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Integrating Lean Warehousing and Systematic Analysis to Minimize Waste in Finished Product Storage: A Case Study and Generalizable Improvement Framework

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Abstract. Efficient warehouse management is critical for make-to-order production systems. This study investigates waste reduction in a metal casting company's finished-product warehouse by applying Lean Warehousing principles. Using time-motion studies, Value Stream Mapping (VSM), Pareto diagrams, and fishbone diagrams, the research analyzed 13 workstations and identified five primary areas of waste. Simulation results demonstrated a significant cycle time reduction from 2,559 to 2,128 seconds, alongside an increased proportion of value-added activities. Although limited to a simulation, the findings highlight the effectiveness of Lean tools in standardizing work and redesigning layouts. The study concludes that continuous monitoring and Lean implementation are essential for achieving sustainable operational efficiency and reducing costs in industrial warehousing.

Keywords: lean warehousing, make-to-order (MTO), process cycle efficiency, reduce waste generation, time motion study, VSM

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1. Introduction

Effective warehouse management is crucial for thriving distribution and trading companies [1]. Although often considered non-value-added due to its repetitive and administrative nature [2], logistics activities, such as receiving and dispatching goods from warehouses, play a vital role in meeting the needs of customers and manufacturers [3]. Therefore, warehouse operations must be optimized for efficiency and cost-effectiveness, making warehouse design a key consideration in industrial management.

Improper warehouse management can lead to problems such as suboptimal space utilization, excessive processing time, and inventory buildup [4], which ultimately create waste that does not provide added value to warehousing activities [5,6]. In a make-to-order (MTO) production system, the finished-goods warehouse functions not as a large distribution center, but rather as a temporary storage and staging area for customized products awaiting shipment after inspection and packaging. This distinction is crucial, as efficiency in the finished goods warehouse directly affects delivery reliability and production continuity in an MTO environment.

A metal casting company that serves various sectors and implements a make-to-order system can provide an example, yet still faces difficulties due to disorganized material handling, which slows the search for goods and increases the frequency of inefficient material movement. A few studies explicitly discuss the optimization of finished goods warehouses in MTO systems, indicating a clear research gap in this area.

Lean principles must be a priority for companies seeking to maintain competitive advantage, as they can accelerate material flow, reduce waste, and minimize excess inventory [7]. To achieve this, an efficient logistics chain design is required to fulfill orders, encompassing warehousing processes, preparation, and delivery, even under conditions that are not always ideal [8]. This optimization opens up opportunities to minimize non-value-added activities by identifying and reducing waste, while increasing value for customers [9,10], defined as anything beyond the minimum requirements to run a process [11]. In addition, the presence of warehouses or distribution centers near the target market is also key to meeting demand on time [12].

In response to these challenges, the lean warehousing approach offers a systematic solution for warehouse management. Lean warehousing is a sustainable approach that focuses on resource efficiency and improving operational performance [13]. Various lean tools applied to warehousing activities are integral to the overall lean methodology [14], enabling the creation of value for customers by optimizing the utilization of space and time [15]. Therefore, lean warehousing-based warehouse management is the right solution, as it integrates tools, systems, and strategies tailored to the company's operational needs [16].

Previous studies have demonstrated the effectiveness of lean warehousing principles in improving operational efficiency across various industrial sectors. Several studies have examined the use of lean tools to improve storage and retrieval processes [17]. In warehousing and industry, research emphasizes the role of 5S and ABC [18–22], Kanban, and other practices in reducing waste [23–30] and improving inventory reliability [31–36]. However, the application of lean warehousing in finished-goods warehouses in the MTO-based metal-casting industry has not yet been fully explored. This study aims to bridge the gap by integrating lean tools to identify and minimize waste in such settings. To address the identified research gap. The following novelty summarizes the study's direction and contributions:

a) Implementing the concept of lean warehousing, particularly in finished goods warehouses in MTO production systems;
b) Integrating various lean tools for comprehensive waste analysis, and
c) Providing a structured improvement framework that can serve as a reference for similar industries

2. Methods

This study applies the lean warehousing approach to identify and minimize waste in managing finished goods warehouses in a make-to-order production system. This approach focuses on mapping and analyzing material and information flows to improve warehouse operational efficiency. The research began with the collection of initial data using a time-motion study (TMS), in which warehouse activities such as receiving, storing, picking, and packaging products were observed directly, and their durations were recorded with a stopwatch. Each observation was conducted at 13 representative workstations across multiple shifts and on various days over a two-week period to capture variations in operator performance and workload. Two trained observers took measurements using a standard stopwatch protocol, and distances traveled were measured with a digital measuring wheel. To ensure data reliability, repeated measurements were taken and averaged to minimize errors. The data collected included process time, labor usage, and the distance traveled by material.

