JOURNAL OF MODERN MANUFACTURING SYSTEMS AND TECHNOLOGY (JMMST)
e-ISSN: 2636-9575
VOL. 7, ISSUE 2, 9 – 16
DOI: https://doi.org/10.15282/jmmst.v7i2.9401

ORIGINAL ARTICLE

Production Cost Modeling and Simulation in the Glove Manufacturing Industry

N. Agus Salim[1] and M. Ab. Rashid[1,*]

[1]Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, 26600 Pekan, Pahang, Malaysia

ABSTRACT – Product costing is an essential aspect of business strategy as it allows companies to forecast a product's future revenues and expenses and make informed decisions about its development and production. One of the main challenges in the manufacturing sector is the difficulty in selecting the optimal production setup. This can be due to changes in the product or component during the manufacturing process, leading to difficulties in defining the best production quantity and forecasting production costs. Low productivity is another challenge faced by industrial organizations, which can affect their profitability. A case study was conducted in the glove manufacturing industry. The main objective of this research is to model the production cost for the selected case study. Cost modeling in the manufacturing industry involves creating a representation or simulation of a manufacturing process to estimate the costs associated with producing a product. Developing a cost model for the manufacturing industry involves collecting data from the industry and existing literature; developing a cost model with several function modules based on the data; validating the model by comparing its estimates to actual costs; and using the model for cost estimation, budgeting, and product pricing while keeping it updated and calibrated regularly to ensure its accuracy over time. Based on simulation analysis, productivity was improved by 4.0% compared to the original layout. In addition, the production cost per box was reduced by 4.2%. The results from this research can help companies to manage their resources and improve their profitability more effectively.

ARTICLE HISTORY
Received: 6th June 2023
Revised: 27th Sept 2023
Accepted:29th Sept 2023

KEYWORDS
Productivity improvement
Cost modeling
Production cost
Discrete event simulation

INTRODUCTION

Most companies rely on introducing new products to maintain profitability, and an early estimate of the product's costs is crucial for evaluating profitability and making decisions about future product development. Product costing can be used to forecast future revenues and expenses, and companies need to find ways to boost efficiency and output to survive in today's competitive global market [1]. Labor studies are used to analyze productivity and cost-effective methods of industrial production. Work efficiency analysis is used to improve the effectiveness of a process or task. When a corporation knows the productivity of a given labor, it can estimate production costs using production cost modeling [2]. In recent decades, global competitiveness has increased substantially, and small- and medium-sized firms must produce rapid product development and high-quality goods at a low cost to survive. The cost of product manufacturing primarily determines these firms' market share, profit, and return on investment [3].

In the early stages of product development, controlling expenses and predicting future costs are difficult, but companies must produce low-cost, high-quality products to remain competitive [4]. Reducing the price of a product during the design phase is more cost-effective than during the production phase. This can be achieved using "design-for-cost" and "design-to-cost" methods, which focus on minimizing life-cycle costs and meeting functional requirements within a defined budget. However, it is becoming increasingly more work for businesses to estimate demand for various products and manage inventory effectively [5]. This research was conducted to gather information from a continuous production line in a glove-making industry, specifically, the line that produces natural rubber powdered gloves. Furthermore, this research aims to understand the impact of product diversification on inventory levels and service quality, as well as to make recommendations for the ideal production quantity based on a cost model.

This research is motivated by the need for small- and medium-sized firms to have rapid product development cycles and high-quality, competitively priced products to be successful in a global marketplace. This research also aims to study the use of concurrent engineering in reducing production costs and time by simultaneously completing all product development processes. Moreover, this research focuses on using cost modeling and optimization in manufacturing industries, which can help management and procurement professionals identify cost components, cost drivers, and causal factors, as well as identify and eliminate wasteful spending. This can lead to cost savings, improved efficiency, and increased profitability for the company. The objective of this research is to investigate the production cost and improve productivity using discrete event simulation.

