Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AP07.20260161
Published: March 25, 2026

Improving the Cutting Process of AC Insulators Using Lean Manufacturing and Simulation Modeling

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Abstract

The integration of lean manufacturing principles with simulation modeling is widely recognized as an effective approach for evaluating, analyzing, and optimizing industrial processes. This study examines opportunities to reduce operational costs, processing time, material waste, and scrap rates associated with the manual cutting process of air-conditioning (AC) insulators at the Saudi Air Conditioning Manufacturing Company (SAMCO). Currently, five workers perform manual cutting operations based on the surface-area specifications of various AC units, using predefined measurement scales. This labor-intensive process results in an estimated annual labor cost of approximately USD 60,000 and requires extended working hours to meet the daily production targets. To address these challenges, the study employed a comprehensive methodology that incorporated time study analysis, simulation modeling, lean manufacturing tools, supplier selection and evaluation, and technical and economic feasibility assessments. Based on the analysis, the study proposes automating the cutting operation by acquiring two insulation-cutting machines. The results indicate significant operational improvements, including annual cost savings of approximately USD 36,000, a projected payback period of 10 months, and a118% return on investment within the first year. Overall, the proposed automation strategy enhances production efficiency, minimizes waste, and supports sustainable manufacturing practices.

Keywords
Lean Manufacturing, Simulation Modeling, Payback Period, and Air Conditioning Manufacturing

1. Introduction

Saudi Air Conditioning Manufacturing Company (SAMCO) is one of the leading manufacturers of air-conditioning and heating systems in Saudi Arabia. The company places strong emphasis on continuous improvement, energy efficiency, and environmentally responsible manufacturing practices. Despite these commitments, the insulation cutting process across its six production lines is still performed manually. Currently, five workers are assigned to this task, resulting in an estimated annual labor cost of approximately USD 60,000. This manual and labor-intensive process often leads to overtime work, longer production cycles, and higher levels of material waste, all of which increase overall operational costs.

The main objective of this study is to improve the insulation cutting process by reducing cutting time, minimizing material waste, and lowering operational expenses through automation. In addition to process improvement, the study also seeks to evaluate potential automated solutions and identify the most suitable supplier for insulation-cutting machines, considering both technical performance and long-term economic feasibility.

This paper is structured into four main sections. Section 1 presents the background and objectives of the study. Section 2 reviews relevant literature on lean manufacturing principles and simulation modeling techniques used for process optimization. Section 3 details the case study conducted at SAMCO, including the research methodology, analytical framework, and key results. Finally, Section 4 discusses the limitations of the study and provides recommendations for future research.

2. Lean Manufacturing and Simulation Modeling

The integration of lean manufacturing principles with simulation modeling offers a powerful framework for analyzing and improving industrial systems. Lean manufacturing primarily focuses on eliminating non-value-added activities, reducing different forms of waste, and improving overall process efficiency. In contrast, simulation modeling allows organizations to evaluate and test process improvements in a virtual environment before implementing changes in real operations. When combined, these approaches enable more informed decision-making and reduce the risks associated with operational modifications. Simulation modeling has long been recognized as an important technology that supports the transformation of organizations into lean, flexible, and responsive systems capable of adapting to changing operational demands (IMTR, 2000). However, earlier research identified challenges in applying simulation effectively, particularly the limited integration between simulation tools and lean practices. Diamond et al. (2002) noted that for simulation to deliver maximum value, it must become a routine component of lean system design and continuous improvement efforts rather than a stand-alone analytical tool.

Despite these challenges, many studies have highlighted simulation as a valuable complement to lean methodologies. Researchers have emphasized its ability to address certain limitations of lean tools, particularly when dealing with complex and dynamic systems (Abdulmalek & Rajgopal, 2007; Ferrin et al., 2005; Uriarte et al., 2016; Jia, 2010; Robinson et al., 2012). For example, simulation enables the modeling of system variability (Standridge & Marvel, 2006), provides insight into how changes in one part of a system influence overall performance (Marvel & Standridge, 2009; Standridge & Marvel, 2006), captures dynamic operational behavior, and allows proposed improvements to be evaluated before actual implementation (Uriarte et al., 2016). More recent research continues to reinforce the role of simulation as a strategic enabler of lean manufacturing and operational excellence (Michalec, 2025). At the same time, Fowler and Rose (2004) identified industry acceptance as a significant barrier to the broader adoption of simulation, suggesting that it should be positioned as a complementary decision-support tool rather than a replacement for lean methodologies. Although the benefits of integrating lean and simulation are widely acknowledged, several studies still highlight the need for more comprehensive frameworks that clearly demonstrate how simulation and other information technologies can be systematically aligned with lean practices (Pinho & Mendes, 2017; Uriarte et al., 2020).

