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Productivity improvement through assembly line balancing by using simulation modeling in case of Abay garment industry Gondar

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ABSTRACT

This study aims to balance the garment line of the polo shirt operation by utilizing line balancing techniques. These techniques are employed to enhance the efficiency and productivity of the Abay garment industry. Observational methods and stopwatch timing were employed to collect data on the processing times for each operation. Subsequently, the standard allowed minute was determined based on work measurement principles. To assess statistical significance and identify appropriate expressions for the existing simulation modeling, all collected data underwent statistical analysis using the Arena input analyzer. Moreover, Arena simulation software was employed in this research to simulate and evaluate the effectiveness of both the current and proposed polo shirt sewing line models. Building upon the existing model, alternative improved models were proposed. The alternative models yielded significant improvements in multiple performance metrics, including output, capacity utilization, waiting time in queues, and number of products waiting. These improvements indicate an increase in productivity resulting from the implementation of balanced production lines. The outcomes of the improved scenario included an increase in output from 288 to 381, a rise in line efficiency from 39.06 % to 55.64 %, and an enhancement in labor productivity from 54.25 % to 66 %. Additionally, the cost of labor was reduced by 15.63 %, while revenue experienced a notable increase of 30 %.

1. Introduction

In today's world, the manufacturing industry has a significant contribution to the growth of one country. Among the different manufacturing sectors, one is garment manufacturing. The garment manufacturing industry is renowned for its labor-intensive nature and has evolved into one of the world's largest economies. It capitalizes on labor-intensive advantages, especially in regions facing increasing urban unemployment rates [1]. Moreover, recent reports highlight the textile and apparel industries as some of the fastest-growing sectors, providing employment to millions of individuals [2]. For countries like Ethiopia, with significant populations and high unemployment rates, these industries hold even greater value.

The garment and textile industries in Ethiopia have a long history, dating back to around 1939, but only recently have they begun to modernize. These industries are now a priority, significantly contributing to the country's GDP. However, many garment factories in

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Ethiopia still operate inefficiently [3]. Therefore, exploring ways to enhance efficiency in this sector has become a crucial focus for researchers. This study aims to seize this opportunity by specifically focusing on improving the Ethiopian garment industry.

To increase the annual earnings potential in Ethiopia, the productivity of the garment sector is a significant factor. Increased productivity is thought to boost profitability and workers' ability to earn a living wage because it is frequently cited as a crucial component of industrial performance [4]. The efficiency with which input resources are converted into value for customers is a critical factor in assessing the productivity of a process. Manufacturers of physical products extensively adopt a variety of productivity frameworks and metrics. Increasing productivity not only bolsters profit margins for enterprises but also curtails the production expenses in the garment industry [5]. For augmenting productivity, a streamlined and balanced workflow is essential. Line balancing plays a crucial role in this process by distributing the amount of work uniformly across all operations within a value stream, thus averting inefficiencies such as bottlenecks and capacity problems [6].

According to the preliminary study, the case company, specializing in polo shirt production, is facing a line balancing challenge that is leading to a significant discrepancy between the target and actual production output. The current assembly line is experiencing imbalanced workloads among operators, which has resulted in bottlenecks, idle time, and excessive workloads. Consequently, the company struggles to meet production targets, resulting in delivery delays and reduced profitability. Therefore, implementing a line balancing strategy is imperative for the company.

Line balancing is a critical aspect of production processes in various industries, including manufacturing [7]. It involves the optimization of task allocation and resources to ensure a smooth and efficient production process. Consequently, this study has chosen to employ line balancing techniques, given their widespread use in addressing issues that arise in assembly line operations and in minimizing disparities between workers and workloads to attain the necessary production rate [8].

Despite its importance, line balancing can be challenging to implement effectively. The primary problem is identifying and addressing bottlenecks in the production process, which can lead to idle time, longer cycle times, and potential quality issues. Additionally, different tasks require different skill levels, and worker fatigue and other factors can impact production efficiency.

Similarly, managers must make informed decisions about the pace at which operators work to maintain process continuity and determine the appropriate number of operators for specific tasks, all while ensuring that efficiency gains remain at satisfactory levels. To handle those difficulties, the researchers use a computer simulation tool, since the simulation is a valuable tool for garment manufacturers in line balancing as it enables them to identify bottlenecks, analyze process efficiency, reduce downtime, optimize worker utilization, and implement changes cost-effectively. Employing simulation in line balancing results in increased efficiency, productivity, and profitability [9].

Equally, it is an important tool for line balancing because it allows manufacturers to evaluate different scenarios and strategies for optimizing their production process without actually implementing them in real life [10]. By creating a virtual model of the production line and running simulations, manufacturers can test different line balancing strategies without incurring the costs associated with physical changes to the production line.

Hence, the main goal of this study is to enhance the production line for polo shirt manufacturing at Abay Garment Industry by applying line balancing through simulation modeling. To achieve this, the study aims to address the following objectives:

1. Analyze the current production line to identify bottlenecks, areas of inefficiency, and opportunities for improvement.
2. Develop a line balancing plan to optimize the production line by eliminating bottlenecks, reducing idle time, and ensuring that each worker is performing tasks that align with their skill level.
3. Determine the effectiveness of the line balancing plan by tracking key performance indicators, such as production output, waiting time, costs, and profits. These indicators can be used to assess the success and impact of the proposed line balancing plan.

1.1. Literature review

1.1.1. Overview of the garment industry in Ethiopia

Ethiopia presents a promising landscape for the future of apparel manufacturing, considering its large youthful populace of 110 million, swift economic advancements with expected sustained annual GDP growth, competitive labor costs, and favorable trade conditions [11]. Despite its potential, Ethiopia faces several challenges that impact commercial viability, environmental sustainability, and ethical business practices. Critical materials such as cotton, fabrics, and accessories necessitate importation, and the country's import-export regulatory framework is complex and often results in protracted processes.

The Ethiopian government is working to increase income and attract foreign investment in the textile and garment sectors. It has offered incentives including export benefits, access to low-cost land, reduced-interest loans, tax holidays, and exemptions on duties for importing equipment. The establishment of entities such as Industrial Development corporations, tasked with the development of modern industrial parks, has notably heightened the country's attractiveness to foreign investors [12].

The garment manufacturing industry in Ethiopia, a priority for the government, faces challenges in productivity. These challenges present a significant opportunity for research aimed at improving productivity, a crucial strategy for enhancing the industry's performance in the country [13].

Analyzing current manufacturing systems in the garment industry can be costly and, at times, unfeasible. The complexity is due in part to the fast-paced and intricate nature of production where multiple processes occur simultaneously. The interactions and transition times between workers add to this complexity, making the examination of the system challenging [14].

1.1.2. Productivity

Productivity, a fundamental concept in economic analysis, has a history spanning over two centuries and finds application in various economic contexts at different levels of aggregation [15]. It measures the efficiency of transforming inputs into outputs, a crucial idea in economic analysis, often evaluated based on the attainment of established goals related to input-output relationships within industries [16]. Mathematically, this concept is encapsulated in Equation (1).

$$\text{Productivity} = \frac{\text{output}}{\text{input}} \tag{1}$$

Productivity is widely regarded as a pivotal factor governing economic production activities, often considered the most crucial one. It serves as a key metric for evaluating the efficiency and effectiveness of service or manufacturing organizations in generating output with the resources at their disposal. One effective approach to enhancing productivity is optimizing task scheduling, involving the sequencing of tasks to minimize the time spent switching tools or work pieces between tasks. Logical and efficient task sequencing minimizes idle time and ultimately leads to increased productivity [17]. Furthermore, investing in worker training and skill development can significantly boost productivity in line balancing. Well-trained worker's complete tasks more rapidly and with higher quality, resulting in enhanced overall efficiency and productivity across the production line [18]. Lastly, technological advancements, such as automation and robotics, play a pivotal role in elevating productivity in line balancing. Automated production lines can operate continuously, resulting in substantial productivity increases. Furthermore, the integration of robotics to perform repetitive tasks enables human workers to redirect their efforts towards more complex and skill-intensive activities [19].

In summary, several strategies exist to enhance productivity in line balancing, including resource allocation optimization, efficient task sequencing, worker training, and technological innovation. By prioritizing these strategies, manufacturing companies can increase productivity and profitability while upholding high standards of quality and customer satisfaction.