Next, the data were mapped onto a current VSM to depict the process flow visually. This stage involved a team from management and relevant workers to identify key processes. Through VSM analysis, each activity is classified as value-added, non-value-added, or as necessary non-value-added. This classification follows the definition of lean manufacturing, where value-added (VA) refers to activities that transform materials to meet customer needs, non-value-added (NVA) refers to unnecessary activities that do not generate customer value, and non-value-added necessary activities (NNVA) refer to necessary supporting activities that are not directly related to customer value. Based on this classification, various process wastes are identified. The Pareto chart is created to prioritize waste that contributes significantly (more than 20% of total NVA time).

A Pareto chart ranks wastes based on their impact and determines the priority of wastes that must be addressed immediately. These priority wastes are further analyzed using a fishbone diagram to find their root causes. Improvement proposals are developed collaboratively through structured brainstorming and cross-functional discussions. Through brainstorming sessions, this analysis examines various factors, including human, methodological, machine, material, and environmental, to identify the most influential causes. Based on the root cause analysis, an improvement plan included concrete steps to reduce or eliminate existing waste. After the improvements are implemented, a statistical comparison is performed between the process time before and after the upgrades to verify the performance change. After the improvements were implemented, a re-mapping was carried out using Future VSM to illustrate the improved process conditions. Finally, this improvement process is continuously monitored through evaluation and follow-up to ensure that warehouse performance is maintained and constantly refined.

3. Results and Discussion

The data collection process was conducted during the production of 3-inch AS 22 mm pulleys, divided into 13 workstations, from raw materials to preparation through the production stage. Each workstation was observed using the time study method to determine activity durations. This study collected data from 15 observations at each workstation to capture variation in observed process time. The data collection results from all workstations are shown in Table 1 below.

Table 1. Production Process Cycle Time

No	Stone Breaking	Mold Making	Pouring Bucket Filling	Lot Pouring	Lot Unloading	Axle Hole Lathe	Belt Track Lathe	Scraping	Drilling	Putty	Sandpaper	Paint	Packing
1	68	576	98	43	81	289	389	203	44	191	94	74	225
2	67	612	130	69	41	244	389	284	81	151	83	56	233
3	123	435	111	49	65	283	397	253	165	171	99	62	263
4	64	541	129	43	102	295	410	192	141	199	110	90	565
5	122	569	97	69	53	230	419	249	82	158	31	86	258
6	71	478	81	58	89	237	399	232	163	145	101	65	495
7	104	434	115	69	112	248	412	155	127	208	38	65	277
8	97	552	86	51	110	269	409	149	165	170	90	58	415
9	99	574	131	55	41	293	388	177	61	144	132	60	323
10	81	488	123	67	45	283	382	251	51	173	81	57	498
11	106	581	72	63	48	287	383	151	123	198	101	58	292
12	99	490	110	67	90	283	418	117	108	181	112	71	510
13	77	642	88	62	72	243	415	202	98	186	61	60	518
14	87	480	80	45	73	278	408	166	164	146	136	87	346
15	107	623	88	47	120	247	391	239	135	161	89	59	498
Total	1372	8075	1539	857	1142	4009	6009	3020	1708	2582	1358	1008	5716
Average	91	538	103	57	76	267	401	201	114	172	91	67	381

The mean and standard deviation (SD) for each process step were calculated to provide a clearer quantitative picture of the cycle time distribution—the total mean cycle time before the improvement was 2,559, equivalent to 0.71 hours per batch. When expressed in operational metrics, this equates to a throughput of approximately 1.4 batches per hour under current conditions.

3.1. Baseline Measurements

To solve this problem, the time required at each pulley production station was identified and measured using VSM tools. The aim was to identify activities that did not add value and caused delays in the work process. Figures 1 and 2 below show the actual VSM for the pulley production process in the warehouse.