3. Case Study

This case study was carried out at SAMCO and focuses on the insulation cutting process across 6 production lines at the company's manufacturing facility in Jeddah. While the overall production of air-conditioning units involves several interconnected operations, the scope of this research is limited to improving the manual insulation-cutting stage, which was identified as a critical bottleneck in the system.

To systematically address the identified challenges, a structured research methodology was developed (Figure 1). The study integrates multiple analytical tools and decision-support techniques, including time study analysis to evaluate process performance, lean manufacturing principles to identify waste and inefficiencies, simulation modeling to test improvement scenarios, and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to support supplier selection. In addition, comprehensive technical, economic, and feasibility analyses were conducted to ensure that the proposed solution is both operationally effective and financially viable.

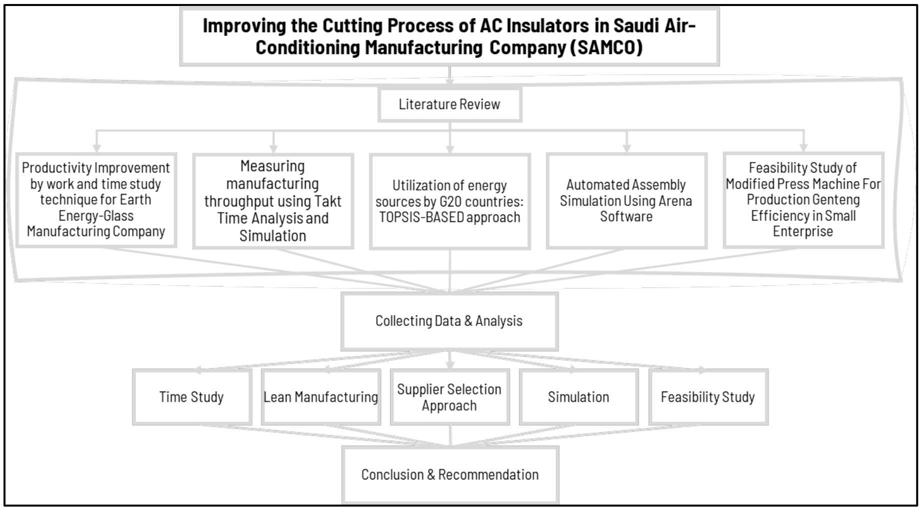

Figure 1. Integrated research framework for improving the AC insulator cutting process at SAMCO

3.1 Data collection:

Data were collected using a time study approach, a well-established method for systematically observing, measuring, and recording task durations under defined working conditions. The purpose of this technique is to determine the time required for an average worker to complete a task at a standard performance level. In this study, a detailed time study analysis was conducted to evaluate the duration of manual insulation-cutting operations across six production lines. The analysis covered the following product types: Model 42TP (Size 60), Model 50TJM (Small size), Model 50TJM (Large size), Model 50TCM (Size 14), Model 50ZPM and Model 40RUM.

For each product category, data was collected specifically for the insulation-cutting process. After compiling the recorded observations, the standard time required for insulation cutting was calculated for each product type. To improve measurement accuracy and reliability, the manual cutting process was broken down into clearly defined work elements. The time required for each element was recorded following standard time-study procedures. These recorded observations were then used to calculate both the normal time and the standard time using established time-study formulas, as presented below.:

$$\mathbf{T_n = T_{obs}\ (PR)}$$

T_n: Normal Time
T_{obs}: Observed Time
PR: Performance

$$\mathbf{T_{std} = T_n\ (1 + A_{PFD})}$$

T_{std}: Standard Time
A_{PFD}: Allowance PFA (Personal Needs, Fatigue, Unavoidable Delays)

For each assembly line, detailed time-study calculations were performed for every work element involved in the insulation-cutting operation. This included determining the observed time, applying a performance rating, accounting for allowance time, and subsequently calculating both the normal time and the standard time.

The collected and processed data are presented in tabular format for clarity. Table 1 presents a representative example from the 50TCM sub-assembly line, showing the step-by-step time study calculations. Table 2 provides a consolidated summary of insulation-cutting times for all product types across the six production lines.

