

Simulation Analysis of the Effect of Working Method Differences on Production Efficiency in the Apparel Industry

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Abstract

In this study, simulation application on a shirt production line was studied. In order to determine which of the two different working methods, with or without yarn clearing, is more efficient, the duration of the operations was taken and work flows created by applying a work and time study. Then, the theoretical distributions of the collected data were analyzed and the distributions of the data obtained transferred to the simulation model. After the model was established, it was run and its validity tested by comparing it with the real system. A new algorithm was developed that can be applied together with simulation to determine the most suitable production method.

Keywords

Apparel industry, simulation, line balancing, motion and time study, heuristic algorithm.

1. Introduction

The rapidly evolving globalized world presents ever-increasing economic and commercial challenges. This is due to the growth in common markets and the presence of diverse producer groups in these markets, as well as the rapid advancement of technology and the spread of information. Consequently, producers are directing their focus towards novel, scientific, and technological projects. Recently, the implementation of simulation systems has been studied to enhance these developments. Therefore, the use of simulation methods in the textile and apparel industry, a crucial sector in the international economy, can provide a competitive edge by creating differentiation and efficiency among rivals.

In the scope of the research, the simulation method was employed to compare the operating modes of a proposed model in a shirt assembly line of a garment factory by conducting time analyses of operations with and without thread cleaning. The simulation method was utilized to provide a comprehensive and accurate understanding of the performance of the model proposed, and to evaluate the effects of the various factors that impact the performance of the assembly line. By employing simulation, the research was able to obtain insights

into the advantages and drawbacks of the model proposed, and to identify opportunities for improvement in the assembly line's performance.

The presence of uncertainty in workshop environments poses challenges to production planning, which, in turn, affects the speed and efficiency of garment production. Consequently, investigating the bottleneck process in sewing lines and proposing solutions is imperative.

In this context, reducing process inventory and balancing sewing lines are critical in improving efficiency.

Numerous studies emphasize the pivotal role of sewing lines in the overall productivity of garment factories. For instance, Cocks et al. [1] developed a simulation program in Fortran 77 to model the sewing section of any garment factory's production. The program specified the operations, machines, job types, cycle times, job sequences, and job quantities in the sewing section of the system.

Rajakumar et al. [2] attempted to balance the production line in garment factories by assigning new tasks to workers with less workload. To this end, they developed a computer simulation program in C++ and employed random, short processing

time first, and long processing time first combinations as scheduling strategies.

Zielinski et al. [3] aimed to optimize the sewing line of a garment factory by minimizing idle times. They attempted to increase the line's efficiency under cost constraints using the Group Witness simulation program.

Ünal et al. [4] employed the Arena simulation program to replicate a t-shirt sewing line in a clothing manufacturing plant. In a separate study, Ünal and associates suggested an intuitive algorithm to equalize sewing lines in clothing manufacturing facilities and verified the proposed algorithm by imitating a pant sewing line in both U-shaped and straight lines, utilizing the Arena simulation software. Also, in another study Ünal et al. [5] proposed an algorithm that can be easily applied for the software practitioner to use in the alternative model development process in order to increase the efficiency of an existing production line.

Kurşun and Kalaoğlu [6] utilized the Enterprise Dynamics simulation program to “simulate t-shirt, sweatshirt, and shirt sewing lines in their research, striving to balance the lines with diverse scenarios and offering recommendations for the firm's investment decisions”. Also, Kalaoğlu and Sarıcam [7] presented an

application of the modular system in the clothing industry by using the ProModel Simulation. The modular system was designed for a base product working on three different motion principles which differ in some way from the ones presented in literature. The performance of the system was determined in terms of productivity, operators and machine efficiency, throughput time and work in process

Caputo et al. [8] equalized the production line of a jeans manufacturing firm using the Kilbridge and Wester approach and conducted a feasibility study to make investment decisions based on the outcome.

Gebrehiwet et al. [9] assert that efficient sewing lines significantly impact production output, quality control, and order fulfillment. Similarly, Nabi et al. [10] highlight how utilization of worker capacity of sewing lines leads to increased efficiency, reduced lead times, and improved customer satisfaction.

