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Enhancing Textile Finishing Processes: A Comprehensive Framework Implementation and Impact Analysis

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Abstract

This study presents a comprehensive framework specifically designed to optimize the finishing process within textile factories. Unlike previous research that often overlooks or provides generic solutions to the finishing stage, our proposed framework tackles the specific challenges of this critical stage, including identifying and addressing bottlenecks, standardizing work methods, optimizing facility layout, and incorporating simulation modeling to evaluate potential improvements. The proposed framework utilizes various engineering methods, including work methods, statistical testing, standard operating procedures (SOPs), systemic layout planning (SLP), and simulation modeling. The proposed framework generated several solution scenarios, with the winning scenario involving standardization of work methods, optimization of the layout, and the introduction of a new packaging station. This resulted in a significant increase in production efficiency, with a 17.7% improvement in production efficiency, a 31% reduction in manufacturing lead time, and a 42.8% decrease in work-in-progress in the premade knitting station. Additionally, queue times in the packaging and gluing stations were reduced by 47.4% and 38.9%, respectively.

Keywords
Textile Industry, Systematic Layout Planning (SLP), Simulation, One Way- ANOVA Analysis.

1. Introduction
Throughout history, the textile industry has been a significant driver of economic progress among nations, particularly after the industrial revolution. In the past, raw silk from China and wool from Europe, including England, were major components of international trade, with shifts in production occurring over time (Singleton, 1997). Today, the global textile market is valued at around $1 billion and accounts for 7% of global exports, with leading producers such as China, India, Pakistan, North Korea, Indonesia, and Thailand. China dominates the industry, while India's textile sector accounts for 35% of its exports (Desore & Narula, 2018; Peng et al., 2015; Raichurkar & Ramachandran, 2015).

According to de Mattos et al. (2022), the global textile industry employs 91 million workers, highlighting the importance of addressing various factors such as production methods, worker performance, standardization, and work environment. In the context of textile production, finishing processes play a crucial role in determining the quality of the final product, including its appearance, glossiness, texture, use, and cleanliness (Choudhury, 2017). For instance, a comparison of two companies revealed that the absence of a Computer-Aided Design (CAD) system and inefficient planning resulted in 12% more waste for company A, underscoring the consequences of relying on manual labor (Risteski & Srebrenkoska, 2020). Therefore, efficient waste management is essential for organizations to maintain lean operations. According to Taiichi Ohno, waste is any activity or process that does not add value to a product or service. Identifying and addressing eight sources of waste, including overproduction, is crucial for improvement. Applying lean principles in the waste management industry can significantly enhance resource utilization, waste reduction, and operational efficiency. Lean principles involve recognizing value flow and assessing consumer-centric product values, prioritizing activities that add value, and minimizing non-value-added operations. Toyota pioneered lean production in the 1950s to compete with US automakers by eliminating non-value-added operations. Lean tools such as value stream mapping, cellular manufacturing, Kanban, 5S, and kaizen were initially used by Toyota and later adapted for various manufacturing sectors. The core goals of lean principles include waste reduction, cost savings, improved quality, productivity enhancement, and job satisfaction.Standardized work methods, motion studies, and time studies are essential when introducing manual processes to maximize efficiency. Implementing lean principles has led to significant improvements in productivity, as demonstrated by a 36% increase in productivity reported by Rehman et al. (2019). Palit et al. (2013) also found a 28% reduction in cycle time in labeling and a 25.83% saving in packaging. Korkmaz et al. (2020) achieved a 75% labor cost saving and a 47% reduction in loading and packaging times through job analysis and time management practices.

The evaluation of efficiency in various industries requires the implementation of practical methods. For instance, Payzievna (2020) defines efficiency as the optimal use of resources to meet human needs. Baptista et al. (2021) enhanced the productivity of a Portuguese textile department by implementing 5S, Single-Minute Exchange of Die SMED, and improved communication. Leunig (2003) improved the productivity of carpet factory workers by introducing flexibility and the one-piece rate principle. Pérez-Gosende et al. (2021) highlighted the significance of Facility Layout Planning (FLP) in optimizing systems. Techniques such as Value Stream Mapping (VSM), simulations (Kelton et al., 2015), and virtual reality (Rodrigues & Queiroz, 2020) can also be employed to enhance efficiency. For example, Silva et al. (2021) used a simulation to improve the efficiency of a textile factory. The Define-Measure-Analyze- Improve-Control (DMAIC) framework, VSM, and SLP were also applied to enhance the carpeting process, resulting in a significant improvement in sigma from 2.297 to 2.886, and a reduction in DPMO from 21,615 to 3,905. These improvements can reinforce market competitiveness, particularly in the textile sector where quantity often takes precedence over quality.

Motion and time studies are essential tools to evaluate work, and improve worker performance and efficiency, also assisting with predicting outputs (Khatkar & Chahal, 2022). Time studies involve task division and analysis, and include all related processes (Gilbreth, 1911). Such studies have been conducted multiple times under different conditions for optimal time determination (Thompson, 1914). They include motion studies to determine the optimal motion required for a task. Techniques used include stopwatch, work sampling, predetermined motion time system (PMTS), and the Maynard operation sequence technique (MOST) (Puvanasvaran et al., 2013). Utilizing the MOST application reportedly improved overall equipment effectiveness (OEE) from 84.32% to 88.94% in a study by Puvanasvaran et al. (2013). In addition, Al-Saleh (2011) was able to reduce car inspection time from 126 to 64 seconds, potentially increasing the inspection rate by 270%.