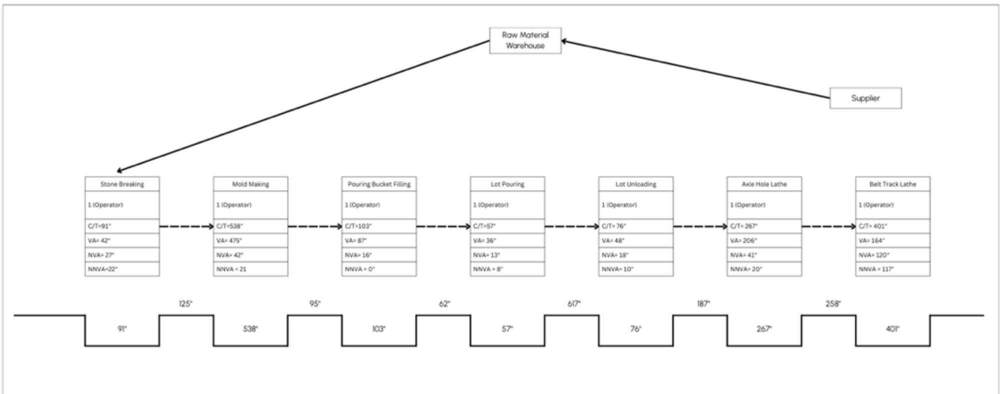

Figure 1. VSM

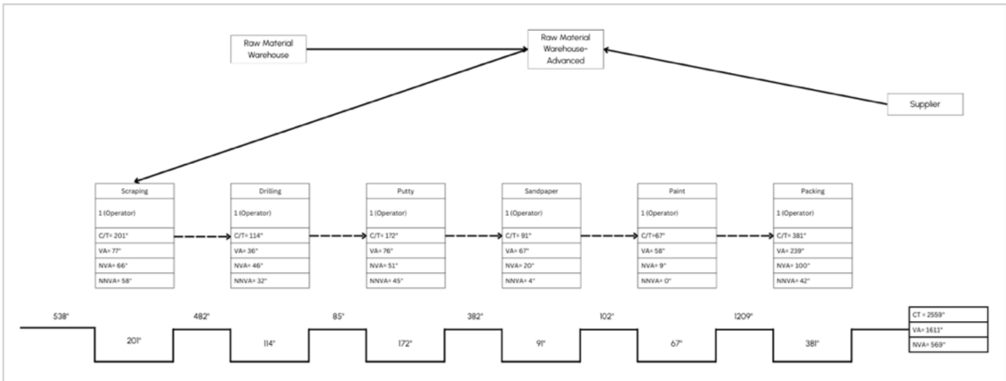

Figure 2. VSM – Advanced

Based on the warehouse's VSM, the process flow and the time required for each stage can be observed. The total cycle time was 2,559 seconds, or 0 hours, 42 minutes, 39 seconds, the sum of the cycle times of each process stage. From the map, it can be seen that activities classified as value added (VA) take 1611 seconds (62.95%), while non-value added (NVA) require 569 seconds (22.24%), and needed non-value added (NNVA) activities are 379 seconds (14.81%). These values are consistent with the typical make-to-order (MTO) casting environment, where manual handling and setup times often dominate waiting times. Similar findings were also reported by Prasetyawan [7], who demonstrated that lean warehousing using VSM can effectively identify and reduce various forms of waste, resulting in increased process efficiency and shorter cycle times. Table 2 shows several forms of waste identified.

Table 2. Details of the Causes of Waste

No	Workstation	Waste	Causes
1	Belt track lathe	Waiting	Machine queues and repetitive setup due to non-standardized work methods.
2	Scraping	Defect rework	Performed because previous results were suboptimal, requiring additional improvements.
3	Drilling	Motion	Excessive operator movements (positioning, tool retrieval), non-ergonomic tool layout.
4	Putty	Overprocessing	Used to cover up defects from previous processes, adding to work time.
5	Packing	Transport	Repetitive movement of goods/double handling between finishing stages.