1.1.3. Efficiency

Efficiency in line balancing refers to the extent to which the production line can achieve maximum output while minimizing waste and idle time. When a production line is efficiently balanced, each workstation is staffed appropriately, and the work is sequenced in such a way as to minimize the time taken to complete each task.

Efficiency serves as a valuable way to gauge productivity, and it offers more meaningful insights than raw productivity numbers. It provides a practical means of assessing performance against scientifically established targets. These targets are typically expressed in terms of time per garment or specific production levels, simplifying the calculation of efficiency. These targets are usually set at a performance benchmark of 100 %. So, when an operator reaches their target production, their efficiency stands at 100 %. Conversely, if they achieve only 50 % of their target, their efficiency is 50 %. This efficiency-focused approach provides a more meaningful assessment of performance in manufacturing settings. The formula for calculating line efficiency is presented in Equation (2).

$$\textit{Line efficiency} = \frac{(\text{Output per day per line}) * (\text{standard time})}{(\text{man power per line}) * (\text{working minutes per day})} * 100 \tag{2}$$

Efforts to improve efficiency in line balancing encompass a range of strategies drawn from multiple sources [20–24]. These strategies can be summarized as follows:

1. Reducing Idle Time: Idle time occurs when workers or machines wait for the next task or workstation to become available. Efficiency can be significantly enhanced by minimizing idle time. This is typically achieved by distributing the workload evenly across workstations, ensuring each worker has a sufficient number of tasks.
2. Sequencing Tasks Efficiently: The sequence in which tasks are performed within the production process is critical for improving line balancing efficiency. Logical and efficient task arrangement can reduce the time required for each task, resulting in overall efficiency gains.
3. Addressing Bottlenecks: Bottlenecks occur when one workstation or process lags behind others, causing a backlog of work. Identifying and eliminating bottlenecks within the production line is crucial for improving overall efficiency.
4. Worker Training: Worker training plays a vital role in enhancing efficiency. Well-trained workers operate more efficiently and maintain higher quality standards, contributing to increased productivity across the entire production line.
5. Technology Adoption: Integrating advanced technologies such as automation, robotics, or AI can significantly enhance efficiency by optimizing various aspects of the production line, ultimately working toward the goal of improved line balancing efficiency.

Incorporating these strategies collectively enhances the effectiveness of line balancing operations, resulting in increased efficiency and productivity.

1.1.4. Efficiency improvement techniques in garment manufacturing

Line balancing, a technique for distributing tasks evenly among workers and machines, boosts efficiency in production lines [25]. It not only standardizes work completion times but also increases output while reducing the need for both manpower and machinery. The technique's effectiveness is evidenced by a study showing a rise in production efficiency from 44 % to 53 % following its implementation [25]. Line balancing plays a significant role in lean manufacturing, contributing greatly to the optimization of production efficiency [26,27].

Cellular manufacturing is one of the techniques for efficiency improvement, and it helps to create a single, smooth flow. This approach grants businesses the flexibility to offer a diverse range of products to their clients by grouping similar items into categories, which can be processed using the same machinery in an identical sequence. Cellular manufacturing benefits factories because it decreases waste and overproduction, shortens lead times, boosts efficiency and quality, and fosters better communication and teamwork [28].

Lean principles, centered around continuous improvement and enhancing employee performance, are cost-effective strategies for boosting efficiency. In the garment industry, these principles have proven to be especially valuable for operational enhancement without requiring large investments [27]. In lean principles, 5S is one approach to organizing, ordering, cleaning, standardizing, and continuously improving a work area in the garment manufacturing industry [29].

The operator skill matrix is instrumental in enhancing efficiency in the garment industry by ensuring tasks align with workers' skills, resulting in optimized performance. It also maintains records of operators' previous performances to guide future task assignments [30].

Productivity in the garment industry can be improved through techniques like time study, visual management, and work standards [31]. These methods led to an 8.07 % increase in efficiency, and specialized operator training further reduced time consumption and enhanced productivity [32].

1.1.5. *Time study*

Time study involves employing specific methods to ascertain the average time a skilled or moderately experienced worker requires to finish a task at a particular work pace [33]. It helps estimate the standard time for an activity, defined as the duration a trained operator takes to accomplish a task efficiently using prescribed methods, tools, and workplace setups under certain conditions. This standard time is pivotal in "work measurement," a process essential for operational planning and control. Without such data, evaluating facility capacity and estimating delivery dates or costs becomes impractical [34].

1.1.6. *Line balancing*

Line balancing, a critical aspect of assembly line efficiency, involves distributing workload evenly among tasks within a cell or value stream. This practice is essential for optimizing assembly line performance [6]. In the garment manufacturing sector, line balancing encompasses the strategic distribution of sewing machines customized to meet the distinct style and design prerequisites of individual garments. The approach adopted is contingent on the nature and type of garment being produced [6].

Implementing time study methods and fully utilizing worker capacity can lead to notable efficiency improvements in the sewing section. For instance, through line balancing, a T-shirt production line's productivity improved from 45.3 % to 58 %, and efficiency increased from 54.22 % to 59.74 % [35].

The process of assembling apparel can be challenging due to the numerous operations involved in the sewing line, and the varying working capacities of different individuals. Improving productivity and quality involves identifying and mitigating the factors that affect them, leading to enhancements in both production and quality [16].

1.1.7. *Techniques of line balancing*

Line balancing is a crucial technique employed in manufacturing to optimize the allocation of resources and ensure the efficient utilization of workstations within the production line [36,37]. Several techniques are commonly used in line balancing:

1. Precedence Diagramming: This technique involves the creation of a diagram that illustrates the sequence of tasks necessary to complete a product or process. By analyzing this diagram, the order of tasks can be optimized to minimize the time spent on each one.
2. Task Grouping: Task grouping entails the consolidation of tasks into clusters that can be executed by a single worker. This method reduces the need for multiple workers, resulting in decreased downtime and improved overall efficiency.
3. Cycle Time Analysis: Cycle time analysis is centered on evaluating the duration needed to accomplish each task along the production line. Optimizing the cycle time of each task contributes to improving the overall efficiency of the production line.
4. Heuristic Approaches: Heuristic approaches rely on practical rules of thumb and best practices to optimize the production line. For instance, the longest task time heuristic involves assigning the longest task to the workstation with the most available time.
5. Time Studies: Time studies involve direct observation and measurement of the time taken to complete individual tasks within the production line. Analyzing the results of time studies enables the identification and resolution of bottlenecks and inefficiencies.
6. Computer Simulation: Using computer simulation, organizations can create virtual production line models to assess various line balancing scenarios. This enables them to identify the most efficient technique, enhancing overall production line effectiveness.

1.1.8. *Modeling and simulation in line balancing*

Modeling refers to the act of constructing a representation, often called a model, of a system, process, or phenomenon with the purpose of studying it and making predictions. This practice is common in the business world, where modeling is employed for analyzing, optimizing, and predicting various processes or systems [38]. The primary goal of a model is to enable analysts to foresee how changes will affect the system. Therefore, a model should closely mimic the real system, encompassing its critical elements. In today's industries, models are essential tools. They allow for the development of virtual representations of intricate systems or processes, which are then subjected to simulations. This approach offers a robust way to test multiple scenarios and make predictions under diverse conditions [39]. In the context of garment manufacturing, simulation has gained paramount importance, delivering substantial benefits to both line balancing and the broader production processes [9]. The following advantages are particularly noteworthy:

1. Identifying bottlenecks: Simulation helps to identify bottlenecks in the manufacturing process by providing a visual representation of the entire production line. This helps manufacturers to pinpoint areas where the flow of production is impeded and take corrective measures to improve efficiency.
2. Analyzing process efficiency: Simulation enables garment manufacturers to analyze the efficiency of the production process by providing real-time data on production rates, cycle times, and operator utilization. This method empowers manufacturers to assess how alterations in the production line affect overall performance, thereby facilitating more informed decision-making and optimization.
3. Reducing downtime: Simulation can help to reduce machine downtime by identifying potential issues early on, allowing manufacturers to take proactive steps to prevent breakdowns and reduce maintenance requirements. This results in increased machine uptime, productivity, and profitability.
4. Optimizing worker utilization: Simulation also helps to optimize worker utilization by providing data on worker performance, identifying skill gaps, and suggesting training programs where necessary. This helps to ensure that workers are deployed to the appropriate workstations, resulting in higher efficiency and productivity.
5. Cost-effective: Simulation helps to identify potential issues and implement changes without disrupting the actual production line. This eliminates the need for costly trial-and-error processes, thus saving time, money, and resources

In a practical application, a study on trouser production used simulation to test different workstation layouts. Although it didn't factor in machine setup times and breakdowns, the insight gained was invaluable [26]. A line balancing algorithm was central to this study, helping unveil the most efficient workstation configurations. Another study employed the Pro-Model simulation package, delving into the modular system's efficiency within the garment industry [40]. Even with the exclusion of factors like machine downtime and the movement of operators between stations, the study still managed to provide significant insights. It underscored the utility of simulation tools in improving productivity, optimizing machine and labor use, and enhancing inventory management.