In the past, cost reduction was the primary focus. However, today facility management emphasizes productivity improvement (Redlein, 2004). Facility Layout Planning (FLP) is vital for aligning production factors with strategic objectives, thereby enhancing efficiency and productivity (Pérez-Gosende et al., 2021). Recently, Lista et al. (2021) developed a plant layout based on lean manufacturing principles, optimizing materials flow and culture-sensitive design. Their results yielded efficiency gains and profitability.

The remainder of this paper is constructed as follows. Section 1.1 provides a brief description of the problem statement. Section 2 provides details concerning the proposed methodology. The results and discussion are summarized in section 3, and finally, conclusions are presented in section 4.

1.1 Problem Statement

The paper focuses on a carpet manufacturing facility in Yanbu, Saudi Arabia, that produces synthetic carpets through a series of processes, including back-sizing, edging, pre-knitting, and packaging. The company has identified inefficiencies in its finishing processes, which can lead to decreased productivity and overall performance. To address these issues, the study aims to improve the factory's efficiency by utilizing engineering tools to optimize several key performance indicators, including production, wait-time, and work-in-process. It is expected that the implementation of the proposed framework will enhance worker performance, reduce non-value-added motions, improve workplace organization, and increase the efficiency of manual work.

2. Methodology and Results

Figure 1 provides details of existing production flow processes in the finishing area. The woven carpet is first taken from a temporary warehouse before entering the automatic back-sizing process. Workers cut it into three vertical sections and then place it on a pallet for transport. The edging machine then processes one vertical section to produce prayer rugs. The rugs are then inspected for quality, and if required, manually sewn. For premade tassel fringe products, workers manually knit at 2 stations. The gluing process to improve each carpet's aesthetic involves manual cutting and gluing. In the final step, the prayer rugs are cleaned, inspected for quality, and individually packaged before transportation to the warehouse. Figure 2 shows the value stream map that displays the processes, the time available for each process, the cycle time, and the total lead time. In addition, it displays the number of shifts, along with the number of machines/workers. It visualizes both the value-added and the non-value-added time in the finishing process. In total, 81.77% of the lead time is wasted (see Figure 2).