3.2. Root-cause Analysis

Based on the identification of waste in the B2 3-inch AS 22mm production process, five main types of waste require further analysis. To determine the root causes of each kind of waste, a study was conducted using a fishbone diagram as follows:

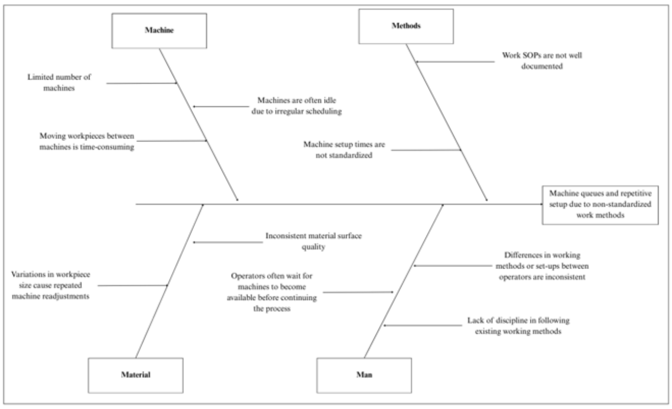

Figure 3. Fishbone Diagram Waiting

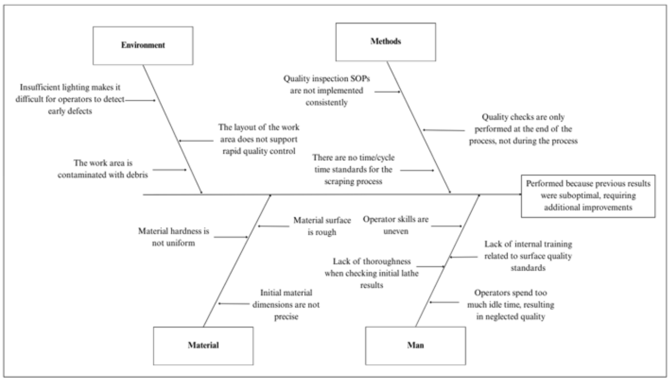

Figure 4. Fishbone Diagram Defect Rework

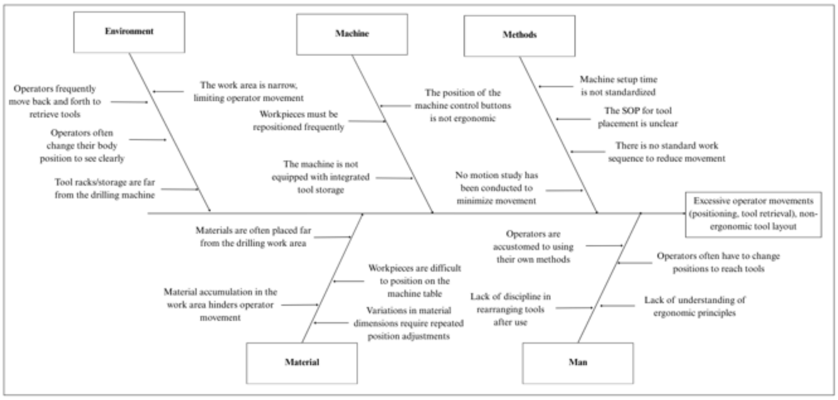

Figure 5. Fishbone Diagram Motion

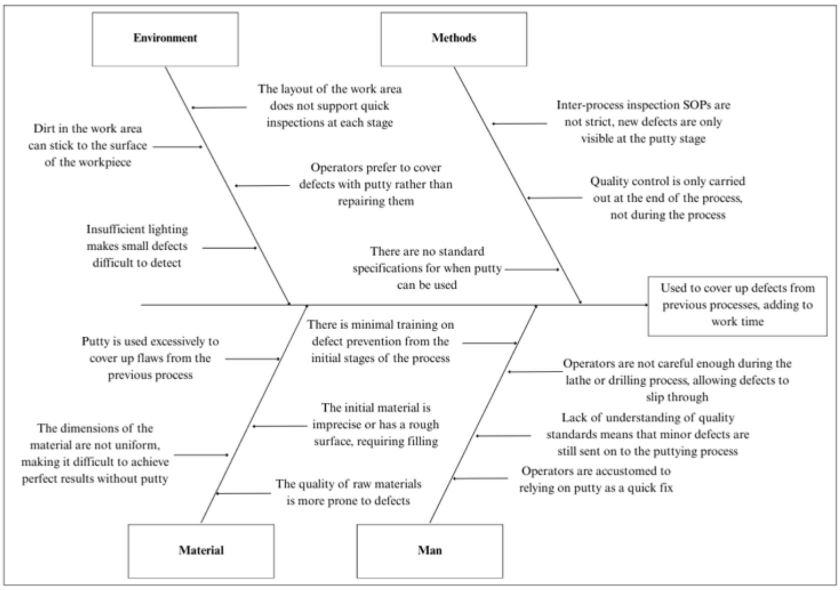

Figure 6. Fishbone Diagram Overprocessing

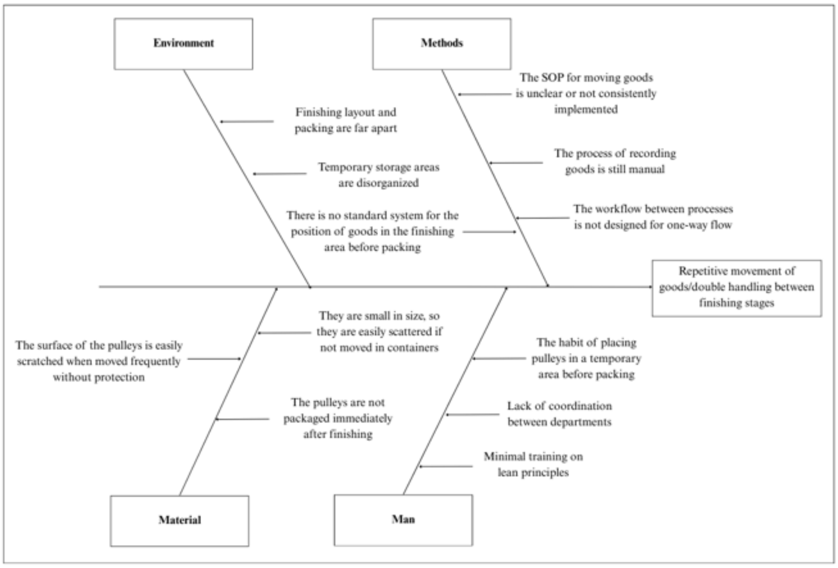

Figure 7. Fishbone Diagram Transport

The analysis results show that lean warehousing in pulley production faces several types of waste, as indicated in the fishbone diagram above. These dominant wastes, particularly waiting and rework, are commonly found in make-to-order (MTO) metal casting systems due to batch-oriented scheduling, high manual involvement, and limited real-time quality control. Detailed analysis reveals non-standard arrangements, suboptimal pre-processing, and double handling during packaging. Similar to the research by Briones-Chávez et al. [25], these conditions indicate that irregular layouts and non-standard work procedures are the leading causes of waste and process delays.

3.3. Improvement Proposals

To overcome this, specific improvement measures are necessary depending on the type of waste, with the following suggestions tailored to each waste category.

1. Waiting (Belt track lathe)

Waste occurs due to machine queues and repeated resets caused by non-standard working methods. Improvements include standardizing work and optimizing machine allocation.

2. Defect rework (scraping)