Table 1.Detailed time study analysis of the insulation cutting process for the 50TCM sub-assembly

Sr. No.	**Work Element**	**Observed and normal duration**	**Performance Rating**	**Allowance Factor**	**Standard Time**
1.	Positioning the insulation roll onto the roller system	88	1	1.05	92.40
2.	Pulling the insulation sheet and positioning it on the worktable	36	1	1.05	37.80
3.	Measuring, trimming excess material, and cutting the first insulation piece	58	1	1.05	60.90
4.	Measuring, trimming excess material, and cutting the second insulation piece	106	1	1.05	111.30
5.	Measuring, trimming excess material, and cutting the third insulation piece	142	1	1.05	149.10
6.	Measuring, trimming excess material, and cutting the fourth insulation piece	108	1	1.05	113.40
7.	Measuring, trimming excess material, and cutting the fifth insulation piece	98	1	1.05	102.90
8.	Measuring, trimming excess material, and cutting the sixth insulation piece	152	1	1.05	159.60
9.	Measuring, trimming excess material, and cutting the seventh insulation piece	102	1	1.05	107.10
10.	Measuring and cutting insulation into linear strip form	50	1	1.05	52.50
11.	Measuring, trimming excess material, and cutting the eighth insulation piece	50	1	1.05	52.50
12.	Measuring, trimming excess material, and cutting the ninth insulation piece	142	1	1.05	149.10
13.	Measuring and cutting insulation into linear strip form (second occurrence)	68	1	1.05	71.40
14.	Measuring and cutting insulation into linear strip form (third occurrence)	72	1	1.05	75.60
15.	Measuring, trimming excess material, and cutting the tenth insulation piece	80	1	1.05	84.00
16.	Measuring and cutting insulation into linear strip form (fourth occurrence)	78	1	1.05	81.90
17.	Returning the insulation roll to its designated storage position	28	1	1.05	29.40
Lead Time (Total of standard time per min.)					**25.52**

Table 1**.** Comparative analysis of insulation cutting process times for all product lines

Product Name	**Cutting Process Time**	**Standard Time**	**Preparation and Measuring Time**
40RUM	16.19	19.65	3.46
42TP	3.52	7.92	4.40
50TJM Small	16.85	34.87	18.02
50TJM Large	12.75	20.73	7.98
50ZPM	5.47	13.76	8.29
50TCM	10.13	25.52	15.39

In this study, lean manufacturing principles were adopted as a guiding framework to calculate takt time and cycle time, and to evaluate overall process performance. These principles also supported the identification of root causes behind operational inefficiencies and provided insight into how well production output matches actual market demand. Takt time was determined based on customer demand, while the calculated standard time was treated as the lead time. The duration of the insulation-cutting operation was considered the cycle time, consistent with lean methodology. The computed values for each product category are presented in Table 3.

Table 2. Lean performance metrics (lead time, cycle time, and takt time) for insulation cutting operations

Model	**Process Lead Time (min)**	**Operational Cycle Time (min)**	**Required Takt Rate (min/unit)**
40RUM	19.65	16.19	158.98
42TP	7.92	3.52	6.98
50TJM Small	34.87	16.85	55.89
50TJM Large	20.73	12.75	37.73
50TCM	25.52	10.13	28.02
50ZPM	13.76	5.47	56.52

The results show that, for all product types, the cycle time is shorter than the corresponding takt time. This indicates that the insulation-cutting process currently has a production capacity that exceeds market demand. As a consequence, worker utilization remains low, and a significant amount of idle time is observed within the system.

Figure 2 presents a comparative analysis of lead time, cycle time, and takt time for each product category, highlighting the relationship between production capacity and demand within the insulation-cutting operation.