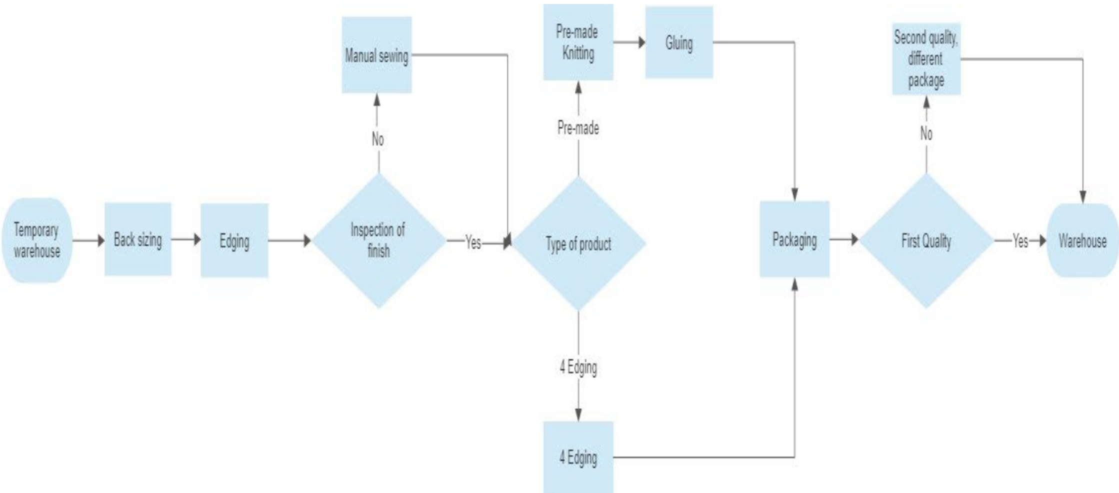


Figure 1. Flow Process Chart

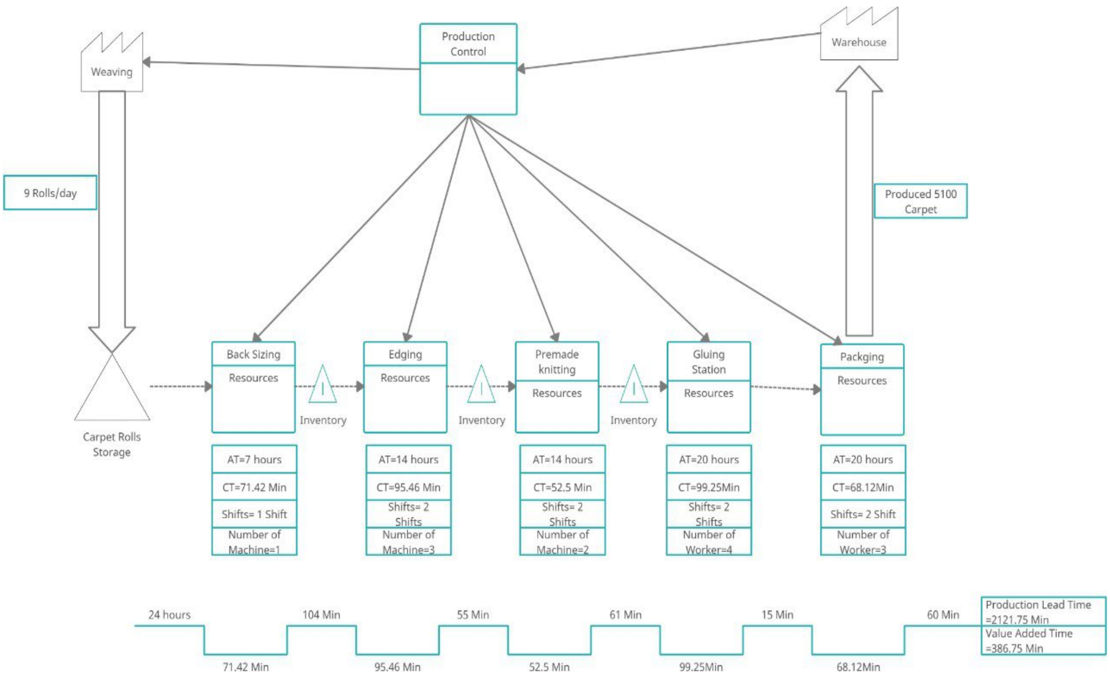


Figure 2. Value Stream Map

2.1 Systematic layout planning (SLP)

The commonly employed SLP approach includes three phases (analyze, search, and select), and is used to enhance factory layout, and handling system, thereby reducing unnecessary steps inside the facility.

2.1.1 Analyze Phase

Table 1 presents a complete summary of the necessary equipment. It contains important details, such as the equipment name, dimensions, corresponding figure from the layout file, and the required quantity. The "workstations" column lists the names of the workstations. The "Dimension" column provides information about the size of each piece of equipment, aiding in proper spatial planning and usage, helping with visual understanding and identification. Lastly, the "Quantity" column indicates the number of units needed for each equipment type in the project. Table 1 is a valuable resource, consolidating crucial information about equipment requirements, facilitating efficient planning, and ensuring smooth project execution.

Table 1. Spatial Requirements

Workstation	Dimension	Quantity
Back-Sizing	37m × 7m	1
Edging	14m × 3.5m	4
Knitting	11.5m × 3m	2
Gluing	7m × 5m	1
Rework	14m × 1m	1
Packaging	2.5m × 1.7m	3
Rolling Line	12m × 4m	1
Control	7m × 5m	1

Careful examination and assessment of various facility factors are conducted during the “analyze” phase to acquire essential insights. This includes evaluating the current layout, use of resources, and operational requirements. Current layout and a from/to chart were considered in this phase. Table 2 displays the from/to chart, representing the rectilinear distances between departments measured in meters. The main reason for using rectilinear distances is forklift travel. As shown in Figure 3, some aisles do not permit the passage of forklifts, and some stations that share a common function are located far away from each other. In addition, Table 3 shows the material flow between stations. A material flow table is a key input in Systematic Layout Planning (SLP), as it quantifies the frequency of movement between stations and highlights critical relationships. This information supports the development of efficient layouts by minimizing handling time and improving overall workflow.

Table 2. From/to chart (units are in meters)

From/to	Back-Sizing	Edging	Knitting	Gluing	Rework	Packaging	Rolling	Control
Back sizing	-	10.65	3.45	3.45	24.65	5.66	11.32	10.5
Edging	10.65	-	1	6.05	0	3.37	1.8	5.06
Knitting	3.45	1	-	1.06	31.88	3.76	11.8	1.06
Gluing	3.45	6.05	1.06	-	35.86	7.74	18.8	0
Rework/ Sewing	24.65	0	31.88	35.86	-	17.33	0	35.86
Packaging	5.66	3.37	3.76	7.74	17.33	-	7.55	10.97
Rolling	11.32	1.8	11.8	18.8	0	7.55	-	18.8
Control	10.5	5.06	1.06	0	35.86	10.97	18.8	-

Table 3. Material Flow chart, Shows the flow of carpets between workstations (Units = carpet).

From/to	Back-Sizing	Edging	Knitting	Gluing	Rework	Packaging	Rolling	Control
Back sizing	-	4194						
Edging		-	3114		1080			
Knitting			-	3114				
Gluing				-		3114		
Rework/Sewing					-	680	400	
Packaging						-		
Rolling							-	
Control								-