Although sewing lines are integral to garment production, they face several challenges that can hinder their productivity. One such challenge is the high demand for labour, which often leads to issues such as worker fatigue, inefficiencies, and quality control problems. Furthermore, the complexity of garment designs and variations in stitching techniques pose additional challenges for sewing line operators [11].

To overcome the challenges faced by sewing lines, garment factories can implement various strategies. Automation technologies, such as computerized sewing machines, can enhance productivity and reduce labour-intensive tasks [12]. Additionally, implementing lean manufacturing principles, such as standardized work procedures and efficient layout design, can optimize workflow and minimize bottlenecks [13].

After conducting an extensive literature review, no similar study focusing on the specific aspects addressed in this research was identified. Despite the considerable body of literature exploring various

facets of textile factories and their production processes, there is a scarcity of scholarly works specifically examining the impact of the thread cleaning process on the efficiency of sewing lines. This highlights the novelty and significance of this research, as it contributes to filling the existing research gap and providing valuable insights into the production efficiency of sewing lines. This study aims to expand existing knowledge in the field and stimulate further research on similar facilities in the textile industry.

2. Material and Method

In this section, general information about the company on which the study was conducted is provided. Additionally, the simulation method was employed in a shirt assembly line. The definition and scope of simulation, steps involved in the simulation method, and modelling and verification of the model in simulation are presented below to provide a general overview of the simulation method used in this study.

This study was conducted with the support of a textile factory located in Çorlu/Tekirdağ, referred to as Company A, which serves as an integrated facility encompassing the entire production process, ranging from the processing of raw cotton materials to the manufacturing of final textile products. Company A exhibits a diverse range of production capacities and a significant workforce across various departments within the facility. Company A encompasses a knitting-tricot plant, which produces 150,000 tricots and the necessary fabric for approximately 2 million polo t-shirts annually. This plant is staffed by 45 employees who maintain the production process. In addition to the aforementioned departments, Company A also operates a ready-made garment facility. With an annual production capacity of 2 million units, this facility employs 445 individuals to ensure the manufacturing of finished garments.

2.1. Definition and Steps of Simulation

Simulation is a method that involves “logical and mathematical relationships and allows experimentation outside the system using a computer or other tools to understand the structure and behaviors of a real system” [14]. The simulation of a system involves creating a model that represents the system. This model allows for the examination of processes that are costly or infeasible to carry out in the actual system. The effects of these processes on the model are subjected to meticulous investigation, wherein the discernible attributes and responses of the real system or its constituent subsystems can be prognosticated through the comprehensive examination carried out [15]. Simulation provides an opportunity to test the possible outcomes of decisions, rather than leaving them to chance. This methodology confers distinct advantages over the traditional trial and error approach, which is often associated with time-intensive, costly, and occasionally adverse outcomes, as expounded by Chung [16] in his study of 2004.

The simulation study should start with defining the problem. Accurate problem definition is crucial for ensuring the accuracy of subsequent steps (Figure 1). After defining the problem, the objectives to be addressed by the simulation study should be determined.

To create a simulation model that ranges from simple to complex, it is important to ensure that it is a summary of the real system. Once the model has been established, the necessary data for running the simulation should be identified, and the collected data should be organized in the required format.

Using the collected data, the computer program codes of the simulation model should be written and the program run. It is important to verify the accuracy of the program's operation for ensuring the accuracy of the results obtained. To check the program's accuracy, the debug menu and the tracking of entities in the animation are used to evaluate the accuracy of the program codes.