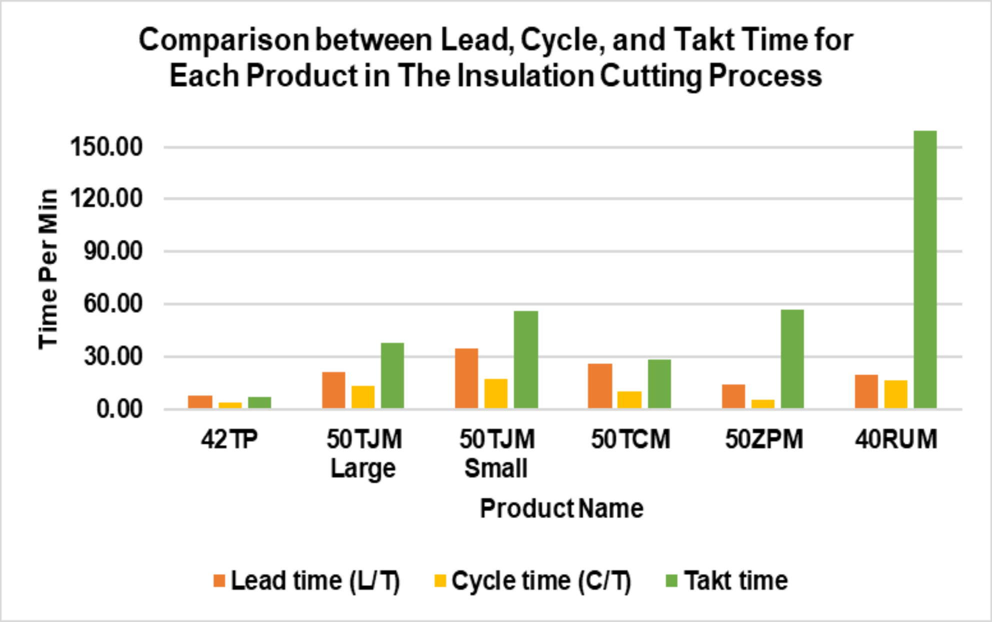

Figure 1. Product-wise comparison of lead, cycle, and takt times in the insulation cutting process

3.2 Simulation Model

3.2.1 Base Model

To evaluate the current performance of the insulation-cutting operation at SAMCO, a discrete-event simulation model was developed to replicate the existing system. This model represents the present operational setup and serves as the baseline for comparison with proposed improvement scenarios. The simulation was built using input data collected from all six sub-assembly production lines.

A representative portion of the input data from the 42TP sub-assembly line is provided in Table 4. The overall structure and flow of the existing insulation-cutting system, as modeled in the simulation environment, are illustrated in Figure 3.

Table 3. Input parameters for the 42TP sub-assembly line used in the simulation model

Parameter	Input	Unit	Data Source
Raw Material Transfer Time from Warehouse	2.50	Minutes	Assumption
Material Setup and Preparation Duration	4.40		Historical Data
Operational Processing Duration	3.52		
Workforce Size	1.00	-	
Material Waste Percentage	5%	-	Assumption
Idle Time Cost per Minute	0.38	Dollar	
Material Transfer Time from Sub-Assembly Line	0.50	Minutes	

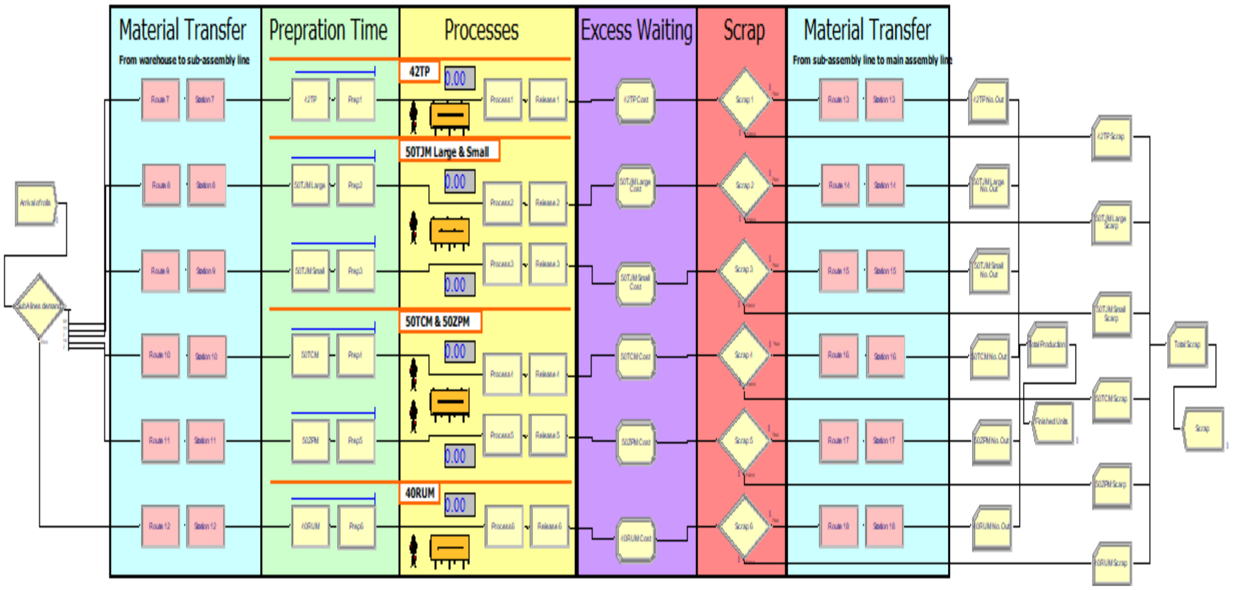

Figure 2. Baseline simulation model of the insulation cutting process across sub-assembly lines

The discrete-event simulation model evaluated system performance using several key performance indicators, including total output, average part waiting time, number of scrap units, overall operational cost, and average worker utilization. The results were computed for an 8-hour production shift, and the simulation was replicated five times to improve the reliability and stability of the findings. A 95% confidence level was applied to the analysis. The simulation results are summarized in Table 5.