*CORRESPONDING AUTHOR | M. Ab. Rashid | ✉ ffaisae@ump.edu.my

The research focuses on how cost modeling can aid strategic budgeting, budget allocation, future planning, and new product development decisions. It can also provide insights into the procurement market, supplier pricing tactics, and supplier relationship management, leading to better supplier selection and lower costs for materials and goods. The project aims to establish a cost model for producing natural rubber powdered gloves. It involves collecting data from the production line, using simulation analysis with open-source software, calculating cost modeling, and making recommendations to improve productivity. The project also aims to enhance collaboration between the company and the supplier by involving the latter in the design process and utilizing their market knowledge. By using cost modeling, both parties can establish long-term partnerships and trust, leading to better supplier relationship management and cost savings.

METHODOLOGY

This case study involved defining and selecting the problem, collecting and analyzing data, interpreting the data, and reporting the findings. Cost modeling can be challenging due to the difficulty in determining the optimal production volume. This phase of the research aims to gain an all-encompassing understanding of the research and related fields by conducting a preliminary search for literature on cost modeling and optimization in the manufacturing industry. The literature review identified the standard stages and activities of production cost modeling, as well as various cost drivers and cost estimation relationships. This research also involved industrial visits to observe the procedure, reading the standard operating procedure, and communicating with engineers, line supervisors, and workers to gain a deeper understanding of the case study. A time study was conducted for each workstation using a stopwatch and used for line balancing and productivity calculations. The time was recorded three times to determine the average time for each workstation.

The accuracy and usability of the data were confirmed by calculating and repeating the time collection. Additionally, other data required for this research (i.e., material, labor, and setup costs) were collected from the industry and used for cost modeling. The line speed for this research was set at 24,000 pcs/h to produce quality gloves daily. The time taken to complete one cycle was between 15 and 20 min. Additionally, there are eight layers for each production line, with four layers on the left side and four layers on the right side. The cost modeling system includes material selection, process planning, and cost estimation as the basic components. Material and setup cost databases were integrated into the selection and planning process. In order to estimate costs, the system captures the design of product models, including information on the materials used and the essential product characteristics. First, the system inputs the design attributes and various materials and processes, and then estimates the costs, such as material, labor, and setup costs. The total cost of production was determined by adding these components.

Quality inspection costs (i.e., labor cost, tooling, and equipment cost, and facility cost) were tallied separately and estimated. The research would result in a comprehensive report of the findings. The analysis found that most of the total manufacturing cost was made up of labor, material, and setup costs. A cost model structure and multiple data spreadsheets were presented to identify design decision-making. The simulation ran 20 times in 12 h to analyze the average idle time, workstation utilization, input, output, and average queue time to assess the simulation accuracy with the current layout output. The simulation could also determine the workstation bottleneck at the utilization percentage value. After identifying the bottlenecks at workstations with low utilization percentages, the analysis focused on improvement. The existing results and progress were compared. The bottleneck of the workstation affects the productivity of production, which can be related to the cost for cost analysis.

Cost Modeling

Cost modeling is an important step in planning and developing new or existing products, as it can reveal efficient manufacturing options and aid decision-making by providing financial analysis of multiple production line design options and potential upgrades. It is especially important during the early conceptual design phase of a production system, where the iterative and inventive nature of the process can restrict the lead time for modeling and data collection. In such applications, the emphasis is often placed on rapidly delivering decision support with adequate simulation quality rather than on achieving a high level of detail. It is important to note that reasonably precise estimates of multiple inputs (e.g., technical and financial considerations) are required for decision-making models to be effective. Incorporating simulation tools into company-specific models for production system development also requires a systematic approach to ensure the acquisition of processed production system data, which could reduce waiting times for data collection.

The costs in cost modeling can be divided into direct and indirect costs [6]. Direct costs include labor, material, set up, and travel expenses, while indirect costs include personnel, administrative, and security expenses. Indirect costs can be either fixed or variable in nature. The cost model is a key component in the reclaim solution as it allows for the estimation and understanding of the costs associated with applying particular life extension energy [7]. It is used to evaluate different scenarios and options for extending the life of an asset and identify the most cost-effective option. The model can also be used to estimate costs over time and identify potential cost savings and efficiency improvement [8]. It is important to ensure that the model is based on accurate and up-to-date information and that the assumptions and boundaries of the model are clearly stated and communicated to the stakeholders.