During the scraping process, waste occurs in the form of defect rework because the previous work results are not optimal, necessitating additional repairs. Improvements can be made through initial quality inspections, operator training, and the use of precision measuring instruments.

3. Motion (drilling)

Motion waste in the drilling process is caused by excessive operator movement due to an ergonomically unsound equipment layout. To reduce this, it is necessary to improve the equipment layout to make it more efficient and standardize work procedures, ensuring a more consistent operator position.

4. Overprocessing (putty)

Excessive use of putty occurs because it covers up defects from previous processes. Improvements can include enhancing initial quality, quality control at each stage, and standard guidelines for putty use.

5. Transport (packing)

Transportation waste during the packing stage occurs due to repeated movement of goods. To overcome this, the flow of materials needs to be reorganized to be simpler, and simple material handling tools such as trolleys or push racks should be used to make movement more efficient.

All improvement proposals are currently still in the planning stage and have not yet been implemented. Therefore, future VSM is a scenario simulation based on the expected results if lean initiatives are implemented. This modeling approach allows for estimates of potential improvements in cycle time, waste reduction, and efficiency gains without disrupting ongoing production.

3.4. Future VSM and Impact Analysis

After implementing the improvement suggestions, a future VSM was prepared for the pulley production process to illustrate a more efficient workflow compared to the previous condition.