Table 4. Discrete-event simulation outcomes for the existing insulation cutting operation

Assembly Line	**Mean Number of Units Processed**	**Average Waiting Time in Queue (min)**	**Mean Scrap Output (Units)**
40RUM	3.6 ± 1.88	1.09 ± 3.02	0.2 ± 0.56
42TP	55 ± 2.32	33.06 ± 23.64	3.2 ± 2.69
50TJM Small	6 ± 3.17	54.14 ± 36.74	0.8 ± 1.04
50TJM Large	8 ± 3.83	70.43 ± 34.97	0.4 ± 0.68
50TCM	12.6 ± 3.12	47.80 ± 34	1 ± 1.24
50ZPM	6 ± 4.65	46.87 ± 56.52	0 ± 0
Average Total	**91.2 ± 2.96**	**-**	**5.6 ± 1.88**

3.2.2 Proposed Model

The proposed simulation model recommends automating the insulation cutting operation by replacing the current manual process performed by five workers with two automated cutting machines. The selection of these machines was carried out using the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) multi-criteria decision-making method. The engineering team at SAMCO first defined the technical specifications required for the insulation material rollers, as detailed in Table 6. Subsequently, Table 7 presents a comparative evaluation of five potential suppliers based on nine predefined assessment criteria.

Table 5. Technical specifications of insulation material rollers for automated cutting

Serial #	**Product Category**	**Material Thickness (mm)**	**Material Width (mm)**	**Insulation Types**
1.	43TP	6.35-12	950-1220	Polyester Urethane
2.	CPU	6.36-12		
3.		10	1200	Closed-cell Ethylene foam (self-adhesive + aluminium face)
4.		13		
5.		20		
6.		13		

Table 6. Comparative evaluation of five potential suppliers based on nine selection criteria

Evaluation Criteria	**OmniTech**	**Ventech**	**Shandong Yuchen**	**Jinan AOL**	**Shandong Hongniu**
Equipment Purchase Cost ($)	10,100	18,200	11,000	15,250	13,200
Transportation Cost ($)	252	350	400	729	400
Delivery Duration (days)	18	50	5	15	30
Warranty Period (years)	2	3	3	3	2
Rated Power Capacity (W)	7,500	10,700	11,000	7,500	10,000
Cutting Speed (mm/s)	800	2,500	1,200	1,200	6,000
Cutting Precision (mm)	0.01	0.1	0.10	0.10	0.03
Maximum Cutting Thickness (mm)	30	50	60	50	50
Number of Cutting Blades (units)	5	4	7	20	3

Based on the TOPSIS analysis results summarized in Table 8, Shandong Hongniu achieved the highest ranking as the preferred supplier of the insulation cutting machine, with a relative closeness coefficient of 83%. OmniTech ranked second with a relative closeness of 82%, indicating only a marginal difference in performance between the two suppliers.

Table 7. TOPSIS ranking results of insulation cutting machine suppliers

Suppliers	**Ci***	**Rank**
Ventech	0.666	5
OmniTech Company	0.823	2
Shandong Yuchen Co	0.810	3
Shandong Hongniu Co	0.831	1
Jinan AOL Company	0.716	4

As previously noted, the proposed model includes two semi-automated sub-assembly lines, each staffed with a single worker. The first line handles the 42TP and 50ZPM products, while the second line manages the 50TJM Large, 50TJM Small, 50TCM, and 40RUM products. Tables 9 and 10 present the input data used for the proposed simulation model.

Table 8. Simulation input parameters for the first semi-automated sub-assembly line

Parameter	**Input Value**	**Measurement Unit**	**Data Reference**
Material Setup Duration	2.17	Minutes	Assumption
Warehouse-to-Production Transfer Time	2.50		
Processing Duration	2.50		
Sub-Assembly Transfer Time	0.50		
Number of Operators	1.00	-	
Scrap Percentage	5%	-	
Idle Time Cost per Minute	0.375	Dollar	

Table 9. Simulation input parameters for the second semi-automated sub-assembly line

Parameter	**Input Value**	**Measurement Unit**	**Data Reference**
Material Setup Duration	2.17	Minutes	Assumption
Warehouse-to-Production Transfer Time	2.50		
Processing Duration	3.50		
Sub-Assembly Transfer Time	0.50		
Number of Operators	1.00	-	
Scrap Percentage	5%	-	
Idle Time Cost per Minute	0.581	Dollar	

Figure 4 illustrates the proposed simulation model for the two semi-automated sub-assembly lines, each operated by a single worker. The corresponding animation of the simulation model is presented in Figure 5.