2. Methodology

This research study focuses on Abay garment industry, aiming to investigate its operational efficiency. To achieve this, a quantitative research approach is employed, utilizing a case study design. The case factory specifically selects less efficient, yet highly demanded production lines for analysis. These selected lines will be thoroughly analyzed to gain insights into their performance and identify potential areas for improvement.

2.1. Data collection and analysis

2.1.1. Observation

Direct observation is a fundamental and significant method for collecting primary data in many research studies. It involves carefully observing and documenting crucial information regarding material flow, job duration, manufacturing operation sequences, and work procedures. This method plays a vital role in visualizing and gathering essential information related to these aspects of the study.

2.1.2. Unstructured interview

Unstructured interviews were conducted to gather pertinent information. These interviews aimed to acquire data regarding various aspects, including working hours, the quantity of machines, workforce allocation per operation, as well as work-related factors like the duration of shifts, the utilization of machines, and the daily production output.

2.1.3. Tools and techniques

The study utilized Arena Simulation Software, specifically the Academic version 14, for modeling and analysis. Additionally, various materials and tools, such as a stopwatch, spreadsheet software, calculator, paper, and pencils, were employed for testing and evaluation.

Table 1
Preliminary sample for five activities.

Operation or activity	Observation	$(\dot{X} - x_i)^2$
Heat cell	54.90	38.56
Placket attach	41.20	56.10
Lower placket top	40.38	69.05
Bottom hem	59.26	111.72
Vent take	47.70	0.98
Total	243.44	276.41
Mean ($\dot{X}$)	48.69	

2.1.4. Sample size and time study

Sampling involves selecting a representative subset from the overall population in a research context [41]. For the 'bracket attach' operation, as illustrated in Table 1, five preliminary samples were considered to ascertain the requisite number of observations for thorough data collection. Effective sampling is crucial in empirical research to prevent data errors or population biases. The primary method is random sampling, which includes simple, stratified, cluster, systematic, and multistage techniques [42]. For the study, the number of observations, the mean of the initial preliminary sample, and the standard deviation were calculated using Equations (3)–(5), respectively.

$$n = \left(\frac{zs}{hx}\right)^2 \tag{3}$$

$$\dot{X} = {}^{1}\Big/ {}_{n} \sum_{x-1}^{n} xi \tag{4}$$

$$S = \sqrt{(xi - \dot{\mathrm{X}})^2 / (n-1)^2} \tag{5}$$

In this context, n represents the number of observations; x denotes the sample measured with a stopwatch; $\dot{X}$ is the mean of the sample; S signifies sample standard deviation; half of the precision interval is represented by h. For example, for a ± 5 % interval, h, half of the precision interval is 0.1; and z represents the standard normal deviation associated with the specified confidence level. Generally, in most industrial settings, a 95 % confidence level is adopted, for which the standard values are $z = 2$ and $h = 0.1$ [43].

$$s = \sqrt{(276.41)^2 / (5-1)^2} = 8.31$$

$n = \left(\frac{zs}{hx}\right)^2 = \left(\frac{2*8.31}{0.1*48.69}\right)^2 = 11.65 \cong 12$, cycle time is required for each operation.

Time Study Procedures: The process of conducting a time study is explained in Fig. 1.

2.2. Simulation modeling

2.2.1. Problem identification and conceptual model (flow chart)

The Abay Garment Industry in Gondar, Ethiopia, specializes in textile production, specifically weaving or knitting fibers to create

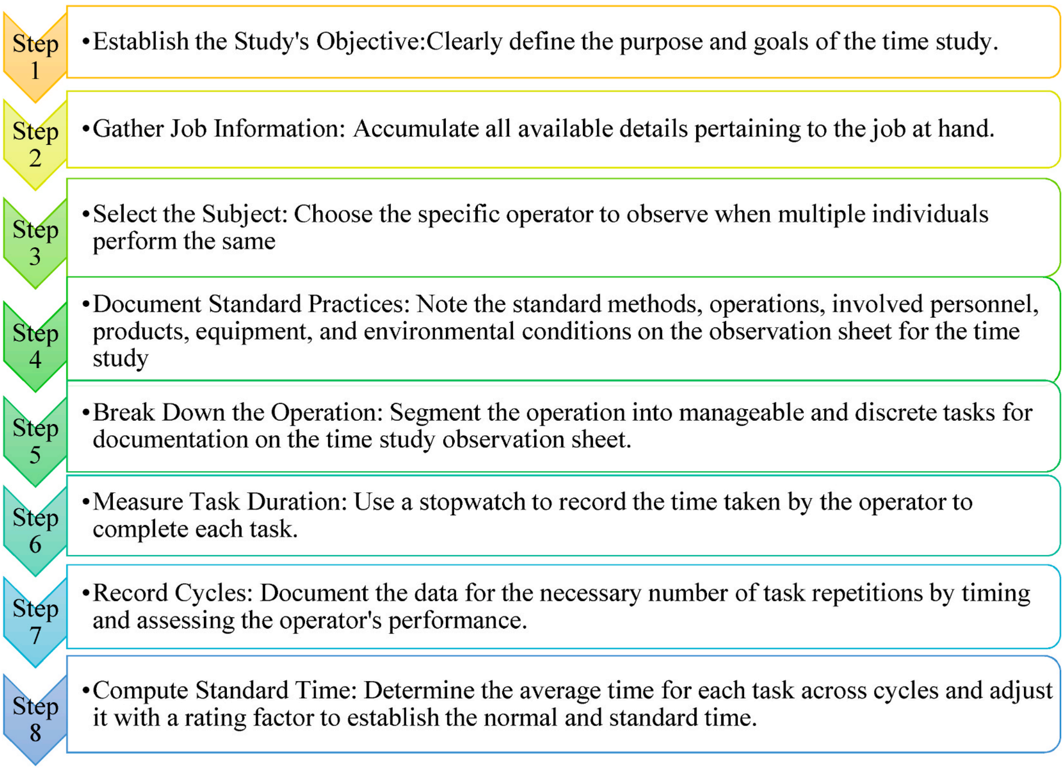


Fig. 1. Time study procedures.

fabrics, with the finishing process of a polo shirt involving 29 steps carried out by both employees and machines, as shown in Fig. 2. The company employs 37 workers and utilizes 29 machines, but a line balancing issue has been identified, resulting in a current production output of about 285 products per shift, falling short of the target of exceeding 400 products per shift.