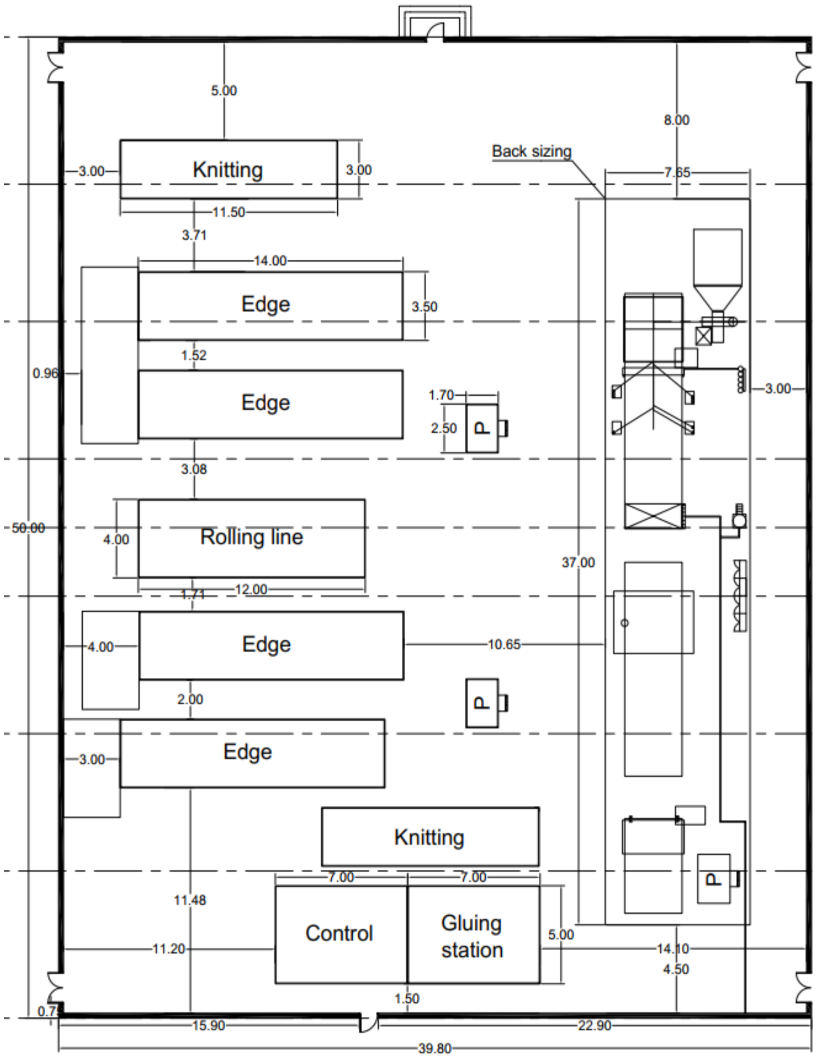


Figure 3. Current Layout of The Finishing Process

2.1.2 Search Phase

When performing facility planning, the search phase requires thorough exploration to find and assess potential options and solutions. This phase involves conducting research, collecting data, and analyzing information pertaining to design trends, industry standards, and best practices. During the search phase, it is crucial to assess the material handling system. In our case, there is one 3-ton forklift, one Walkie Stacker, and some workers who are responsible for moving the carpets manually by hand. To facilitate the manual movement of carpets, a cartwheel trolley designed to transport carpets is used. The capacity of the trolley is 1.8×0.9×1.0 m, which is equal to 1.62 cubic meters. It can accommodate up to 125 (i.e., 8 mm thick) carpets weighing 175 kg. Figure 4 shows the drawing sheet and the design of the cartwheel trolley.

Utilization of trolleys for carpet transportation is compared here to manual methods. If a worker's maximum capacity is 20 carpets weighing 1 kg each, 156 trips would be needed to transport 3,114 pieces of carpet (there are 3114 carpets transported between stations daily). In contrast, a trolley with a capacity of 125 carpets would necessitate only 25 trips. The time required to transport 3,114 carpet pieces is reduced to 48.5 minutes, compared to 115.44 minutes when manually handled. In addition to the significant time advantage, the use of the trolley is expected to reduce worker fatigue, contributing to overall efficiency.

In addition, different layouts were developed based on the objective of minimizing motion between operations, and the logical relationships between stations, considering several limitations. The area size is limited to 2000 m². Aisles are limited to use by workers and forklifts. To be accessed by a forklift an aisle must have a minimum width of 3.6 meters, and a one-meter aisle is required for workers. Another limitation is that the edging machines cannot be placed in the lower portion of the plant due to the HVAC system. Three different layouts can then be created accordingly, as shown in Figure 5.