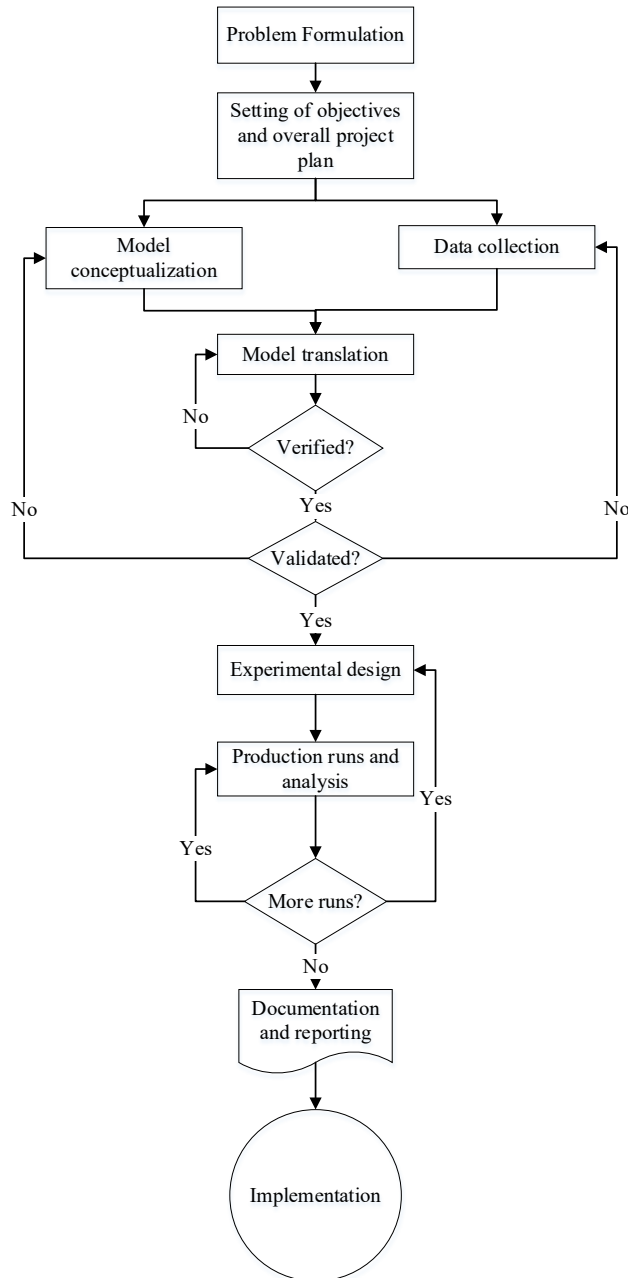


Fig. 1. Steps in a simulation study [16]

The validity of the simulation model is represented by whether the results obtained from the functioning program demonstrate those of the real system. The results obtained from the simulation program should be compared with those from the real system, and a decision should be made about the validity of the model.

Subsequently, the validated system ought to be subjected to execution for all conceivable solutions to address the problem at hand. The ensuing outcomes warrant comprehensive evaluation,

thereby enabling the assessment of potential exigencies for additional experiments. Upon attaining satisfactory results, the pertinent data should be duly preserved, and a comprehensive report ought to be meticulously prepared, as articulated by Banks [17] in his seminal work published in 1998.

There are many simulation programs available for the simulation of production systems. ARENA 14 simulation program is one such and was used in this study.

3. Research Findings and Analysis

A study was undertaken to determine the comparative efficiency of work in the shirt assembly line section, where workers perform the same operations with and without thread cleaning on the same production line.

In the beginning, flow diagrams were created to scrutinize the structure of the system. A detailed time study was then conducted, followed by an examination of whether the distributions obtained from the “input analyzer” program in Arena were suitable. Finally, a model was constructed and run.

3.1. Workflow of the Shirt Assembly Line

Section by section, the workflow of the shirt assembly line was defined to identify the problems and see the stages through which the products pass. The workflow of the assembly line with and without thread cleaning is depicted in Figure 2.

3.2. Transferring Operation Times to Simulation

To analyze the shirt production line’s assembly section, a detailed time study was conducted along the line. The observations, time studies, and records were examined to obtain the following information:

- Operation name,
- Machine number,
- Operator number,
- Route (operation sequence),
- Operation time,

It is known that several factors affect the operation time in a production line, such as the operator’s psychological state, aptitude for the job, fabric and material characteristics, environmental conditions, and the quality level of the job. Therefore, at least 50 measurements were taken for each job to capture the actual operation time. The time required for occurrences such as thread breakage, needle change, and bobbin change were included in the measured times.