The process typically starts with a list of expenses, which are then classified and grouped based on their drivers and relationships. The next step is to identify the drivers of the costs, which are typically intermediate inputs that are calculated automatically based on the model's inputs. These drivers are then incorporated into the model, and the range of these variables is specified to avoid improper extrapolation and inaccurate results. It is important to consider the total cost of a decision, including all relevant expenses, and to consider variable supplier costs and the impact of different suppliers' terms and services [8]. The goal of cost modeling is to develop a standard costing system that allows businesses to monitor upcoming expenses, compare actual and standard costs, and adjust their standard cost estimates to minimize variances. This process should be repeated until the variance is negligible and the model is perfected.

Discrete Event Simulation

Discrete-event simulation (DES) is a practical method that enables construction professionals to evaluate various production scenarios in a virtual setting before production. It is a quantitative method of decision-making in complex systems that simulates reality through a computational model. This model contains the characteristics and logic necessary to represent the actual behavior of the system [9].

One of the main advantages of DES is its ability to model and analyze complex systems in a controlled environment, which can be useful for identifying and addressing potential problems before they occur in the real world[10]. This can save time and resources, as well as improve the efficiency and effectiveness of operations. In addition, DES can be used to optimize the use of resources, such as energy and materials, which can lead to cost savings and environmental benefits.

In this study, a DES model was developed in JaamSim software, which is an open-source DES software with a user-friendly interface. The initial simulation model to represent the process is shown in Figure 1.

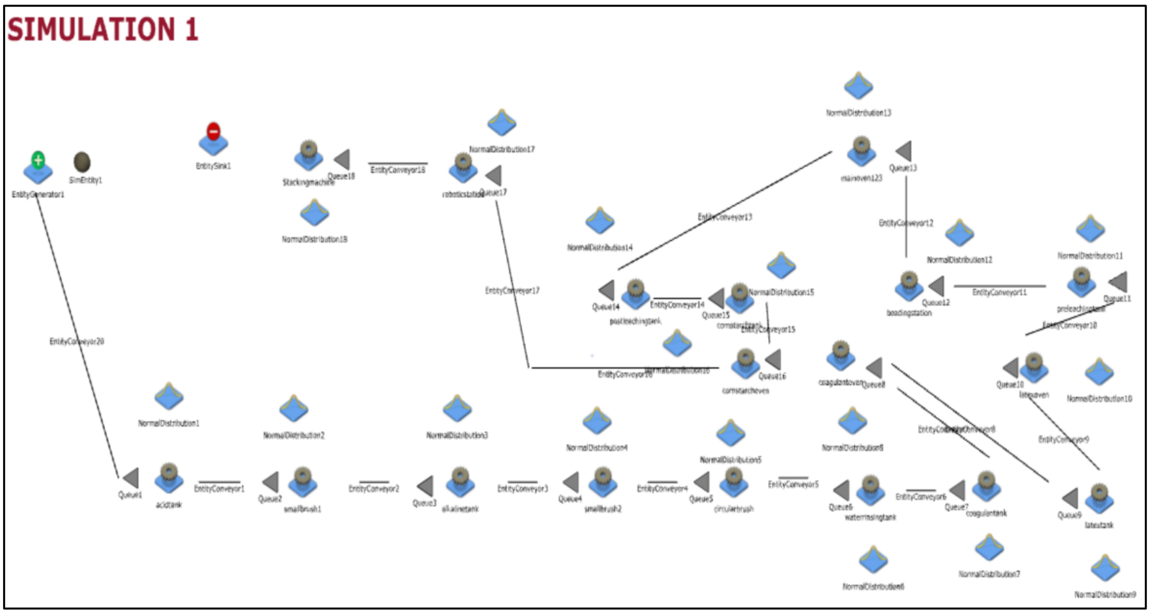

Figure 1. DES model for the glove-making process.

The discrete event simulation was run 20 times with 12 h per run to observe the average idle time, workstation utilization, input, output, and average queue time to analyze the simulation accuracy with the current layout output. This is because one shift working hour for the workers is 12 h per day.