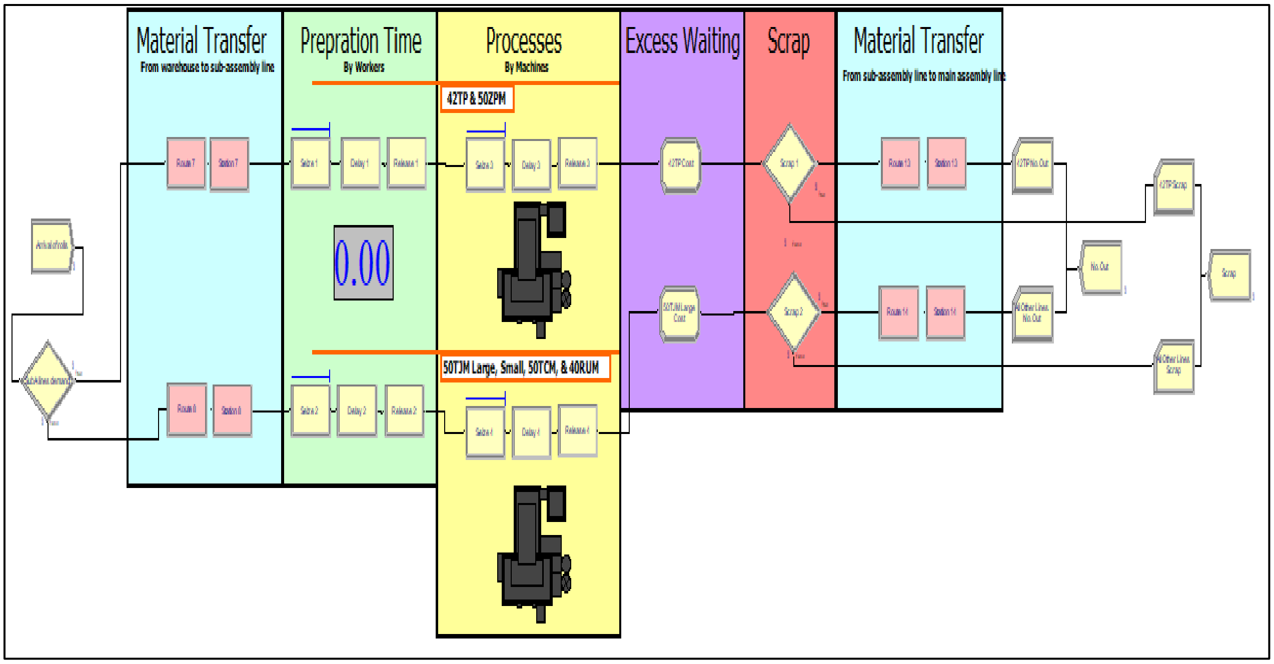

Figure 3. Development of a discrete-event simulation model for the proposed semi-automated insulation-cutting process