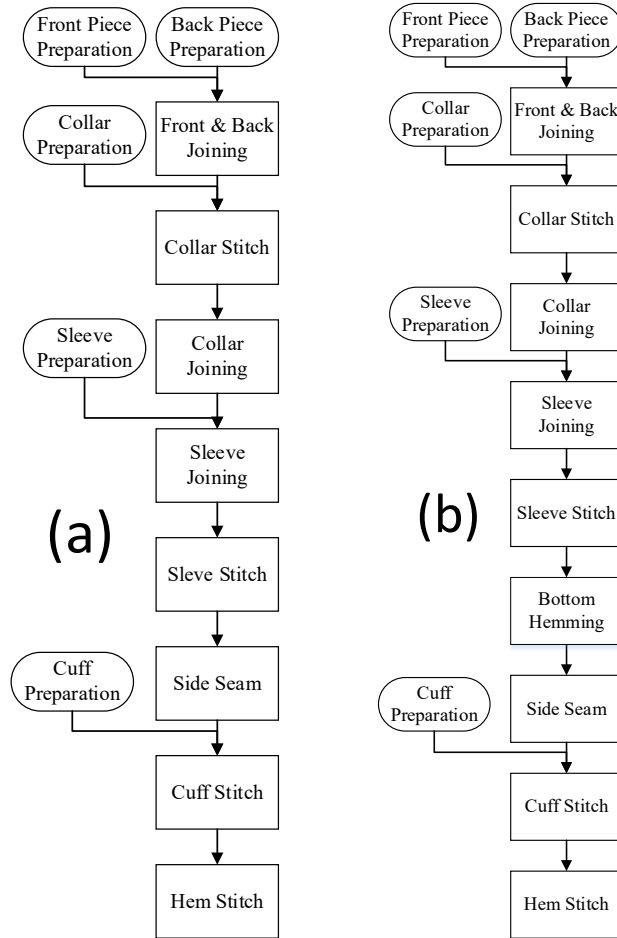


Fig 2. Workflow (a) with thread cleaning operation and (b) without thread cleaning operation

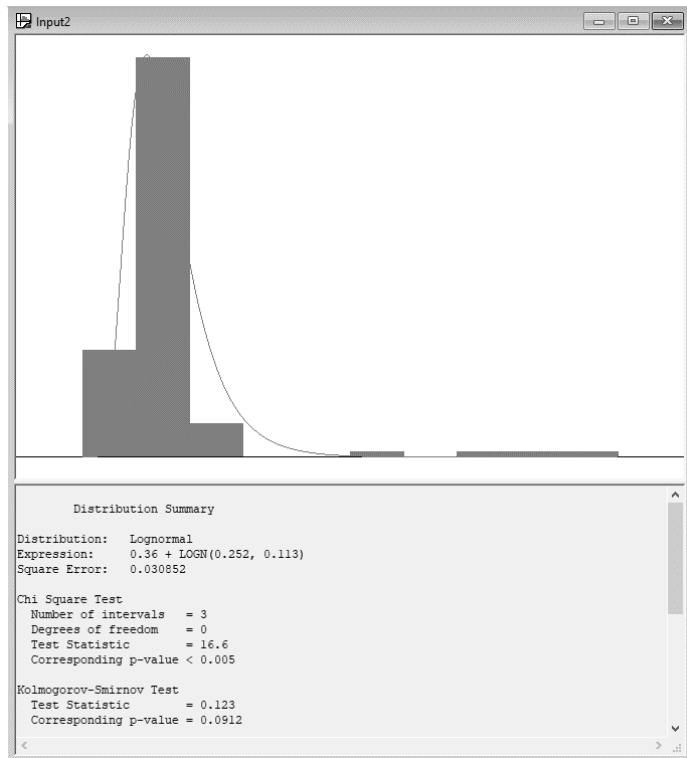


Fig. 3. Theoretical distribution

3.3. Compliance with Theoretical Distributions

To determine which distribution each set of data corresponds to, the “input analyzer” program was used. As shown in Figure 3, the program assigns a new time for each new piece to the relevant operation using the statistical distribution defined by the program for each operation. The best distribution for the front and back joining operation was found to be $0.36 + \text{LOGN}(0.252, 0.113)$.

The statistical distributions for the operations with and without thread cleaning are provided in Table 1 and Table 2 for all other operations.