The study follows a four-phase approach to achieve its objectives. This is represented in a flow chart Fig. 3. In the first phase, the researchers identify the problems and establish three main objectives, as outlined in the concluding paragraph of the introduction. Moving on to the second phase, real data is collected using primary techniques such as observation and unstructured interviews. This data is then translated into the Arena simulation software to develop the input and simulation model for the polo shirt operations. The developed model is subsequently verified and validated to ensure its accuracy in representing the real system of Abay garment's polo

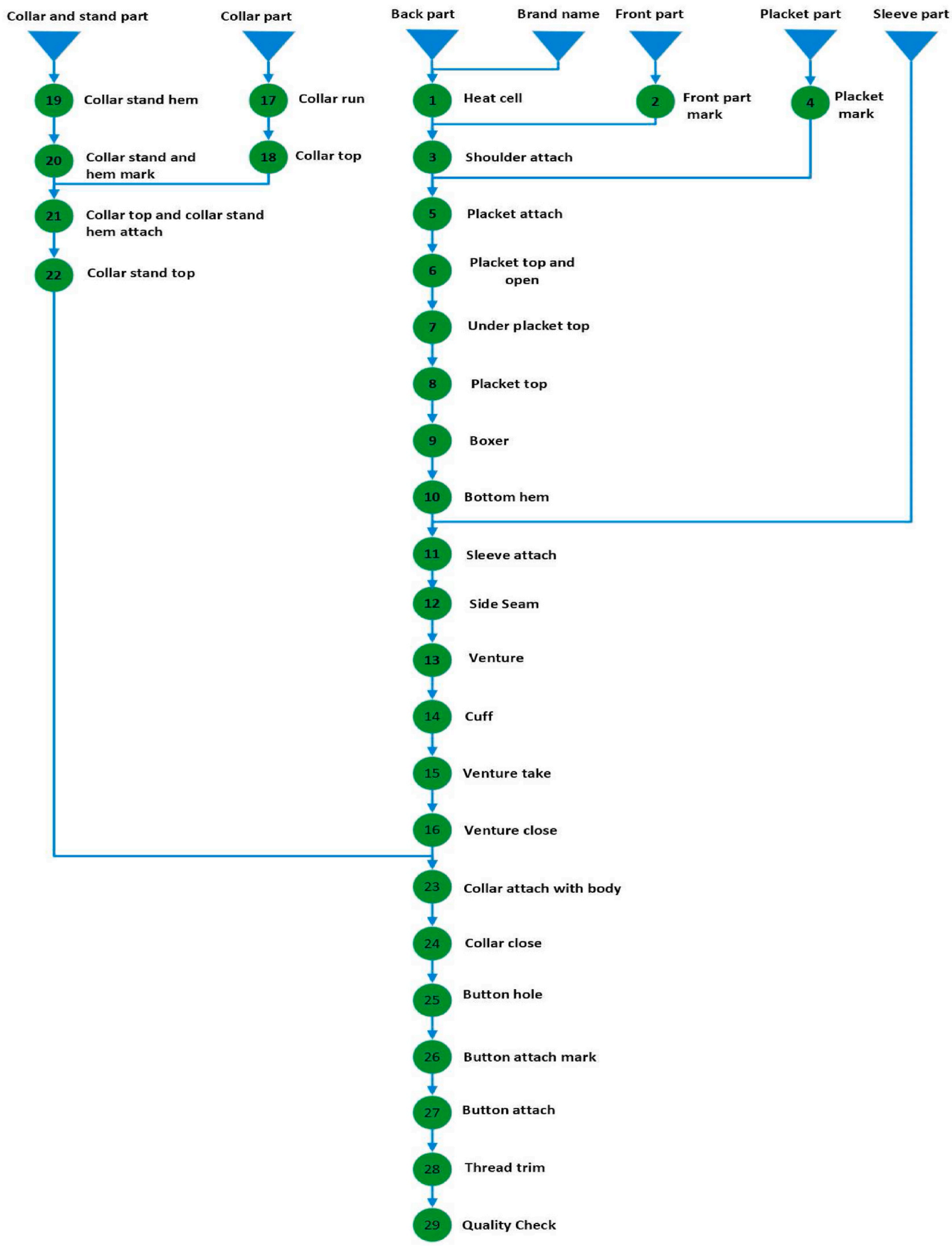


Fig. 2. Flow process chart of Polo shirt.

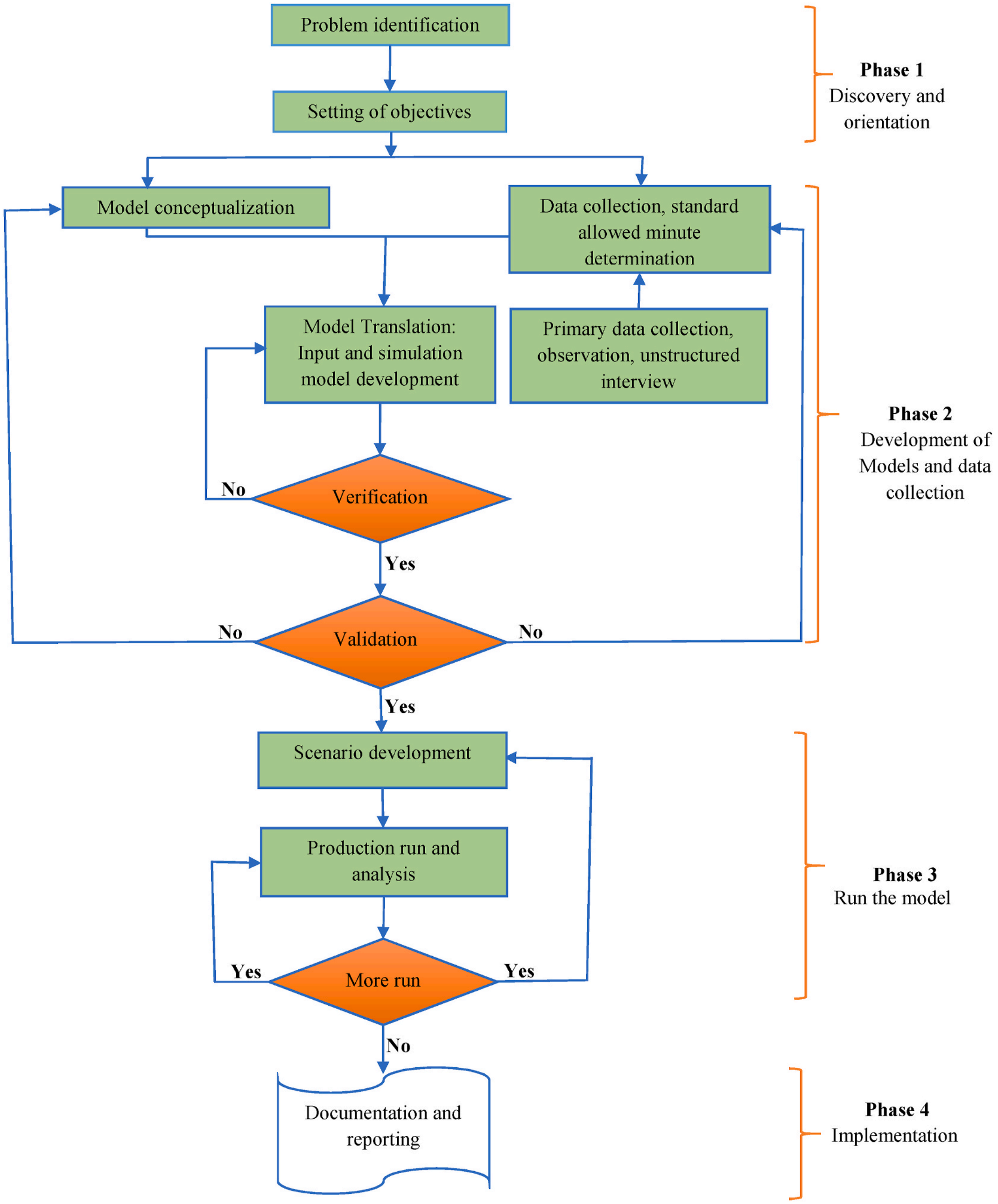
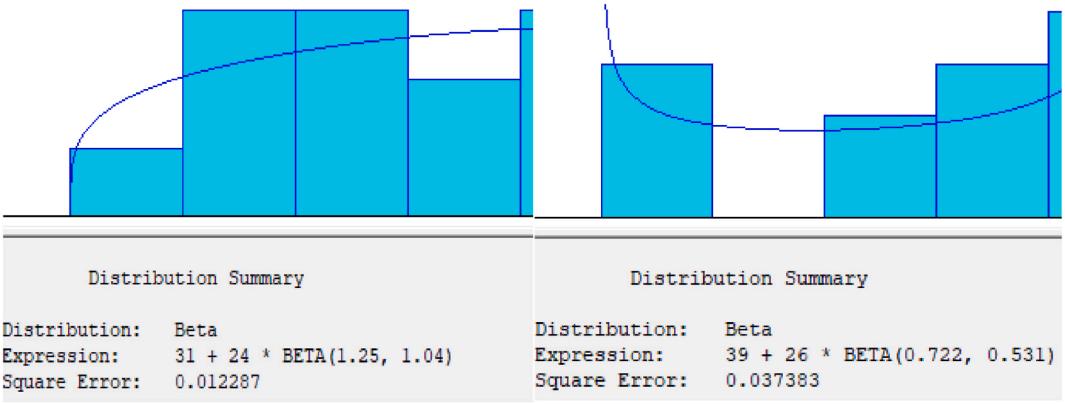


Fig. 3. Methodological approach for the study.

shirt operation. In the third phase, various scenarios are experimented with, and the results are observed. In the final phase, conclusions are derived from the results yielded by the simulation software.