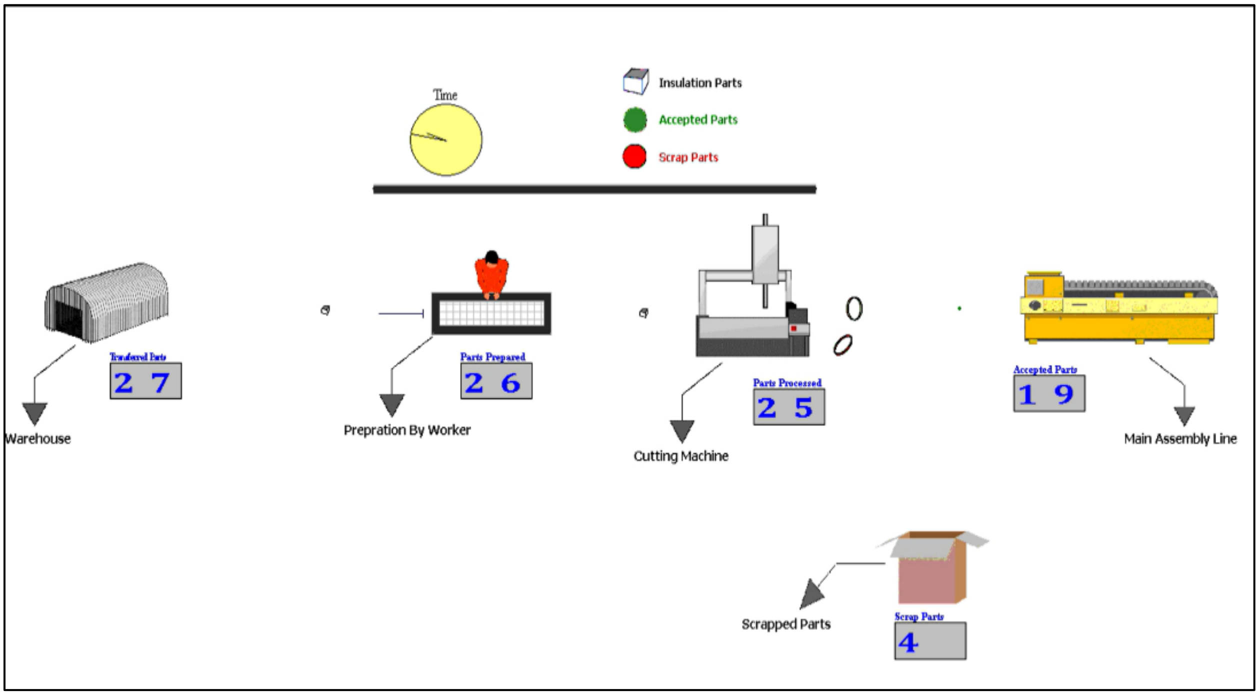

Figure 5. Dynamic visualization of the proposed insulation cutting process

Table 11present the simulation results of the proposed model.

Table 10. Simulation-based performance analysis of the semi-automated sub-assembly system

Semi-Auto sub-assembly line	**Related Product Models**	**Average Throughput (Units)**	**Mean Queue Waiting Time (min)**	**Average Scrap Output (Units)**
First	42TP 50ZPM	73.00 ± 4.73	0.00 ± 0.00	5.00 ± 2.32
Second	50TJM Large 50TJM Small 50TCM 40RUM	37.60 ± 9.23	0.00 ± 0.00	2.40 ± 2.86

3.3. Comprehensive Feasibility Evaluation

The proposed improvement requires an initial capital investment of USD 27,200 for the purchase of two insulation-cutting machines. At present, the company incurs approximately USD 60,000 annually in labor costs for the manual cutting process, excluding additional overtime expenses needed to meet production demands. With the implementation of the semi-automated system, the operation would require only two workers, resulting in projected annual labor cost savings of approximately USD 36,000. To assess the economic viability of this investment, a financial feasibility analysis was conducted, including the calculation of the return on investment (ROI), as summarized in Table 12.

Table 12. ROI and Net Present Value (NPV) analysis for the proposed automation investment

Years	**0**	**1**	**2**	**3**
Net Flow	-27,200	36,000	36,000	36,000
Discounted Factor	1	0.8928	0.7972	0.7118
NPV	-27,200	32,140.8	28,699.2	25,624.8
Cumulative NPV	-27,200	4,940.8	33,640	59,264.8
ROI	-	118.16%	223.6%	317.88%

The results highlight significant improvements in operational performance. The proposed system is expected to generate annual savings of nearly USD 36,000, achieve a payback period of about 10 months, and deliver an estimated 118% return on investment within the first year. Overall, the adoption of the semi-automated cutting solution improves process efficiency, lowers material waste, and promotes more sustainable manufacturing operations, as reflected in the simulation outcomes presented in Table 13.

Table 13. Comparison between the current manual process and the proposed automated system

Manually Cutting			**Mechanic Cutting**		
42TP	Avg. Parts Produced	58.2	**First Line**	Avg. Parts Produced	73
	Avg. Waiting Time (min)	33.06			
	Avg. Scrapped Parts	3.2± 2.69		Avg. Waiting Time (min)	0
50ZPM	Avg. Parts Produced	6			
	Avg. Waiting Time (min)	46.87		Avg. Scrapped Parts	5 ± 2.69