3.4. Model Building

To build the model, the ARENA14 simulation program was utilized, and all operations of the relevant production were incorporated into the program (Figure 4).

As parts enter the system from the preparation department in real life, there is no feeding problem. Therefore, all parts that can be produced for both models are entered into the system collectively at the beginning of the day. Although this creates a significant queue in the first operation, “front-back joining,” the necessary precautions have been taken with the line balancing algorithm mentioned in the results section.

The only difference between the thread-cleaning and non-cleaning production lines is the additional “hemming” operation in the non-cleaning method, and separate models were developed for both production types. The progression of the parts in the model and the queue sizes formed were observed to verify the accuracy of the model.

3.5. Model Validation

To test the validity of the models, each production line model was run 50 times in the Arena program and compared with data from the actual production

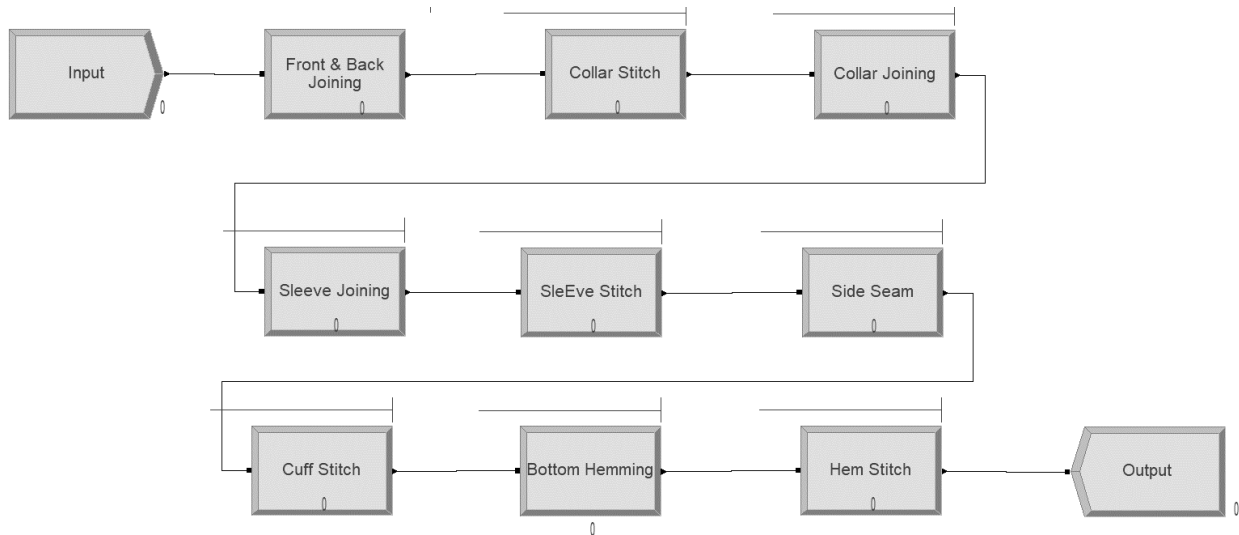


Fig. 4. ARENA 14 simulation programme model

Operation Title	Distribution
Front & Back Joining	0.34 + ERLA(0.0277, 11)
Collar Stitch	0.34 + 0.27 * BETA(1.97, 2.26)
Collar Joining	0.69 + 0.75 * BETA(3.13, 3.93)
Sleeve Joining	0.48 + ERLA(0.0917, 4)
Sleeve Stitch	0.34 + 0.57 * BETA(3.5, 3.97)
Side Seam	0.57 + ERLA(0.0746, 6)
Cuff Stitch	0.4 + LOGN(0.493, 0.172)
Hem Stitch	0.41 + WEIB(0.835, 2.41)

Table 1. Statistical distribution of operations in the system with thread cleaning

Operation Title	Distribution
Front & Back Joining	0.36 + LOGN(0.252, 0.113)
Collar Stitch	0.34 + 0.27 * BETA(1.97, 2.26)
Collar Joining	0.32 + LOGN(0.703, 0.25)
Sleeve Joining	0.3 + 2.02 * BETA(6.12, 17.1)
Sleeve Stitch	0.34 + 0.57 * BETA(3.5, 3.97)
Side Seam	0.39 + LOGN(0.547, 0.195)
Cuff Stitch	0.4 + LOGN(0.493, 0.172)
Hem Stitch	0.21 + LOGN(0.543, 0.172)
Bottom Hemming	0.29 + 0.53 * BETA(5.28, 7.93)

Table 2. Statistical distribution of operations in the system without thread cleaning

line using the Minitab 17 program. The findings obtained by running the models for 540 minutes per day and the statistical comparison of the daily production count confirmed the validity of both models (Figure 5, Figure 6).