2.2.2. Input modeling

The recorded data was analyzed using the input analyzer feature of the Arena software. This analysis aimed to determine the distribution of the data, which would then be utilized in developing the simulation model within the Arena software. The distribution serves as a function that defines the relationship between observations in the recorded sample space. Fig. 4 illustrates an example of the processing time distribution for the heat cell and front mark operations. Additionally, Table 2 outlines the resource and operation time distribution for all operations involved.



a b

Fig. 4. Heat cell (a) and front mark (b) processing time distribution.

2.2.3. Model development

The simulation model used the Arena® version 14.0 simulation software and was constructed based on a production diagram provided by the case company, as shown in Fig. 2. The arrangement of sewing machines followed the diagram, while the line balancing algorithm dictated the number of machines allocated to each operation.

The study employed discrete-event modeling, with the case company operating for 540 min (9 h) per day. There were approximately 29 operations and a labor force of around 37 individuals required for these operations. At the start of each order, the manufacturing line was initially empty, a state that was replicated in the simulation. However, it is important to note that this initial start-up condition could potentially introduce bias to the results, as the line requires time to stabilize and reach a steady state. Entities queued for sewing machine usage were organized in a first-in-first-out system, awaiting availability of the resource. In the design of the system, the following assumptions were taken into account:

- The manufacturing line is assumed to be empty at the beginning of each order.

Table 2
Resource and operation time distribution.

No	Operations	Machine types	No of operators	No of machine	Expression
1	Heat cell	Heat cell	1	1	31 + 24 * BETA (1.25, 1.04)
2	Front mark	Manual	1	0	39 + 26 * BETA (0.722,0.531)
3	Shoulder attach	Over Lock	1	1	31 + 19*BETA (0.75,0.942)
4	Placket mark	Manual	1	0	9 + 13 * BETA (1.32, 1.31)
5	Placket attach	Single Needle	1	1	NORM (32.3, 5.05)
6	Placket top and open	Single Needle	1	1	19 + LOGN (10.5, 19.7)
7	Under placket top	Single Needle	1	1	NORM (28.7, 7.18)
8	Lower placket top	Single Needle	1	1	33 + LOGN (11.9, 15.8)
9	Boxer	Single Needle	1	1	TRIA (46, 54.3, 76)
10	Bottom hem	Over Lock	2	2	UNIF (63, 87)
11	Sleeve attach	Over Lock	2	2	NORM (85.5, 6.42)
12	Side seam	Over Lock	2	2	TRIA (60, 91.6, 117)
13	Venture	Single Needle	1	1	TRIA (25, 30, 35)
14	Cuff	Over Lock	1	1	UNIF (73, 90)
15	Vent take	Single Needle	1	1	47 + ERLA (2.01, 2)
16	Vent close	Single Needle	1	1	66 + EXPO (12.3)
17	Collar run	Single Needle	1	1	25 + 26*BETA (1.02,0.632)
18	Collar top	Single Needle	1	1	39 + GAMM (15, 1.14)
19	Collar stand hem	Single Needle	1	1	TRIA (80, 93.2, 124)
20	Collar stand hem mark	Manual	1	0	34 + GAMM (4.16, 1.52)
21	Collar run and Collar stand hem attach	Single Needle	2	2	TRIA (22, 38.8, 46)
22	Collar stand top	Single Needle	1	1	20 + 18 * BETA (1.17, 1.11)
23	Collar attach	Single Needle	2	2	66 + WEIB (44.8, 1.23)
24	Collar close	Single Needle	2	2	78 + 29*BETA (0.83,0.948)
25	Buttonhole	Buttonholing	1	1	29 + 6*BETA (0.705,0.994)
26	Button attach mark	Manual	1	0	UNIF (19, 44)
27	Button attach	Button attaching	1	1	28 + 29 *BETA (0.543,0.707)
28	Thread trim	Manual	3	0	98 + ERLA (5.95, 2)
29	Quality check	Manual	1	0	29 WEIB (20.5, 1.17)

- No maintenance work is conducted during working hours.
- Breaks are not included in the 540-min working time.
- Setup times are excluded from the system model, aligning with real-world practices where setups usually occur outside of working hours.
- It is assumed that the polo shirt assembly line consistently receives a steady flow of input materials from the cutting section.

Considering all these factors, we have developed the current simulation model for the production of polo shirts, as depicted in Fig. 5.

2.2.4. Number of replications

In simulation studies, the term 'number of replications' denotes how frequently a simulation is executed, each time with varying randomly generated input parameters or initial conditions. The purpose of running multiple replications is to estimate the variability in the simulation output and to reduce the impact of random noise on the results.

The number of replications needed in a simulation study is contingent upon several factors, including the complexity of the simulation model and the degree of variability present in the input parameters and the desired level of precision in the output estimates. Generally, the more replications that are run, the more precise the estimates will be, but this comes at the cost of increased computational time and resources. A prevalent method for ascertaining the suitable number of replications involves performing a power analysis, which estimates the necessary sample size to attain a specified degree of statistical power. This analysis takes into account the expected effect size, the variability in the input parameters, and the desired level of significance. Therefore, to determine the required number of replication number the first 10 outputs has been extracted from the first ten replications as mentioned in Table 3. Then, using mathematical techniques the replication number is determined.

In various fields, a 95 % confidence level (equivalent to a 5 % statistical significance level) is commonly employed for data representation. The standard deviation reflects the extent of variation in the results of the replications from their mean. The half-width represents a sampling error incurred during the sampling process and can be calculated using the standard error. To achieve a 95 % confidence level, the *t* value is derived from the table of t-distribution, yielding a *t* value of 2.262.

The half-widths (h_0) of the polo production line is determined as follows:

$$h_0 = \frac{(t * \sigma)}{\sqrt{n}} = \left(\frac{2.262 \ * \ 0.948}{\sqrt{10}}\right) = 0.678.$$

Consequently, the percentage error for polo shirt production lines equal to:

Percentage error = [(mean value + half width)/mean] −100 %

= [(293.3 + 0.678)/293.3]-100%

= 1.0023–100 % = **0.0023.**

Therefore, by using the replication number equations:

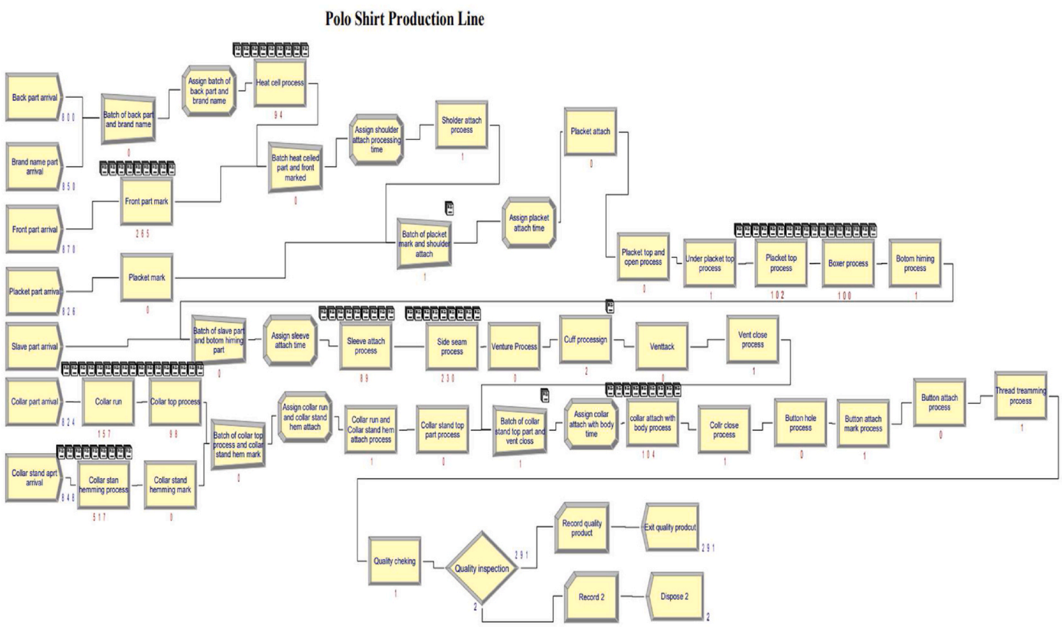


Fig. 5. Existing simulation model of the polo shirt production.