	Avg. Scrapped Parts	0			
50TJM Large	Avg. Parts Produced	8.4	**Second Line**	Avg. Parts Produced	37.6
	Avg. Waiting Time (min)	70.42			
	Avg. Scrapped Parts	0.4±0.68			
50TJM Small	Avg. Parts Produced	6.8			
	Avg. Waiting Time (min)	54.14		Avg. Waiting Time (min)	0
	Avg. Scrapped Parts	0.8±1.04			
50TCM	Avg. Parts Produced	13.6 units			
	Avg. Waiting Time (min)	47.8			
	Avg. Scrapped Parts	1±1.24		Avg. Scrapped Parts	2.4
40RUM	Avg. Parts Produced	3.8			
	Avg. Waiting Time (min)	1.08			
	Avg. Scrapped Parts	0.2±0.56			

4. Limitations And the Future Work

Despite the valuable insights provided by this study, several limitations must be acknowledged. First, variations in material transfer times from the warehouse to each sub-assembly line were simplified by assuming that raw materials were prepared at fixed intervals and delivered according to production line location. In reality, transfer times may vary due to operational disruptions, logistical constraints, and workforce availability.

Second, although product dimensions differ across models, the analysis assumed that all insulation components within a specific sub-assembly line were uniform. This assumption was made to simplify the simulation modeling process but may not fully capture real production variability. In addition, scrap rates were estimated based on observational data, as obtaining precise and consistently recorded measurements proved challenging. The processing times for the proposed automated cutting machines were also assumed, since the selected equipment had not yet been physically implemented at the time of the study. Finally, neither the existing manual system model nor the proposed semi-automated model was formally validated through full-scale industrial implementation or controlled experimental testing.

Future research should adopt a more comprehensive and integrated approach to evaluate each production line in greater detail, with the objective of further optimizing takt time and reducing time-related waste. Additional studies could focus on identifying and alleviating bottlenecks between sub-assembly and main assembly operations, improving raw material supply rates to increase overall production capacity, and conducting real-world validation of both current and proposed simulation models to enhance their reliability and practical applicability.

Acknowledgment

The author sincerely thanks Faisal Alsolmi, Osama Alzahrani, Shaker Aljabri, and Abdulmohsen Alnajrani for their valuable contributions to this study. Their support and involvement were instrumental in the successful completion of this research.

References

Abdulmalek, F.A., and Rajgopal, J. “Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study,” *International Journal of Production Economics*, Vol.107, No.1, pp.223–236, 2007.

Diamond, R., Harrell, C.R., Henriksen, J.O., Nordgren, W.B., Pegden, C.D., Rohrer, M.W., Waller, A.P., and Law, A.M. “The current and future status of simulation software (panel),” *Proceedings of the Winter Simulation Conference*, San Diego, CA, 2002.

Ferrin, D.M., Miller, M.J., and Muthler, D. “Lean sigma and simulation, so what’s the correlation? V2,” *Proceedings of the Winter Simulation Conference*, Orlando, FL, 2005.

Fowler, J.W., and Rose, O. “Grand challenges in modeling and simulation of complex manufacturing systems,” *Simulation*, Vol.80, No.9, pp.469–476, 2004.

IMTR. “Integrated manufacturing technology roadmapping project: Modeling & simulation,” Integrated Manufacturing Technology Initiative Inc., Tennessee, 2000.

Jia, Y. “SimLean: A reference framework for embedding simulation in lean projects,” PhD Thesis, Sheffield Hallam University, 2010.

Marvel, J.H., and Standridge, C.R. “Simulation-enhanced lean design process,” *Journal of Industrial Engineering and Management*, Vol.2, No.1, pp.90–113, 2009.

Michalec, V. “Leveraging simulation as a tool for lean manufacturing process improvement: Case study,” *Journal of Innovation & Business Best Practice*, Vol.2025, Article ID 688574, 2025.

Pinho, C., and Mendes, L. “IT in lean-based manufacturing industries: Systematic literature review and research issues,” *International Journal of Production Research*, Vol.55, No.24, pp.7524–7540, 2017.

Robinson, S., Radnor, Z.J., Burgess, N., and Worthington, C. “SimLean: Utilising simulation in the implementation of lean in healthcare,” *European Journal of Operational Research*, Vol.219, No.1, pp.188–197, 2012.

Standridge, C.R., and Marvel, J.H. “Why lean needs simulation,” *Proceedings of the Winter Simulation Conference*, Monterey, CA, 2006.

Uriarte, A.G., Ng, A.H.C., and Moris, M.U. “Lean, simulation and optimization: A maturity model,” *Proceedings of the International Conference on Industrial Engineering and Engineering Management (IEEM)*, Singapore, 2017.

Uriarte, A.G., Ng, A.H.C., and Moris, M.U. “Bringing together lean and simulation: A comprehensive review,” *International Journal of Production Research*, Vol.58, No.1, pp.87–117, 2020.

Biography

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