4. Results & Conclusions

Once the model validity has been established, users can make changes to the model as desired. This is because the

model's validity proves that the studies on operations and the model design have been carried out without errors. From this point on, the most suitable line balancing method for both the thread cleaning and non-thread cleaning models are investigated in order to improve their efficiency. The algorithm for this balancing, which will move in conjunction with the simulation, is given below (Figure 7). The algorithm, which aims to increase worker efficiency, changing with the smallest possible steps while improving efficiency, is called

the "turtle algorithm." As a result, the algorithm is designed to keep the possible queue lengths at a minimum during each iteration.

The purpose of the study presented above was to examine the changes in efficiency and production per person by reducing the current number of personnel by one in the operations on the assembly line shown. In the findings obtained, the production per person was taken as the basis for efficiency calculation. An important part of the algorithm used for this purpose is the calculation of the new efficiency values that will occur when the number of operators in the operation is reduced. This is done using the Formula (1):

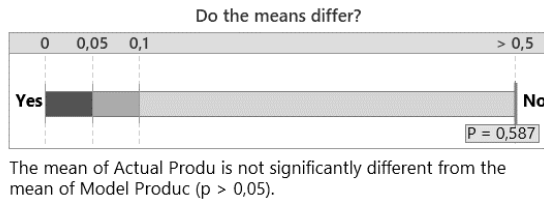
$$\text{New Efficiency} = \frac{\text{Current Operator Count}}{\text{Operator count} - 1} * \text{Current Operator Efficiency} \quad (1)$$

The algorithm was applied to models with and without thread cleaning. In the without thread cleaning model, the most efficient result was obtained with 8 iterations (Table 3-a). Accordingly, it was observed that a total of 1764 units of production can be achieved daily with 26 personnel. The operation with the smallest difference between the current and new efficiency values is marked in grey colour. In Table 3-b, iterations of the thread cleaning model are given.

The study results indicate that the production line, incorporating the

2-Sample t Test for the Mean of Actual Produ and Model Produ

Summary Report

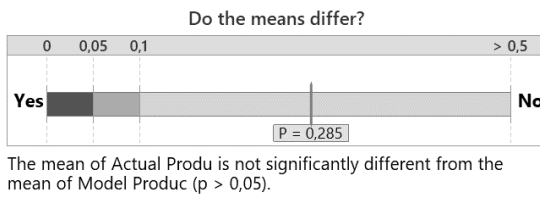


Statistics	Individual Samples	
	Actual Produ	Model Produ
Sample size	50	50
Mean	1772,4	1762,9
95% CI	(1737; 1807)	(1760,7; 1765,0)
Standard deviation	123,30	7,4286

Fig. 5. Validity of the model without thread cleaning

2-Sample t Test for the Mean of Actual Produ and Model Produ

Summary Report



Statistics	Individual Samples	
	Actual Produ	Model Produ
Sample size	8	50
Mean	1593,9	1600,4
95% CI	(1581; 1607)	(1598,8; 1601,9)
Standard deviation	15,752	5,3866