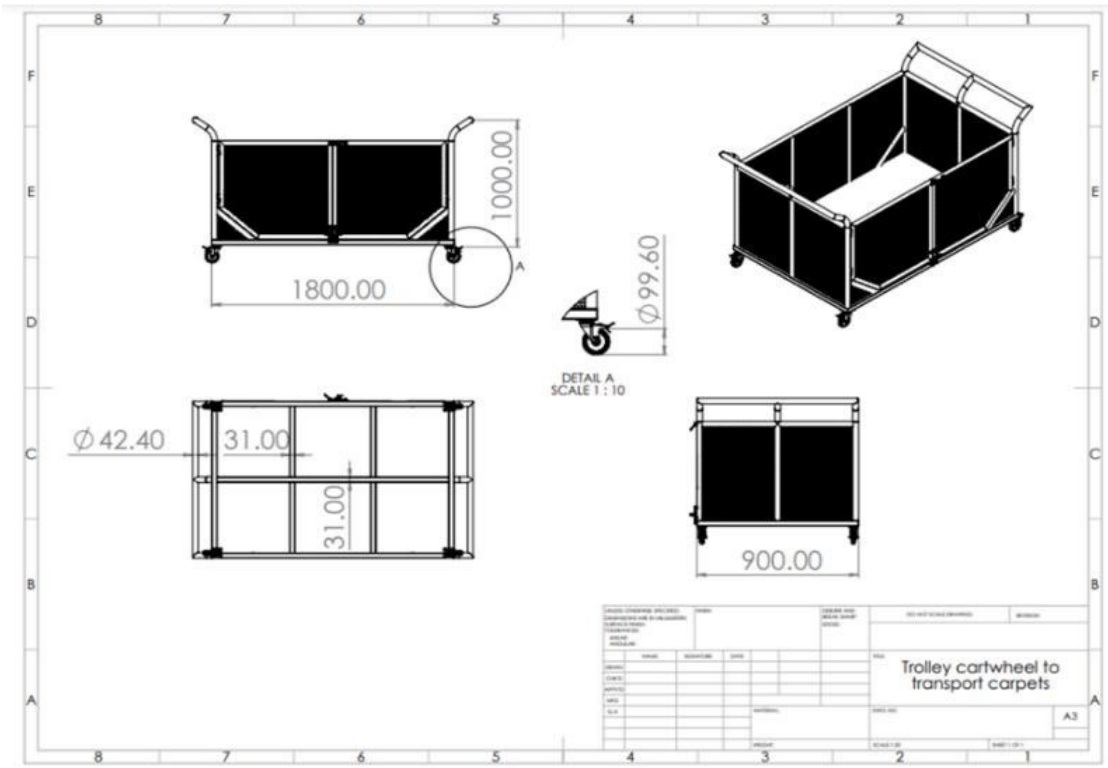


Figure 4. Drawing sheet of the designer cartwheels trolley design

2.1.3 Select Phase

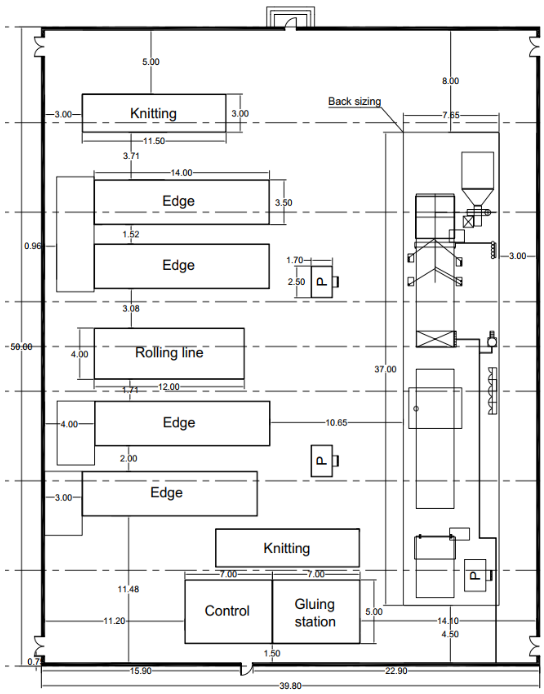
To compare the proposed layout alternatives, Aa distance-based objective is used. This is defined as follows:

$$min\, z = \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} c_{ij} d_{ij}$$

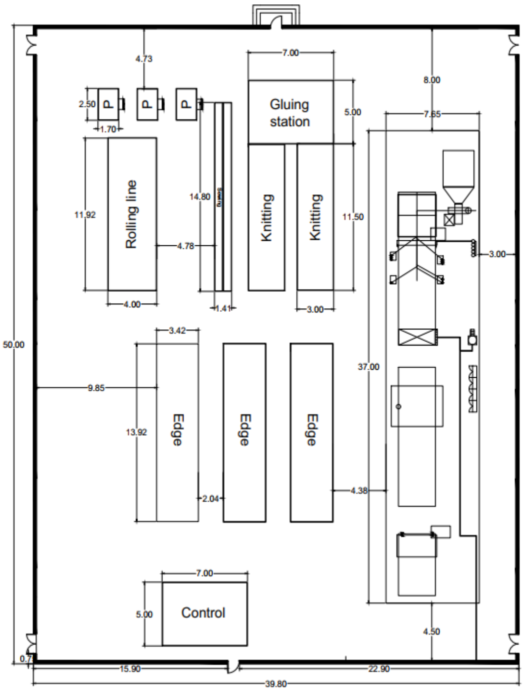
Where m represents the total number of departments, f_{ij} represents the flow from department i to j (measured as number of unit loads transported per unit of time), and c_{ij} represents the cost of transferring one unit load over a distance unit from department i to department j. The goal is to minimize the cost per unit of time associated with the movement between departments. In this case the cost is assumed to be one because there is no cost data available. Table 4 shows the total cost (TC) for each alternative, as well as the original layout. In terms of distance-based objectives, we determine layout (a) is the best choice for the plant layout. But it is also important to look for other factors such as layout flexibility, adaptability, operability, etc. Another important point to note here is that the utilization of space is very poor. Where the available space is 2000 m^2 the total area used is 934.94 m^2, meaning the current utilization is 46.75%.