RESULTS AND DISCUSSIONS

Simulation Model Validation

The simulation model was validated by comparing the actual output data and the simulation output data. The actual output is 3,000 pcs/h for each layer, with a total of 24,000 pcs/h. The average simulation output is 2,989 pcs/h for each layer, with a total output of 23,912 pcs/h. The difference is 0.37%, which is less than 10%, indicating that the simulation can be used to investigate the behavior of the actual layout [11]. Table 1 shows the simulation results of the existing layout.

Table 1. DES results for the initial layout.

Station	Idle (hr)	Working (hr)	Utilization (%)	Input (pcs)	Output (pcs)	Average queue (hr)
1. Acid tank	3.21E-04	11.999	99.9	36016	36015	0.9981
2. Small washing brush tank	4.991	7.009	58.4	36014	36013	8.03E-08
3. Alkaline tank	0.007	11.993	99.9	35970	35969	0.008
4. Small washing brush tank 2	5.008	6.992	58.3	35969	35968	6.77E-08
5. Circular washing brush tank	5.009	6.991	58.3	35967	35966	9.18E-07
6. Water rinsing tank	0.027	11.973	99.8	35962	35961	2.10E-03
7. Coagulant tank	5.001	6.999	58.3	35960	35959	7.53E-08
8. Coagulant oven	0.021	11.979	99.8	35941	35940	2.50E-03
9. Latex tank	5.017	6.983	58.2	35939	35938	7.99E-08
10. Latex oven	0.025	11.975	99.8	35925	35924	2.20E-03
11. Pre-leaching tank	5.014	6.986	58.2	35923	35922	7.89E-08
12. Beading station	5.015	6.985	58.2	35922	35921	9.04E-07
13. Main oven 1-3	0.037	11.963	99.7	35908	35907	2.10E-03
14. Post-leaching tank	0.030	11.97	99.8	35903	35902	2.70E-03
15. Cornstarch tank	5.018	6.982	58.2	35901	35900	8.27E-08
16. Cornstarch oven	0.045	11.955	99.6	35891	35890	1.70E-03
17. Robotic station	0.042	11.958	99.7	35878	35877	1.70E-03
18. Auto stacking machine	0.046	11.954	99.6	35870	35869	1.99E-03

Production Cost

Labor Cost

For each production line, there were only two operators for each shift working hour, four technicians on standby for all production lines, and one supervisor. Based on the survey of the workers, the average salary of workers is RM 3,600 per month. In normal operation, each worker works for 12 hours per day, 25 days per month. Based on the average salary, the average labor cost per hour is RM 12.

The duration for each batch of production is normally 48 hours. The required labor hour is calculated as follows:

Labor-hour = (No. of operator + No of techician/4 + No of supervisor/4) x Working hour
= (2 + 4/4 + 1/4) x 48 hours
= 156 labor-hours

Labor cost = Labor-hour x Labor cost per hour
= 156 hours x RM 12
= RM 1,872 (for 48 hours)

The number of technician and supervisor are divided into four because they are shared among four production lines. Based on the calculation, the total labor cost for each production run is RM 1,872.

Material Cost

The total amount of material cost for each production running the process is RM 7,150.00.

Setup Cost

For the setup cost per overhead worker to set up the production line, it usually takes 2–3 days to set up the production line. Several setups should be made, such as the material tank, where former installation depends on the glove size; AI at the robotic station; and all sprockets at the production line must be well-maintained. Each setup needs 4–5 workers.

Setup cost = Labor cost/hour x No of technician x Duration
= RM 12 x 4 x 40 hours
= RM 1920

Noted that the production line setup is made before the production run. Therefore, the setup duration is not included the production run duration.

Total Cost

The total cost for 48 hours of production, and 40 hours of setup are as follows:

Total Production Cost = Labor Cost + Material Cost + Setup Cost
= RM 1,872 + RM 7,150 + RM 1,920
= RM 10,942

Therefore, the total cost for 48-h production is RM 10,942.00, including the chemicals (raw material) for the operation and the labor cost for two shifts, where one shift consists of 12-h operation.