Table 3
The number of polo shirt output for the first ten replications.

Number of replications	Number of polo shirt outputs
1	293
2	292
3	293
4	292
5	293
6	294
7	293
8	294
9	295
10	294
Mean	293.3
Standard deviation (S)	0.948

$$\mathbf{n} = (\mathrm{Z}^2 1 - \frac{\mathrm{a}}{2}\mathrm{s}^2\Big) \Big/ \mathrm{h}^2 \text{ and } n = \left(no * \ \mathrm{ho}^2\right) \Big/ \mathrm{h}^2$$

Where $h = \left(\frac{1}{4} * \mathrm{h0}\right) = h = \left(\frac{1}{4} * 0.678\right) = \mathbf{0.1695}$

Actual replication of the polo shirt:

$$n = \frac{\left(\mathrm{Z}^2 * 0.975 * \mathrm{S}^2\right)}{\mathrm{h}^2},$$

$$n = \frac{\left(1.96^2\right) * (0.948)^2}{(0.1695)^2}$$

$$n = \mathbf{120} \text{ option 1}$$

$$n = \left(\mathrm{no} * \ \mathrm{ho}^2\right) / \mathrm{h}^2$$

$$n = \left(10 * 0.678^2\right) / 0.1695^2$$

$$n = \mathbf{160} \text{ option 2}$$

Consequently, among the two presented options, the maximum number of replications chosen is 160.

2.2.5. Model verification and validation

Validation and verification are crucial steps in simulation modeling. If the model fails to accurately represent the real system, the reliability and quality of decisions based on its outputs may be compromised. Thus, to ensure that this model accurately mirrors the behavior of the production line, it is essential to conduct thorough verification and validation. In the test run, the model operated seamlessly across various input settings, particularly with adjustments in arrival times, and did not generate any errors or warnings. The process animations were monitored, confirming the accuracy of the path. Given that the test run proceeded without issues, indicating a smooth, uninterrupted operation of the production line within the model, it can be concluded that this model is verified and effectively represents the real system.

To affirm the model's reliability, its output was compared with that of the real system. This was achieved by performing a test run, during which a comprehensive comparison was conducted between the output values of the model and those of the existing system to ensure their alignment. As the actual data indicates, the company can produce 285 parts per shift on average. The simulation result of the existing system that considers 9 h of working time and a 160-repliction number is about 293, which is close to the actual output, mathematically the validity of the model can be checked as follows:

$$\text{Model Error } (\%) = [(\text{SimulationValue-ActualSystemValue})/\text{ActualSystemValue}]\text{x } 100\%$$

$$= \left(\frac{293 - 285}{285}\right) * 100 = 2.8\% \text{ which is less than } 5\%$$

The ARENA model used in this study is considered valid based on the acceptable error criterion set by certified analysts from Rockwell Automation, which is ±5 %. This error margin ensures the reliability and accuracy of the model.

2.3. Line balancing

Line balancing involves allocating sewing machines based on the style and design of a garment, tailored to the specific type of garment being produced. Therefore, after the standard allowed minute (SAM) has been determined by the work measurement techniques, the line balance can be used, allowing the following procedure as mentioned below in Fig. 6.

2.3.1. Line balancing procedure

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2.3.2. Key performance measures

Vital metrics for evaluating the success of an organization or team are provided by Key Performance Measures (KPMs). This study adopts KPMs from relevant literature, covering aspects like daily output, operations, required operators, line efficiency, labor productivity, costs, revenue, and profits. These metrics provide a comprehensive assessment, aiding informed decisions and enhancements.

2.3.3. Line balancing scenarios

In line balancing research, scholars often examine different scenarios to address specific issues and align with their research goals. These scenarios are drawn from existing literature and applied in this study, encompassing strategies like adding extra time, merging operations, adding resources, optimizing worker allocation, and task distribution. Each scenario offers a potential solution to line balancing challenges, adaptable to specific study or real-world needs.

3. Results and discussion

3.1. Standard allowed minute calculation

When considering work tasks, it is essential to prioritize taking breaks. Even the most skilled operators require time to rest or attend to personal needs. Consequently, it is crucial to account for break allowances when determining standard times for operations. In this regard, three types of allowances are considered: relaxation allowance (11 % for sitting jobs), machine allowances for specific machine types (Single needle lock stitch: 12.5 %, Overlock stitch: 12 %, Double needle lock stitch: 14 %), and contingency allowance (5 %) [44]. These allowances are applied separately from the rating factor to ensure accurate calculations.

In this study, close collaboration was established with the company's management team to determine appropriate allowances. After thorough consideration, a total allowance of 15 % was designated for manual operations. Additionally, operators using single needle machines were allotted a 28.5 % allowance, while operators utilizing overlock machines received a 28 % allowance. This approach guarantees that our standard times accurately reflect the realities of operators' day-to-day work.

For the third operation, known as "Shoulder attach," which involves using an overlock machine, we have calculated the standard time using the procedure outlined below. This same procedure has been applied to all the subsequent operations.

Observed time = 50 s

$$\text{Rating factor} = \frac{\text{observed performance}}{\text{normal performance}}$$

$$= 329/350 = 0.94$$

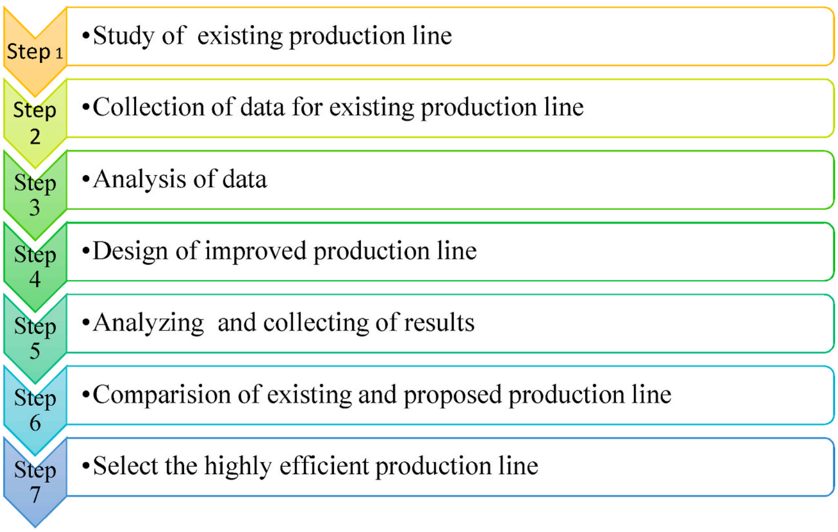


Fig. 6. Line balancing procedures.

$$\text{Normal time} = \text{Average observed time (OT)} \times \text{Rating factor (RF)}$$

$$= 50 * 0.94 = 47 \text{ seconds}$$

$$\text{Standard time (ST)} = \text{Normal time (NT)} + \text{Allowances time (AT)}$$

$$= 47 + 0.28 = \mathbf{47.28}$$

Therefore, the same procedure has been taken for the remaining operations.

3.2. Base/existing simulation model

The results obtained from the simulation model offer valuable insights into the behavior of the system being studied. These results enable us to assess the initial performance of the system and identify areas that require improvement. One significant key performance indicator is the system output, which is illustrated in Table 5 and indicates that the number of polo shirts produced is 293 shirts. However, this falls below the company's target, highlighting the need for further enhancements.

The company operates for 9 h per day, and the performance metrics extracted from the existing simulation model are presented in Table 5. The selling price of one polo shirt is 250 birr, while the monthly labor cost amounts to approximately 3300 birr. With a workforce of 37 employees, the total monthly labor cost reaches 122,100 birr (37 workers * 3300 birr).