Fig. 6. Validity of the model with thread cleaning

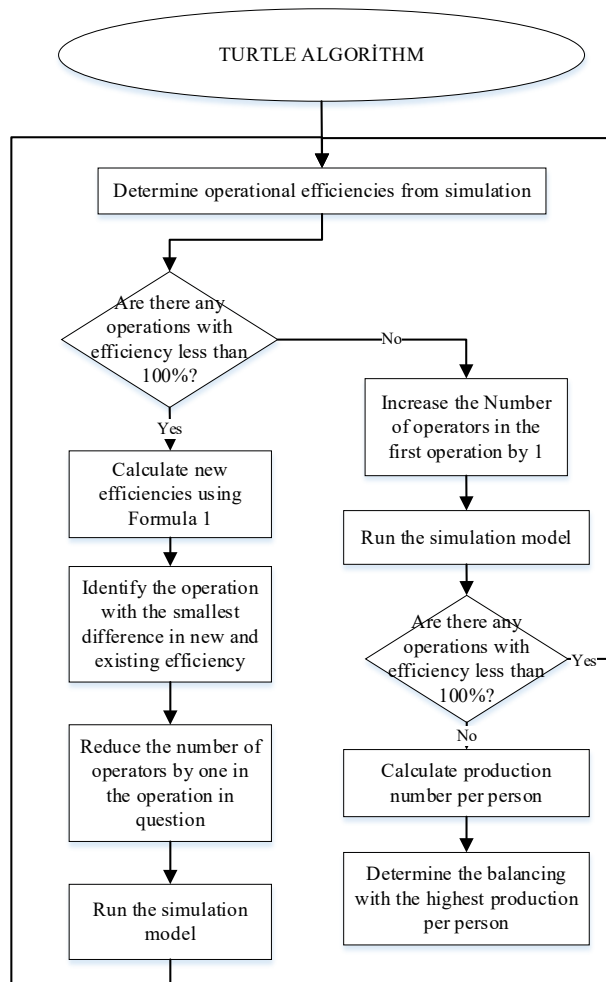


Fig. 7. Turtle algorithm

thread cleaning process, achieved a per-person production rate of 70.2 pieces with a workforce of 25. In contrast, the production model previously used, which lacked the thread cleaning process, is projected to yield a per-person production rate of 67.8 pieces with a workforce of 26. The difference in production rates is primarily attributed to the elimination of the “thread cleaning” operation.

Simulation models in textile garment manufacturing provide numerous advantages from scientific and academic perspectives. Firstly, they offer cost-effectiveness by allowing researchers to test various scenarios without physical prototypes, saving resources. Secondly, they enhance time efficiency by enabling rapid iteration and optimization of parameters, accelerating research and development. Additionally, simulation models facilitate flexibility and reproducibility, enabling researchers to study different aspects of the manufacturing process and validate findings more reliably.

Moreover, these models contribute to risk reduction by assessing the potential impact of new techniques without disrupting actual production. They support in-

(a)

Operation	1. Iteration			2. Iteration			3. Iteration		
	NO	COE	NE	NO	COE	NE	NO	COE	NE
Front & Back Joining	2	1	2,00	2	1	2,00	2	1	2,00
Collar Stitch	2	0,76	1,52	2	0,76	1,52	2	0,76	1,52
Collar Joining	4	0,84	1,12	4	0,83	1,11	4	0,84	1,12
Sleeve Joining	5	0,54	0,68	4	0,69	0,92	4	0,68	0,91
Sleeve Stitch	4	0,49	0,65	4	0,5	0,67	4	0,5	0,67
Side Seam	4	0,76	1,01	4	0,77	1,03	4	0,77	1,03
Cuff Stitch	5	0,58	0,73	5	0,59	0,74	4	0,73	0,97
Hem Stitch	4	0,61	0,81	4	0,62	0,83	4	0,62	0,83
Bottom Hemming	2	0,81	1,62	2	0,82	1,64	2	0,82	1,64
Total	32			31			30		
Daily Production	1764			1765			1765		
Production per Person	55,13			56,94			58,83		
Operation	4. Iteration			5. Iteration			6. Iteration		
	NO	COE	NE	NO	COE	NE	NO	COE	NE
Front & Back Joining	2	1	2,00	2	1	2,00	2	1	2,00
Collar Stitch	2	0,76	1,52	2	0,76	1,52	2	0,77	1,54
Collar Joining	4	0,84	1,12	4	0,84	1,12	4	0,85	1,13
Sleeve Joining	4	0,68	0,91	4	0,68	0,91	3	0,92	1,38
Sleeve Stitch	3	0,66	0,99	3	0,66	0,99	3	0,66	0,99
Side Seam	4	0,76	1,01	4	0,77	1,03	4	0,77	1,03
Cuff Stitch	4	0,73	0,97	4	0,73	0,97	4	0,73	0,97
Hem Stitch	4	0,62	0,83	3	0,82	1,23	3	0,83	1,25
Bottom Hemming	2	0,82	1,64	2	0,82	1,64	2	0,82	1,64
Total	29			28			27		
Daily Production	1766			1764			1764		
Production per Person	60,90			63,00			65,33		
Operation	7. Iteration			8. Iteration					
	NO	COE	NE	NO	COE	NE			
Front & Back Joining	2	1	2,00	3	0,73	1,095			
Collar Stitch	2	0,84	1,68	2	0,84	1,680			
Collar Joining	4	0,76	1,01	4	0,92	1,227			
Sleeve Joining	3	0,9	1,35	3	0,99	1,485			
Sleeve Stitch	3	0,67	1,01	3	0,72	1,080			
Side Seam	4	0,77	1,03	4	0,84	1,120			
Cuff Stitch	3	0,98	1,47	3	1	1,500			
Hem Stitch	3	0,83	1,25	3	0,84	1,260			
Bottom Hemming	2	0,82	1,64	2	0,84	1,680			
Total	26			27					
Daily Production	1764			1814					
Production per Person	67,85			67,19					