Suggestions for Improvement

All workstations must be well-maintained by following the total preventive maintenance to reduce breakdowns in the production line that will affect the process and quality of production. There are four categories of common glove defects: major visual, freedom of hole, critical non-acceptable, and non-functional. There are many root causes for these defects. Based on the prior analysis, one of the major defect causes is the inappropriate conveyor speed. The production associates tend to set the allowable maximum speed to ensure the production target is achieved. In some cases, when the conveyor speed is increased, the dipping duration becomes too short and causes defects.

Based on the simulation results of the existing layout, there were eight stations with low utilization. These stations are:

- Small washing brush tank 1 (58.4%).
- Small washing brush tank 2 (58.3%).
- Circular washing brush tank (58.3%).
- Beading station (58.2%).
- Coagulant tank (58.3%).
- Latex tank (58.2%).
- Pre-leaching tank (58.2%).
- Cornstarch tank (58.2%).

In order to increase the productivity of production at the low utilization percentage, it is suggested to accelerate the process by increasing the number of formers being processed at a time. Currently, the number of formers is four at a time. In order to increase the number of former processing, the following modification is needed: increasing the number of formers that are dipped into the coagulant, latex, pre-leaching, corn starch, small washing brush, circular washing brush tank, and beading station that will touch the brush and dip into the tank from four to six formers. The angle of the former track at the low utilization station will be modified, and the cost is RM 2,000 per station.

Based on the analysis made, another simulation was conducted to simulate the suggested improvement. The average simulation results for the improved layout are presented in Table 2.

Table 2. DES results for the improved layout.

Station	Idle (hr)	Working (hr)	Utilization (%)	Input (pcs)	Output (pcs)	Average queue (hr)
1. Acid tank	3.26E-04	11.9997	99.9	39306	39305	0.5407
2. Small washing brush tank 1	4.355	7.645	63.7	39304	39303	3.67E-07
3. Alkaline tank	0.0025	11.9975	99.9	39294	39293	1.60E-03
4. Small washing brush tank 2	4.3578	7.6422	63.6	39292	39291	4.06E-07
5. Circular washing brush tank	5.445	7.554	64.6	39290	39289	1.23E-06
6. Water rinsing tank	0.0055	11.9945	99.9	39274	39273	2.90E-03
7. Coagulant tank	4.3675	7.6325	63.6	39272	39271	1.18E-09
8. Coagulant oven	0.0148	11.9852	99.8	39628	39627	1.01E-03

9. Latex tank	4.3613	7.6387	63.6	39266	39265	1.59E-09
10. Latex oven	0.018	11.982	99.8	39262	39261	1.40E-03
11. Pre-leaching tank	4.3574	7.6426	63.6	39260	39259	1.32E-09
12. Beading station	4.3621	7.6379	63.6	39259	39258	9.30E-07
13. Main oven 1-3	0.0224	11.9776	99.8	39257	39256	1.10E-03
14. Post-leaching tank	0.0138	11.9862	99.8	39245	39244	1.40E-03
15.Cornstarch tank	4.3699	7.6301	63.5	39243	39242	2.16E-09
16. Cornstarch oven	0.0091	11.9909	99.9	37530	37529	2.61E-01
17. Robotic station	0.0213	11.9788	99.8	37486	37485	0.0055
18. Auto stacking machine	0.0228	11.9772	99.8	37447	37446	0.0038

Table 2 shows the average simulation results from 20 independent runs for 12 h for one layer of the production line output. The output for the production line at the last station (i.e., the auto stacking machine), was 37,446 pieces of gloves for 12-h operation, which is a 4.4% increase from the current output. There are eight layers for each production line, and if the output for each production layer is similar, the total amount of gloves for 1 h of each production line is 24,960/h. Small washing brush tanks 1 and 2, circular washing brush tank, coagulant tank, latex tank, pre-leaching tank, beading station, and corn-starch tank are utilized less than 60% for the existing layout simulation. However, for the improved simulation, the utilization of these workstations has been increased. The improved plan is a modification of the former track, from four formers being dipped into the tanks to six formers. The cost for improvement is RM2,000 for each track at the tank. Since there are eight stations that need modification, the total modification cost is;