Table 4. Total cost for each alternative

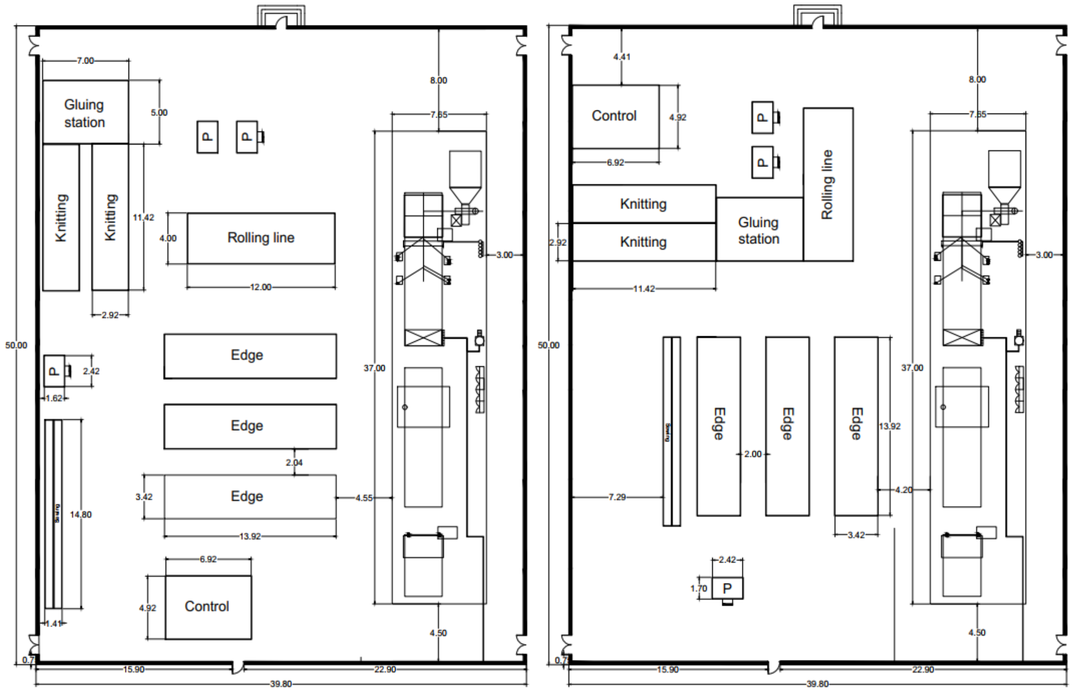
Layout Alternative	TC (SAR)
Original Layout	186,633
Alternative (a)	85,089
Alternative (b)	104,341
Alternative (c)	87,807



Current Layout



Alternative (a)



Alternative B Alternative C

Figure 5. Proposed Layouts

2.2 Experimental Design

Management claimed that the gluing process creates a bottleneck. Therefore, the process was monitored thoroughly. It was noted that it is unstandardized, as workers follow three different methods to complete the gluing task. Work methods were documented, and data collected for each process. The three different methods are: Side-by-Side, where all carpets are first cut on one side and then glued before switching to the other side; Carpet-by-Carpet, where each carpet is fully cut and glued on both sides before moving to the next; and Tool-by-Tool, where all carpets are first cut completely using scissors, then glued afterward using a glue gun.

The average tool-by-tool method takes 224 seconds to complete, while the side- by-side and carpet-by-carpet methods take 279 and 332 seconds, respectively. The next step was a One-Way ANOVA to determine how the three work methods affect completion time, to establish which method is most appropriate. The One-Way ANOVA investigated statistical differences among three or more groups and proved adequate to establish findings. Meanwhile, the p-value for the normality test of residual values was 0.87 which is greater than 0.05, suggesting the data follows a normal distribution pattern. Based on the results summarized in Table 5, it was concluded that the factor of the work method is significant. The P-value proved to be less than 0.05, and the tabular F value was equal to 3.3541, which is less than the calculated F-value (i.e., 27.87); thus, it supports rejection of the null hypothesis which claimed that the method of work is not affected by the completion time.

Table 5. One-Way ANOVA test results

Analysis of Variance ANOVA							
Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Method of Work	2	93476	55.33%	93476	46738	27.87	0.000
Error	45	75470	44.67%	75470	1677		
Total	47	168945	100%				

To investigate the potential problems affecting the gluing station further, a correlation analysis was conducted evaluating worker experience and average time taken to complete the task. The result was a weak and negative correlation emerged between experience and task completion time (inverse correlation). The value of the correlation coefficient was -0.290, while the P-value was 0.636, indicating the variables were not mutually affected, supporting the diagnosis of the problem as resulting from unstandardized work and potentially indicating another problem linked to worker performance. Finally, to ensure that the gluing process output is controlled, a SOP document has been prepared to guide the completion of the process.

2.3 Simulation

A simulation was used to compare the layouts proposed in section 2.1. A comprehensive and detailed simulation model was built referencing the process flow chart. The simulation model realized the statistical distributions, and the model was run accordingly. Subsequently, a data collection plan was developed including the data type, measurement unit, and how to collect data. After this, the input analyzer was used to gather details of the appropriate statistical distribution. Moreover, the input analyzer provides a chi-square test and K-S test to ascertain the reliability of the data. In our case, the collected data fulfilled the K-S test criteria successfully. The results are expressed as p-values, where p is the maximum type-I error probability value possible while still enabling the distribution to fit the data. In general, the better the fit, the higher the p-value. To calculate transfer time and distances between each station, time was defined based on the transporter speed. For example, for a forklift the assigned speed is 15 km/h.