NO: Number of Operators

COE: Current Operator Efficiency

NE: New Efficiency

(b)

Operation	1. Iteration			2. Iteration		
	NO	COE	NE	NO	COE	NE
Front & Back Joining	2	1	2,00	2	1	2,00
Collar Stitch	2	0,69	1,38	2	0,69	1,40
Collar Joining	4	0,89	1,19	4	0,75	1,00
Sleeve Joining	4	0,62	0,83	3	0,84	1,30
Sleeve Stitch	2	0,89	1,78	2	0,9	1,80
Side Seam	4	0,75	1,00	4	0,75	1,00
Cuff Stitch	4	0,65	0,87	4	0,66	0,90
Hem Stitch	4	0,84	1,12	4	0,85	1,10
Total	26			25		
Daily Production	1581,0			1581,0		
Production per Person	60,8			63,2		
Operation	3. Iteration			4. Iteration		
	NO	COE	NE	NO	COE	NE
Front & Back Joining	2	1	2,00	3	0,83	1,20
Collar Stitch	2	0,69	1,40	2	0,86	1,70
Collar Joining	4	0,75	1,00	4	0,95	1,30
Sleeve Joining	3	0,83	1,20	3	1	1,50
Sleeve Stitch	2	0,89	1,80	2	0,99	2,00
Side Seam	4	0,75	1,00	4	0,83	1,10
Cuff Stitch	3	0,87	1,30	3	0,97	1,50
Hem Stitch	4	0,84	1,10	4	0,94	1,30
Total	24			25		
Daily Production	1580,0			1755,0		
Production per Person	65,8			70,2		

NO: Number of Operators

COE: Current Operator Efficiency

NE: New Efficiency

Table 3. Iterations of (a) thread cleaning-free model, (b) thread cleaning model

depth analysis by capturing intricate details of the process, leading to deeper insights and optimization possibilities. Furthermore, simulation models help researchers optimize parameters like production speed, resource allocation, and machine utilization, resulting in improved efficiency and cost savings.

Another benefit is design validation, as simulation models can identify potential issues early on and reduce the risk of

design flaws. They also aid in resource management, allowing researchers to analyse resource utilization, energy consumption, and waste generation, leading to more sustainable practices.

In the realm of education, simulation models are valuable tools for training students in textile engineering and manufacturing, providing hands-on experience and a deeper understanding of complex processes. Moreover, as

industries move towards Industry 4.0 and digitalization, simulation models play a crucial role in integrating different components of the manufacturing process, creating a more efficient and interconnected production environment.

Lastly, academics can use simulation models for benchmarking and comparative studies, helping to identify best practices and areas for improvement in textile garment manufacturing. These

powerful tools empower researchers, advance the field, and enhance industrial practices. It is recommended to expand this study to include preparation and quality departments in a more comprehensive manner, given the limited time frame of the current investigation.

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