Total Modification Cost = RM 2,000 x 8 stations
= RM 16,000

For the modification cost, the return on investment (ROI) is calculated. The ROI is achieved when the total cost is equivalent to the total revenue [12]. The total cost is presented using equation (1):

$$\text{Total Cost} = \text{Fixed Cost} + (\text{Volume} \times \text{Variable Cost}) \tag{1}$$

In this case study, the fixed cost is the total modification cost. Meanwhile, the variable cost is given by the material and labor costs. From the available information, the total material cost for each production run (approx. 48 hours) is RM 7,150. While, for every 12-hour shift, the output is 288,000 pcs. Based on this information, the material cost per piece is calculated as follows:

Material cost for 48-hours production = RM 7,150

Output for 48-hour production = 288,000 x 4 shifts
= 1,152,000 pcs
= 11,520 units (1 unit/box contains 100 pcs)

Material cost per unit $\dfrac{\text{RM7150}}{11{,}520}$
= RM 0.62 / unit

Meanwhile, the total labor cost for 48-hour production is RM 1,872 as presented earlier.

Labor cost for 48-hours production = RM 1,872

Labor cost per unit $\dfrac{\text{RM 1,872}}{11{,}520}$
= RM 0.16 / unit

Therefore, the total variable cost:

Variable cost = Material cost + Labor cost
= RM 0.62 + RM 0.16
= RM 0.78 / unit

The selling price for each unit (or box) that contains 100 pcs is RM 15.90. The ROI is achieved when the total cost is equivalent to the total revenue. Therefore the ROI for this case is calculated as follows:

ROI: Total Cost = Total Revenue	
Total Cost	= Fixed Cost + (Volume × Variable Cost)
	= 16,000 + 0.78 × Volume
Total Revenue	= Selling Price × Volume
	= 15.90 × Volume
Total Cost = Total Revenue	16,000 + 0.78 × Volume = 15.90 × Volume
	15.12 × Volume = 16,000
	Volume = 1058.2 ≈ 1059 units

Based on the calculation, the ROI to recover modification cost is to manufacture 1,059 units.

The production cost before and after improvement is calculated. On average, the existing output per hour is 24,000 pcs for eight layers. After improvement, the average simulation output is 37,446 pcs for a 12-hour shift. Therefore, the output per hour for the improved layout is 3,120 pcs per layer per hour. Considering there are eight layers, the total output is 24,960.

Existing layout	= 3,000 pcs per-layer per-hour
For a total of eight layers	= 3,000 pcs x 8 layers
	= 24,000 pcs/hour
For a 48-hours production run	= 24,000 x 48 hours
	= 1,152,000 pcs = 11,520 units
Improve layout	
Simulation output	= 3,120 pcs per-layer per-hour
For eight layers and a 48-hours	= 3,120 x 8 layers x 48 hours
	= 1,198,080 pcs = 11,980.8 units

Production Cost	
Total cost per production run	= Labor Cost + Material Cost + Setup
	= RM 1,872 + RM 7,150 + RM 1,920 = RM 10,942
Existing cost	$= \frac{\text{RM } 10{,}942}{11{,}520}$
	= RM 0.95 per unit
Improved cost	$= \frac{\text{RM } 10{,}942}{11980.8}$
	= RM 0.91 per unit

Therefore, the difference between the existing and the improved price per box is only RM 0.04, or a 4.21% increase. The existing price per box is RM0.95, and the improved price is RM0.91.