Revenue is calculated as $Revenue = Sp \times q$, where Sp represents the selling price and q denotes the quantity produced.

$$Revenue = (250 * 293) = 73,250 \text{ birr}$$

The same procedures were applied to the other scenarios to calculate the revenue and direct labor cost. Another important performance measure to consider is the waiting time of parts in the queue. Table 4, derived from the simulation results of the current system, identifies operations experiencing the highest waiting times. These include collar attachment with body, collar run, collar stand hemming, front part marking, heat cell process, and side seam process. These operations are identified as bottleneck operations due to their extended waiting times. Consequently, significant modifications in these processes can markedly reduce waiting times, boost output numbers, enhance line efficiency, and improve labor productivity.

3.3. Line balancing scenario 1

Extending Replication by 30 Minutes for Workers with High Wait Times: To address the issue of high waiting times, a solution was proposed to enhance the replication length by 30 min for workers experiencing this problem. Consequently, considering all the conditions of the existing model, a second alternative was developed by allocating an additional 30 min for operations that are busy and have high waiting times. Given that the sewing line operates for a single 9-h shift each day, the most practical window for scheduling overtime is during the lunch break, specifically between 5:00 a.m. and 5:30 a.m. By incorporating this adjustment of 30 min for the identified busy operations with high waiting times, the average output per shift of the system has increased. Further details and performance measures are summarized in Table 5.

3.4. Line balancing scenario 2

Merge similar operations: Merging similar operations is a commonly employed technique in line balancing to enhance production efficiency. This approach involves consolidating tasks or operations that share similarities and can be effectively executed by a single workstation or machine instead of multiple ones. With this approach in mind and considering the conditions of the reference model, a new model has been developed that merges operations utilizing similar resources. As a result, several operations have been merged in the production process for increased efficiency. These merged operations include operations 6, 7, and 8; operations 17 and 18; operations 21 and 22; operations 25 and 26; and operations 27 and 29. The outcomes of these mergers, along with pertinent details, are presented and summarized in Table 5 for reference and analysis.

Table 4
Scenario analysis.

Scenario properties		Controls					Responses		
No.	Name	Single needle 10	Replication length	Single needle 11	Single needle 12	Over lock 5	Collar attach with body	Side seam process queue	System number out
1	Existing system	1.00	540.00	1.00	1.00	1.00	68.282	136.612	293.00
2	Scenario 1	1.00	570.00	1.00	1.00	1.00	75.885	144.856	326.00
3	Scenario 2	1.00	540.00	2.00	1.00	1.00	38.548	100.074	297.00
4	Scenario 3	1.00	540.00	1.00	2.00	2.00	0.012	1.918	343.00
5	Scenario 4	1.00	570.00	1.00	2.00	2.00	0.011	2.114	381.00

Table 5
Comparative study of the various scenarios.

Performance measures	Existing scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Average daily output	293 units	297 units	326 units	343 units	381 units
Total count of operations and machines	29	29	25	25	25
Total number of operators required for the Line	37	37	32	32	32
Line efficiency	39.06	41.17 %	45.70 %	52.80 %	55.64 %
Labor productivity	54.25 %	57.20 %	55 %	63.50 %	66.80 %
Annual labor cost	122,100 birr/month	122,100 birr/month	105,600 birr/month	105,600 birr/month	105,600 birr/month
Total revenue from the product	73,250 birr/day	81,500 birr/day	74,250 birr/day	85,750 birr/day	95,250 birr/day

3.5. Line balancing scenario 3

Resource Adjustment and Merging at High-Wait Stations: Considering all the conditions of the existing model, a third alternative has been developed by merging similar operations and reallocating resources from idle operations to busy operations that experience high resource utilization. In the sewing section, certain operations like collar run, attachment, stand hemming, front part marking, heat cell processing, and side seam processing face considerable waiting times. Presently, these operations are allocated just a single resource in the existing production line. To resolve this bottleneck, a strategy of merging and reallocating resources to these high-wait operations has been implemented, simultaneously reducing resource allocation to operations experiencing higher idle times. As a result, this model scenario leads to an increase in the system's output from 298 to 343 shifts per day. Detailed performance measures can be found in Table 5.

3.6. Line balancing scenario 4

Integrating Scenarios 2 and 3: This combined scenario emerges from the fusion of Scenarios 2 and 3, incorporating strategies for merging operations with similar requirements and adjusting resource levels according to their usage. Moreover, an additional 30 min is allocated to operations experiencing high demand. The outcomes of this integrated approach are detailed in Tables 4 and 5

3.7. Comparative study of the different scenarios

The aim of this research was to evaluate how line balancing affects production efficiency in a garment manufacturing setting. To accomplish this, data was gathered both prior to and subsequent to the introduction of line balancing in a production line exclusively dedicated to the manufacturing of polo shirts. The results indicate a substantial improvement in production efficiency following the implementation of line balancing, as illustrated in Table 4 and Fig. 7.

The results demonstrate a significant change in the number of outputs and waiting times at the collar attach and side seam processes between the existing system and the improved scenarios. The existing system produces 293 products and has waiting times of 68.2 min at the collar attach with body process and 136.6 min at the side seam process.

In the first scenario, the number of outputs increases to 326 while the waiting times at the collar attach with body and side seam processes are 75.5 min and 144.85 min respectively. The second scenario has 297 outputs and waiting times of 35.8 min and 100.074 min at the two processes. The third scenario produces around 343 products and reduces the waiting times at the collar attach with body and side seam processes to around 0.012 min and 1.918 min respectively. Finally, the fourth scenario produces 381 products and has waiting times of 0.011 min and 2.114 min at the two processes.

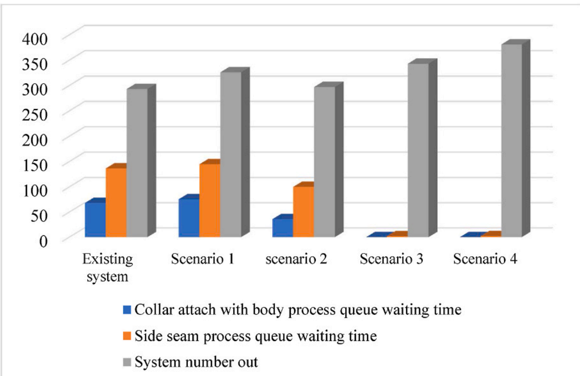


Fig. 7. Comparison of simulation outcomes across scenarios.

Overall, the enhanced scenarios demonstrate higher outputs and reduced waiting times compared to the existing system. Notably, the fourth scenario excels, yielding the highest outputs and the shortest waiting times. For enhanced visual representation, these comparisons are depicted in a bar chart, as shown in Fig. 7.

Table 5 presents an in-depth and comprehensive summary of the results obtained from the examination of four distinct scenarios. This table delivers a clear and succinct presentation of the main findings, simplifying the process of comparing and analyzing the results in a straightforward and systematic manner.

The implementation of line balancing has proven to be a highly effective strategy for improving production efficiency within the context of this study. It has yielded substantial enhancements in various critical aspects of the production process, thereby contributing to heightened overall efficiency and productivity. This achievement aligns closely with the overarching objective of optimizing production operations. To comprehensively illustrate the beneficial impact of line balancing, the subsequent sections present detailed results and supporting evidence:

1. Average Daily Output: The average daily output increased substantially, rising from 293 to 381 units.
2. Reduction in Operations and Machines: The number of operations and machines involved in the production process decreased, going from 29 to 25, streamlining the overall process.
3. Decrease in the Number of Operators: Line balancing led to a reduction in the number of operators required, declining from 37 to 32, while maintaining efficiency.
4. Improved Line Efficiency: The line efficiency metric witnessed a notable improvement, surging from 39.06 % to 55.64 %, signifying a more streamlined production process.
5. Enhanced Labor Productivity: Labor productivity exhibited a substantial boost, climbing from 54.25 % to 66.8 %, indicating more efficient utilization of workforce resources.
6. Reduction in Direct Labor Costs: The direct labor cost associated with producing polo shirts witnessed a significant decrease, dropping from 122,100 birr to 105,600 birr per month, which can contribute to cost savings.
7. Increased Company Revenue: The positive impact of line balancing extended to the company's financial performance, with daily revenue rising from 73,250 birr to 95,250 birr, reflecting enhanced profitability.