One key factor in the simulation was the number of replications, which determined how many independent simulation experiments would be performed. In this case, the number of replications was assigned applying the trial-and-error method. The objective of this method was to achieve a balance between reasonable computational time and statistical accuracy. To determine whether the system delivers statistical accuracy, the half width of the system throughput of the pre-made product was observed, with a lower width indicating that it is a precise estimate.

Table 6 details the process of identifying the number of replicates. Multiple replicates were tested. The reasoning behind stopping at 282 replicates was that the jump from 232 to 282 resulted in an insignificant change in the width.

Table 6. Mean and Half Width of Pre-made system throughput.

Number of Replicates	Mean	Half Width
50	1838.46	40.38
150	1808.17	36.33
232	1797.58	30.98
282	1779.57	30.92

The system was further verified and validated to ensure the system's reliability. The entity tracking method was used, so the entity was tracked from its initial system entry as it passed through the different processes until it reached the end of the system. It was confirmed that the flow process was identical to that in the real system. Finally, we consulted experts to evaluate and test the model. To ensure the system is validated, multiple results were compared with the real system, such as production quantities of pre-made and 4edges products. Table 7 shows the comparison for real system output against the simulation model's output, revealing the simulation model satisfactorily reflects the real system.

Table 7. Production quantities in the Simulation Model compared to the Real System

Type of system	Pre-made Products	Four-edges Products
Real system	1760	425
Simulation Model	1780	393

Moreover, the mean absolute error (MAE) and root mean squared error (RMSE) were used for additional validation and verification, so the simulation model would represent the real system. On average, the simulation results deviated from the real system by approximately 26 carpets. Similarly, the RMSE value was designed to give an estimate of the typical size of the errors in the predictions, as summarized in Table 8. Finally, the management claim regarding gluing station bottleneck was detected in the Arena model as well, lending additional validity to the simulation model; the waiting time before the gluing station was 43.9 minutes, representing a total of 241 carpets.

Table 8. Analysis of MAE and RMSE

Product	MAE	RMSE
Pre-made	1.47%	1.51%
Four-edge	6.35%	6.52%

After constructing the model, verifying the reliability of the input data, adjusting the run setup, and establishing validity and verifying the system, Table 9 was built to summarize current performance. Nine performance indicators are listed for use as a baseline from which to evaluate system efficiency and identify areas for improvement focusing on finishing.

Table 9. Results of the base model in ARENA

Criteria	Base Model Results
Production (Carpets)	1,989
Average Waiting Time 4edges Products (Minutes)	27.2
Average Waiting Time Premade Products (Minutes)	82.93
Transfer Time 4edges Products (Seconds)	35.4
Transfer Time Premade Products (Seconds)	24.05
WIP 4edges (Carpets)	7.72
WIP Premade (Carpets)	331.08
Gluing Queue (Minutes)	43.93
Packaging Queue (Minutes)	19.69

3. Implementation and Discussion

Nine scenarios for enhancing textile finishing processes were proposed based on the methodology set out in section 2, the potential costs incurred, and discussions among factory managers. The proposed layouts in Figure 5 were considered in the first three scenarios; however, the cartwheel trolley presented in Figure 4 was adapted for all the scenarios to replace moving the carpets by hand. Scenarios 4-6 were like the layouts suggested in Figure 5, but the tool-by-tool work method was enforced at the gluing station. Finally, scenarios 7-9 were like scenarios 4-6, but a packaging station was added to avoid transferring the bottleneck from the gluing station to the packaging station.

Worth mentioning that the previous validation tests of the base model in section 2.3 confirm the validity of the alternative layouts generated in Arena, as the primary difference among the alternatives is the distance between stations. The route module employed is of the 'Transport' type, with data input differing in each alternative. The outputs for each scenario were compared to determine what would be optimal. The evaluation criteria included assigning weights to multiple criteria based on importance. The next step involved scoring the values within specific ranges, with scores ranging from five (indicating the best) to one (indicating the worst). Finally, each score was multiplied by its weight, and the sum of each scenario calculated. Then, the scenario scoring the highest value was selected as superior. The criteria were set based on the most impactful parameters in the model, to ensure the evaluation captures the key factors that contribute to determining the optimal scenario. Table 10 shows the parameters identified. The weight of each criterion was determined in accordance with information received in several meetings with management. Each has been given a value based on its importance and alignment with factory goals.

Table 10. The parameters and their weights.

