket	0.4648	0.00	0.4621	0.4681
helper with IRN for collar turn	0.00	0.00	0.00	0.00
IRN for cuff	0.4045	0.00	0.4022	0.4089
IRN for pocket mouth	0.00	0.00	0.00	0.00
iron upper and lower sleeves placket machine	0.4900	0.00	0.4864	0.4938
JUKI LBH	0.8958	0.00	0.8881	0.9028
label attaching machine	0.5938	0.00	0.5892	0.5992
notching sleeve machine	0.4569	0.00	0.4532	0.4607
pocket attaching machine	0.7751	0.00	0.7708	0.7817
Resource 11	0.4767	0.00	0.4730	0.4796
Resource 12	0.8515	0.00	0.8447	0.8564
Resource 13	0.8434	0.00	0.8369	0.8490
Resource 14	0.6114	0.00	0.6060	0.6147
Resource 15	0.6870	0.00	0.6802	0.6943
Resource machine	0.7926	0.00	0.7853	0.7974
Resource machine sew	0.6073	0.00	0.6039	0.6107
SNL auto	0.7475	0.00	0.7422	0.7523

SNL for collar band centre	0.3801	0.00	0.3776	0.3830
SNL for collar run stitch	0.5669	0.00	0.5639	0.5705
SNL for placket attaching	0.8048	0.00	0.7986	0.8115
SNL for pocket	0.4046	0.00	0.4022	0.4065
SNL for runstitch cuff	0.7190	0.00	0.7152	0.7218
SNL VT for collar attch to band	0.6161	0.00	0.6120	0.6202
SNLM	0.6874	0.01	0.6219	0.7378
SNLS for attaching back yoke	0.5932	0.00	0.5893	0.5957
SNLS for back yoke top stitch	0.4239	0.00	0.4208	0.4262
SNLS for top stitch	0.3965	0.00	0.3940	0.3983
SNLSM	0.6287	0.00	0.6242	0.6321
upper yoke attaching machine	0.4225	0.00	0.4201	0.4245

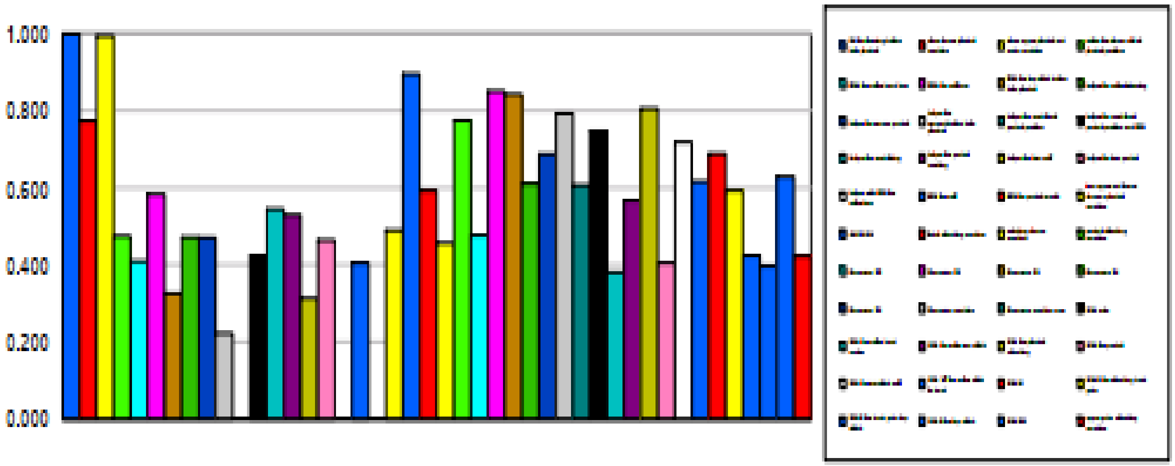


Table D-13 Resource Seized Report

Resource

Usage

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
BH for forming button hole placket	537.10	0.62	533.00	541.00
close lower placket machine	560.00	0.00	560.00	560.00
close upper placket and make machine	470.97	0.51	468.00	473.00
cutter for sleeve slit at placket position	561.00	0.00	561.00	561.00
DNL for collar band hem	480.00	0.00	480.00	480.00
DNL for cuffhem	561.00	0.00	561.00	561.00
DNL for top stitch button hole placket	535.90	0.63	532.00	540.00
helper for collar trimming	480.00	0.00	480.00	480.00
helper for crease pocket	560.00	0.00	560.00	560.00
helper for creasebbutton hole placket	536.10	0.62	532.00	540.00
helper for mark front pocket position	0.00	0.00	0.00	0.00
helper for mark front pocket position and IRN	561.00	0.00	561.00	561.00
Helper for mark lining	481.00	0.00	481.00	481.00
helper for pocket marking	561.00	0.00	561.00	561.00
helper for turn cuff	560.00	0.00	560.00	560.00
helper for turn pocket	560.00	0.00	560.00	560.00
helper with IRN for collar turn	0.00	0.00	0.00	0.00
IRN for cuff	560.00	0.00	560.00	560.00
IRN for pocket mouth	0.00	0.00	0.00	0.00
iron upper and lower sleeves placket machine	560.00	0.00	560.00	560.00
JUKI LBH	1053.57	0.55	1046.00	1054.00
label attaching machine	534.70	0.63	531.00	538.00
notching sleeve machine	560.00	0.00	560.00	560.00
pocket attaching machine	535.43	0.62	532.00	539.00
Resource 11	552.80	0.21	552.00	554.00
Resource 12	552.70	0.20	552.00	554.00
Resource 13	552.50	0.19	552.00	553.00
Resource 14	510.87	0.31	509.00	512.00
Resource 15	510.47	0.25	509.00	511.00
Resource machine	546.80	0.33	545.00	549.00
Resource machine sew	546.47	0.29	545.00	548.00
SNL auto	560.00	0.00	560.00	560.00
SNL for collar run stitch	480.00	0.00	480.00	480.00
SNL for placket attaching	560.00	0.00	560.00	560.00
SNL for pocket	560.00	0.00	560.00	560.00
SNL for runstitch cuff	560.00	0.00	560.00	560.00
SNL VT for collar attch to band	480.00	0.00	480.00	480.00
SNLM	527.00	0.00	527.00	527.00
SNLS for attaching back yoke	560.00	0.00	560.00	560.00
SNLS for back yoke top stitch	560.00	0.00	560.00	560.00
SNLS for top stitch	480.00	0.00	480.00	480.00
SNLSM	494.77	0.16	494.00	495.00
upper yoke attaching machine	561.00	0.00	561.00	561.00