3.7.1. Output analyzer

To compare differences among scenarios, ANOVA analysis was performed at a 95 % confidence level. In Fig. 8a, the average waiting time at the bottleneck operation "collar attach with body" is shown, where L1 represents the existing scenario and L5 represents the fourth scenario. The mean values are statistically unequal, indicating the fourth scenario with the shortest waiting time. Similarly, Fig. 8b illustrates waiting times in the side seam process queue, with differing mean values among scenarios, and the fourth scenario displaying the shortest waiting time. Fig. 9 presents the number of system outputs, with distinct mean values among scenarios, and the fourth scenario yielding the highest number of outputs.

In this study, ANOVA (analysis of variance) was used to compare mean values among various scenarios. Figs. 8 and 9 show unequal mean values between these scenarios. This suggests that the fourth scenario reduces waiting times at bottleneck operations and increases output. Consequently, implementing the fourth scenario improves production efficiency.

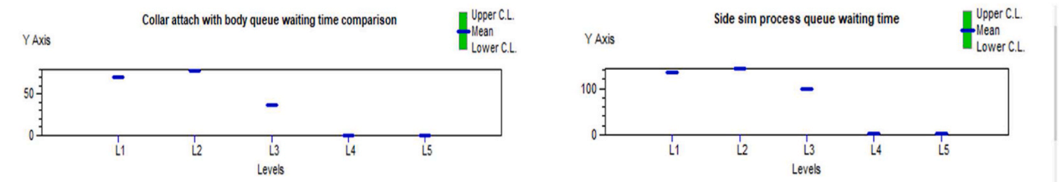
Previous studies have demonstrated the beneficial effects of combining line balancing with simulation in terms of production efficiency, productivity, and system output, ultimately resulting in reduced waiting times. An example is a strategy that utilized the OptQuest simulation tool to decrease waiting time and boost output [45]. This approach successfully reduced waiting time and increased output. However, it should be noted that their approach relied on increasing resources, which can potentially lead to higher labor costs.

Simulation has been effective in improving line balancing and increasing labor productivity, with notable results in areas like the polo shirt assembly line [8,14]. Increased throughput and labor efficiency were also achieved using similar computer simulation techniques [9].

Building on these previous studies, the present research sought to not only improve productivity, efficiency, and reduce waiting times but also reduce labor costs and increase profits for the case company. Our findings align with previous research, indicating that line balancing is an effective strategy for enhancing production efficiency. The suggested simulation model for balancing the production line of polo shirts offers decision makers a simulation-driven optimization tool that enables them to acquire insights and enhance system performance without disrupting the real system.

Additionally, the model allows managers to test new systems before implementation without disrupting real production. This tool enables them to enhance system performance and gather insights without impacting the actual operational system. Moreover, the model provides managers the ability to trial new systems prior to their implementation, ensuring no disruption to actual production processes.

In summary, our study provides strong evidence that line balancing, integrated with simulation, can be a powerful tool for improving production efficiency in manufacturing settings. By optimizing the allocation of tasks and resources, line balancing can reduce waiting times, increase productivity, and significantly improve system output while reducing labor costs, ultimately leading to increased profitability for the company.



One-Way ANOVA Table : Collar attach with body queue waiting time comparisor

L1 - Collar attach with body queue waiting time
L2 - Collar attach with body queue waiting time
L3 - Collar attach with body queue waiting time
L4 - Collar attach with body queue waiting time
L5 - Collar attach with body queue waiting time

SOURCE OF VARIATION	SUM SQUARES	DF	MEAN SQUARES	F-EXP
BETWEEN TREATMENTS	8.975e+005	4	2.244e+005	14939.260
ERROR (W.TREATMENTS)	1.194e+004	795	15	
TOTAL	9.094e+005	799	F-CRIT	2.383

REJECT H0 => NOT ALL MEANS ARE EQUAL AT 0.05 LEVEL

One-Way ANOVA Table : Side sim process queue waiting time

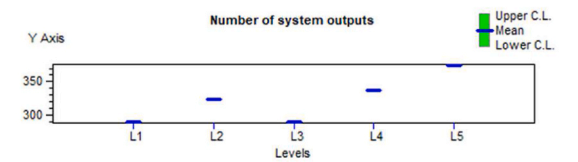
L1 - Statistic 2
L2 - Statistic 2
L3 - Statistic 2
L4 - Side sim process queue waiting time
L5 - Side sim process queue waiting time

SOURCE OF VARIATION	SUM SQUARES	DF	MEAN SQUARES	F-EXP
BETWEEN TREATMENTS	3.102e+006	4	7.755e+005	164824.089
ERROR (W.TREATMENTS)	3741	795	4.71	
TOTAL	3.106e+006	799	F-CRIT	2.383

REJECT H0 => NOT ALL MEANS ARE EQUAL AT 0.05 LEVEL

a b

Fig. 8. ANOVA output of waiting time comparison for collar attach (a) and side sim process (b).



One-Way ANOVA Table : Number of system outputs

L1 - Number of system outputs
L2 - Number of system outputs
L3 - Number of system outputs
L4 - Number of system outputs
L5 - Number of system outputs

SOURCE OF VARIATION	SUM SQUARES	DF	MEAN SQUARES	F-EXP
BETWEEN TREATMENTS	8.063e+005	4	2.016e+005	7978.444
ERROR (W.TREATMENTS)	2.009e+004	795	25.3	
TOTAL	8.264e+005	799	F-CRIT	2.383

REJECT H0 => NOT ALL MEANS ARE EQUAL AT 0.05 LEVEL

Fig. 9. ANOVA system output of different scenarios.

4. Conclusion

This study focused on improving the productivity and line efficiency of Polo shirt production through the development of a line-balancing model utilizing simulation techniques. The researchers began by meticulously determining the standard time for 29 different operations through work measurement procedures and principles, and then developed a simulation model for the existing system based on the standard allowed minutes. The simulation results revealed bottleneck operations, leading to the development, and testing of four different scenarios. The fourth scenario proved the most effective, utilizing strategies such as merging similar operations, adjusting resources, and adding extra time for busy operators.

The proposed line-balanced model brought significant improvements, including an increase in average daily output from 293 units to 381 units, a reduction in the number of operations, machines, and operators, an enhancement in line efficiency from 39.06 % to 55.64 %, and an increase in labor productivity from 54.25 % to 66.8 %. The direct labor cost of producing polo shirts also reduced from 122,100 birr to 105,600 birr per month, while company revenue increased from 73,250 birr to 95,250 birr per day. These remarkable results demonstrate that line balancing is a highly effective strategy for improving production efficiency.

In conclusion, line balancing plays a pivotal role in enhancing production and efficiency within garment factories. By optimizing the allocation of tasks and resources, line balancing can help reduce bottlenecks, improve productivity, and enhance the quality of the finished product. To achieve successful line balancing, it is essential to consider the unique requirements of each production line, including worker skills, machine capabilities, and production targets. Regular monitoring and adjustment are also necessary to maintain optimal line balancing and continuously improve the manufacturing process. In this study, our focus was on analyzing a single line of polo shirt manufacturing using a simulation model. However, future researchers have the opportunity to expand upon this work by exploring multi-line balancing utilizing various line balancing techniques. By implementing effective line-balancing strategies, garment factories can enhance their competitiveness, meet market demand, and uphold high product quality standards.

5. Limitation of the study

This study is subject to certain limitations. To create a practical simulation model, simplifications and assumptions were made, which may have impacted the accuracy and validity of the findings. Additionally, the precision needed for some time study goals may not be achieved by using a stopwatch, which can only measure time in seconds or fractions of seconds. The rating factor was also established using the researcher's observations.

Data availability statement

The data supporting the findings of this study are included within the article, its supplementary materials, and are referenced accordingly.

CRediT authorship contribution statement

Melkamu Mengistnew Teshome: Writing – review & editing, Visualization, Supervision, Project administration, Methodology, Formal analysis, Investigation, Resources, Software, Validation, Data curation, Conceptualization. **Tamrat Yifter Meles:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Chao-Lung Yang:** Writing – review & editing, Supervision, Project administration, Investigation, Data curation, Formal analysis, Funding acquisition, Methodology, Resources, Software, Validation, Visualization, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e23585.

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