Criteria	Weight
Total Production (Carpets Quantity)	20%
Average Waiting Time 4edges Products (Minutes)	3%
Average Waiting Time Premade Products (Minutes)	8%
Transfer Time 4edges Products (Seconds)	8%
Transfer Time Premade Products (Seconds)	8%
WIP Premade (Carpets)	10%
Gluing Queue (Minutes)	15%
Packaging Queue (Minutes)	13%
Cost (Based on Change, Training, and additional Resources)	15%

Table 12 presents the detailed scores for each scenario and the scenario rating out of 500 according to the adopted scoring method. The seventh scenario yielded an increase of 17.7% in the average quantity produced and a decrease of 31% in the average waiting time at the premade knitting Station, in addition to achieving a 42.8% reduction in the number of Work-In-Process WIP in the premade knitting Station. The fourth scenario achieved a decrease in the transfer rates in the 4-edges and premade knitting stations at 71.1% and 77.4%, respectively. The seventh scenario slightly outperformed the ninth and eighth scenarios in the queuing time at the gluing station and the packaging station, as it achieved a decrease of 47.4% and 38.9%, respectively. All the results mentioned are compared to the results of the base model, illustrated in Table 9.

The base model is the best model in terms of waiting time in the 4-edges station, as it is 20% less on average than the proposed scenarios. It is worth noting that the scenarios in which the work methodology was standardized (the fourth, fifth and sixth scenario) achieved a retroactive effect on the packaging station's queue time (an increase in the queue time by 88.8%, 95.05, and 86.8%, respectively). Table 11 summarizes the best scenario for each parameter.

Table 11. Best scenario of each parameter compared to the current state.

Criteria	Best Scenario	Results
Total Production (Carpets Qty.)	7	Increased 17.7%
Average Waiting Time 4edges Products (Minutes)	Base	Approximately 20% Better
Average Waiting Time Premade Products (Minutes)	7	Decreased 31%
Transfer Time 4edges Products (Seconds)	4	Decreased 71.1%
Transfer Time Premade Products (Seconds)	4	Decreased 77.4%
WIP Premade (Carpets)	7	Decreased 42.8%
Gluing Queue (Minutes)	7	Decreased 47.4%
Packaging Queue (Minutes)	7	Decreased 38.9%

Table 12. Comprehensive Evaluation Criteria

Alternatives / Criteria	Weight	Base	Score	S1	Score	S2	Score	S3	Score	S4	Score	S5	Score	S6	Score	S7	Score	S8	Score	S9	Score
Total Production (Qty.)	20	1,989	1	2029	1	2018	1	2015	1	2022	1	2026	1	2009	1	2341	5	2336	5	2338	5
Average Waiting Time 4edges Products (Mins.)	3	27.2	5	33.91	1	34.05	1	33.92	1	33.98	1	33.619	1	33.92	1	33.74	1	33.63	1	33.54	1
Average Waiting Time Premade Products (Mins.)	8	82.93	1	78.22	1	78.95	1	78.58	1	77.92	1	78.67	1	77.47	2	56.85	5	58.33	5	58.03	5
Transfer Time 4edges Products (Sec)	8	35.4	1	10.72	5	33.46	1	11.28	5	10.2	5	33.45	1	11.28	5	10.7	5	33.46	1	11.28	5
Transfer Time Premade Products (Sec)	8	24.05	1	5.89	5	11.54	4	17.004	2	5.4	5	11.5	4	16.95	2	5.988	5	11.4	4	16.89	2
WIP Premade (Qty.)	10	331.08	1	315.53	1	315.33	1	313.05	1	305.32	1	316.47	1	304.74	1	189.16	5	194.81	5	191.84	5
Gluing Queue (Mins.)	15	43.93	1	40.37	1	40.17	1	40.16	1	22.66	5	23.04	5	22.94	5	23.1	5	23.33	5	23.355	5

4. Conclusion

The objective of this study was to improve the efficiency of finishing processes within the textile industry. Several issues were identified in the selected case study as leading to inefficient resource utilization. The gluing process was identified as a bottleneck, prompting a One-Way ANOVA to analyze the three different work methods implemented. The results indicated a significant difference ($p < 0.05$) across the methods used, supporting rejection of the null hypothesis. A further correlation analysis between worker experience and task completion time revealed a weak and negative correlation (-0.290), suggesting potential issues arising from unstandardized work methods.

In addition, the current layout was evaluated thoroughly, revealing inefficiencies in the rectilinear distances between departments. A suboptimal utilization of space was also observed (46.75%). Three alternative layouts were then proposed and assessed based on a distance-based objective, with layout (a) showing a 54% improvement in terms of total distance, making it the preferred option. Furthermore, a detailed simulation model was constructed to compare alternative layouts and validate the findings. Layout (a) remained the most efficient, and the simulation results aligned closely with real system outputs, indicating the model's reliability. The simulation confirmed the gluing station to be the source of a bottleneck, with a waiting time of 43.9 minutes resulting in 241 pieces of carpet in the queue.

Nine different scenarios were modeled and evaluated through simulation, and the results suggested that a scenario; involving layout (a), standardized gluing methods, and the addition of a packaging station, is expected to boost production by 17.7%. In addition, it is expected to reduce waiting times before the premade knitting process as well as decreasing the queuing times at various stations, making it the best scenario overall.

The framework proposed in this study should assist engineers and decision makers in the textile industry to streamline processes through adopting the proposed framework, including a comprehensive problem definition, implementing structured data collection and validation processes, and leveraging engineering tools like SLP and DOE for in-depth analyses. This integrated framework also offers practical guidance for manufacturers seeking to enhance production processes, improve efficiency, and embrace continuous innovation.

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