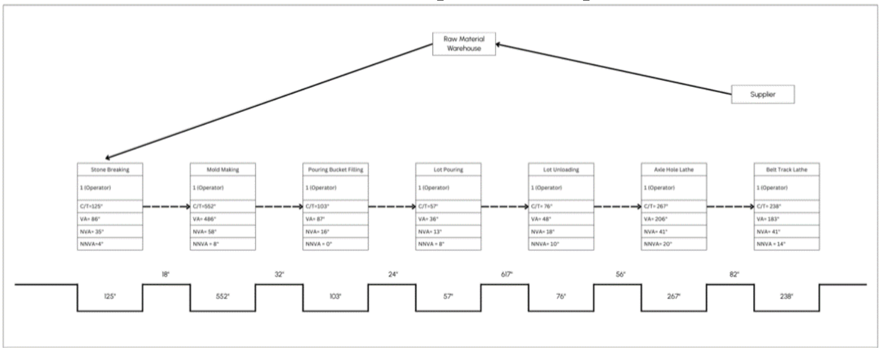

Figure 8. Future VSM

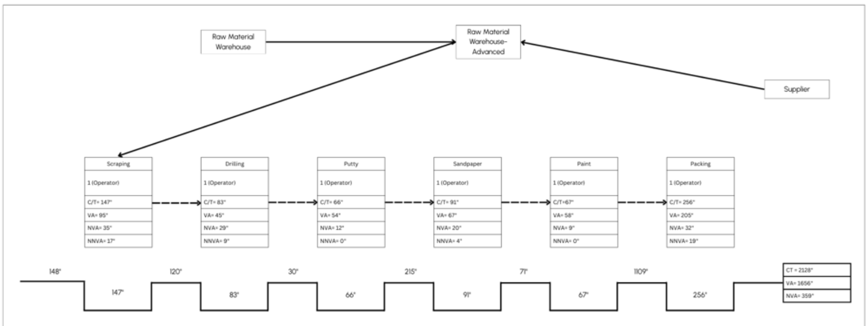

Figure 9. Future VSM – Advanced

The future VSM is shown in Figures 8 and 9. Based on the future current value stream mapping of the pulley production process, the cycle time achieved is 2,128 seconds or 0 hours, 35 minutes, 28 seconds; this calculation is derived from the total cycle time of each process. The total average cycle time for the current condition was 2,559 or 214 seconds, equivalent to 0.71 hours per batch. Based on the modeled future VSM, the total cycle time is expected to decrease to 2,128 or 195 seconds (0.59 hours per batch). Using a paired-sample t-test on pre- and post-improvement values, the reduction was statistically significant ($p < 0.05$, 95% CI: 338–515 seconds). This reduction of 431 seconds (16.8%) results in approximately 0.12 working hours of savings per batch. Assuming labor costs of IDR 35,000/hour, this improvement results in operational savings of approximately IDR 4,200 per batch or IDR 1.2 million per month at current production levels. Among these improvements, layout reorganization, standardization of settings, and operator training were implemented and measured directly. In contrast, the introduction of handling tools and inspection devices was proposed as a phase, modeled in future VSM scenarios.

3.5. Validation and Limitations
Sensitivity analysis confirmed that variations in daily production (±10%) led to a reduction of less than ±5%, indicating stable results. Implementation barriers such as operator adaptability and budget constraints were mitigated through cross-training and layout standardization. Furthermore, digital monitoring was recommended for long-term sustainability.

4. Conclusion
This study confirms that implementing lean warehousing in finished goods warehouses with a make-to-order system can significantly improve operational efficiency by reducing non-value-added activities. These proposed improvements are expected to reduce lead times by around 18% and reduce handling movements by approximately 22%, based on simulations and observed process mapping. These findings demonstrate that lean warehousing effectively identifies root causes and formulates relevant corrective actions, including layout optimization, standard work procedures, and eliminating waste in material handling.

From a managerial perspective, these results provide actionable insights for warehouse managers to prioritize layout redesign and worker training to sustain efficiency gains. However, this study is limited to a single facility and a single product type, so caution is required when generalizing the results. Future quantitative research could expand on this study by integrating process-cycle efficiency metrics, time-motion analysis, or cost-benefit simulations to statistically validate improvements and strengthen decision-making in a broader industrial context.

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Conflict of Interest Statement
The authors state no conflict of interest.

AI Statement
Grammarly improved the grammatical structure of this article, and the authors have rechecked the accuracy and correctness of the generated sentences with this study's topic and data.

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