CONCLUSIONS

This research aimed to investigate production costs and improve productivity for the manufacturing industry (glove) to help designers and cost engineers estimate the manufacturing cost in the early development stages. The research set several objectives to achieve this goal, including conducting a case study in the manufacturing industry, modeling the production cost for the selected case study, and suggesting the optimum production quantity based on the cost model. In addition, the discrete event simulation was able to simulate the modification and come out with a 4% improvement in terms of output. In conclusion, this research has developed a cost model for glove manufacturing by conducting a case study. The simulation allows the user to estimate the output of the production per hour, and the capacity of the production line to produce gloves. It can help cost engineers and designers understand the impact of design changes on production costs in the early stages. The research results indicate that process planning is an efficient way to understand the manufacturing process at each workstation. Accurate time estimation is crucial for production cost estimation and can be achieved through DES. Furthermore, material and labor costs comprise most of the total production cost. The developed cost modeling system can be applied to powdered glove manufacturing, covering only direct costs. The raw materials for other gloves may be different and affect the material and production costs. However, the cost modeling calculations are based on survey data, which include randomized data collection times, making the estimates conservative, and potentially underestimating the cost of modeling and optimization. Additionally, the model does not include utility costs, such as energy, and data collection was restricted to two weeks due to scheduling constraints, and the simulation design is based on the given production layout. Lastly, it is important to note that the cost modeling calculations and formulations are specific to the industry and may not be directly applicable to other industries.

ACKNOWLEDGEMENT

The authors would like to thank UMP for funding this work under an internal grant RDU223017.

REFERENCES

[1] L. Jiang, D. Walczyk, G. McIntyre, and W. K. Chan, "Cost modeling and optimization of a manufacturing system for mycelium-based biocomposite parts," *J Manuf Syst*, vol. 41, pp. 8–20, Oct. 2016, doi: 10.1016/j.jmsy.2016.07.004.

[2] A. L. Gazoli de Oliveira and W. R. da Rocha Junior, "Productivity improvement through the implementation of lean manufacturing in a medium-sized furniture industry: A case study," *South African Journal of Industrial Engineering*, vol. 30, no. 4, pp. 172–188, Dec. 2019, doi: 10.7166/30-4-2112.

[3] C. Windmark and C. Andersson, "Cost modelling as decision support when locating manufacturing facilities," *International Journal of Production Management and Engineering*, vol. 4, no. 1, p. 15, Jan. 2016, doi: 10.4995/ijpme.2016.4177.

[4] W. Du, Y. Tang, S. Y. S. Leung, L. Tong, A. v. Vasilakos, and F. Qian, "Robust Order Scheduling in the Discrete Manufacturing Industry: A Multiobjective Optimization Approach," *IEEE Trans Industr Inform*, vol. 14, no. 1, pp. 253–264, Jan. 2018, doi: 10.1109/TII.2017.2664080.

[5] H. A. K. Krebish and A. Berberoglu, "The effect of management (style) on cost of quality in engineering projects," *Proceedings on Engineering*, vol. 2, no. 1, pp. 31–40, 2020.

[6] A. Eriksson, "Developing a product costing model using Process-Based Cost Modeling."

[7] N. Amaitik *et al.*, "Cost Modelling to Support Optimum Selection of Life Extension Strategy for Industrial Equipment in Smart Manufacturing," *Circular Economy and Sustainability*, Mar. 2022, doi: 10.1007/s43615-022-00154-0.

[8] C. R. Cunningham *et al.*, "Cost Modelling and Sensitivity Analysis of Wire and Arc Additive Manufacturing," *Procedia Manuf*, vol. 11, pp. 650–657, 2017, doi: 10.1016/j.promfg.2017.07.163.

[9] V. Alejandro Huerta-Torruco, Ó. Hernández-Uribe, L. Adriana Cárdenas-Robledo, and N. Amir Rodríguez-Olivares, "Effectiveness of virtual reality in discrete event simulation models for manufacturing systems," *Comput Ind Eng*, vol. 168, Jun. 2022, doi: 10.1016/j.cie.2022.108079.

[10] V. J. Mawson and B. R. Hughes, "The development of modelling tools to improve energy efficiency in manufacturing processes and systems," *Journal of Manufacturing Systems*, vol. 51. Elsevier B.V., pp. 95–105, Apr. 01, 2019. doi: 10.1016/j.jmsy.2019.04.008.

[11] C. Baril, V. Gascon, J. Miller, and N. Côté, "Use of a discrete-event simulation in a Kaizen event : A case study in healthcare," *Eur J Oper Res*, vol. 249, no. 1, pp. 327–339, 2016, doi: 10.1016/j.ejor.2015.08.036.

[12] J. Heizer and B. Render, *Operation Management - Eighth Edition*, 8th ed. New Jersey: Prentice Hall, 2006.