



Integrating Lean Manufacturing and Facility Layout Optimization to Reduce Transportation Waste in Tempeh Production

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SUBMITTED: 5 March 2026; REVISED: 13 April 2026; ACCEPTED: 16 April 2026

ABSTRACT: This study aimed to reduce transportation waste in tempeh production by integrating Lean Manufacturing tools with facility layout optimization and to evaluate the resulting operational and economic improvements. The study employed a descriptive quantitative case study conducted at a traditional tempeh production facility in Bandung, Indonesia. Waste identification was carried out using the Seven Waste framework and was prioritized using the Borda Count method. Lean tool selection was guided by the Value Stream Analysis Tool (VALSAT). Process analysis was conducted using Value Stream Mapping (VSM), Process Activity Mapping (PAM), and Root Cause Analysis (RCA). Facility layout optimization was performed using the Systematic Layout Planning framework, supported by Activity Relationship Charts and the Blocplan algorithm. Improvement effectiveness was evaluated using Future Process Activity Mapping (FPAM), Future Value Stream Mapping (FVSM), and Operator Material Handling (OMH) cost analysis. The results showed that transportation waste was the dominant inefficiency in the production system. The layout redesign reduced transportation time by approximately 57% and total material handling distance by 19%, while value-added processing time remained unchanged. These improvements generated measurable cost savings based on the OMH metric.

KEYWORDS: Lean manufacturing; facility layout optimization; transportation waste; blocplan; food SMEs

1. Introduction

The food processing industry played a strategic role in Indonesia's economic development, contributing approximately 18.67% to the national Gross Domestic Product (GDP) and ranking as the second-largest economic sector after trade [1]. Increasing domestic demand and dynamic market conditions intensified competition in the agrifood sector, particularly for small and medium-sized enterprises (SMEs), which were required to continuously improve operational efficiency, product quality, and managerial capability to remain competitive and sustainable [2, 3].

Field observations indicated that non-value-added (NVA) activities, such as excessive manual material handling and unnecessary movement, were prevalent due to facility layouts

that were misaligned with the actual process flow. Similar transportation and motion waste associated with suboptimal layouts had been widely reported in food manufacturing SMEs using Lean Manufacturing and Value Stream Mapping (VSM) [4, 5], as well as in broader manufacturing contexts [6]. Previous diagnostic research at IKM Tempe Haji Emah identified transportation as the dominant source of waste, accounting for the highest Borda weight of 0.194 (19.4%) among all waste categories, primarily caused by inefficient layouts and repeated manual handling activities [7]. However, this earlier study focused on waste identification and prioritization without extending to process redesign or economic impact evaluation.

Empirical evidence confirmed that Lean practices were effective in SMEs, with transportation waste emerging as a critical inefficiency in labor-intensive production systems [8–10]. Although initially developed for large-scale manufacturing, Lean principles had been widely adapted for SMEs due to their scalability and continuous improvement orientation [11, 12, 13]. Within the Lean framework, transportation and motion waste directly disrupted process flow and generated non-value-added activities [14–16]. While Lean tools such as VSM and Root Cause Analysis (RCA) had been shown to improve productivity and reduce waste in manufacturing and food SMEs [11, 17], many studies remained focused on diagnostic analysis rather than physical process redesign or economic impact evaluation.

Facility layout design played a central role in minimizing transportation waste by determining workstation arrangement and material flow paths. Inefficient layouts increased travel distance, material handling effort, and workload imbalance [18–20]. Previous studies demonstrated that systematic layout redesign using algorithms such as BLOCPLAN and CORELAP improved space utilization, streamlined workflow, and reduced total transportation distance, thereby supporting Lean objectives in manufacturing systems [21–23]. Accordingly, integrating Lean Manufacturing principles with facility layout optimization provided a comprehensive approach to operational improvement.

Building upon previously published diagnostic findings that identified transportation as the most critical waste in the tempeh production process [7], this study did not reidentify the dominant waste. Instead, it extended prior work by translating diagnostic results into solution deployment and measurable impact evaluation. Lean Manufacturing tools, including Value Stream Mapping (VSM), Process Activity Mapping (PAM), and Root Cause Analysis (RCA), which had been widely applied and validated in previous studies for identifying and reducing process inefficiencies, were used to redesign the production process, followed by systematic facility layout optimization using the Blocplan algorithm. Improvement effectiveness was evaluated through reductions in material handling distance and was quantified economically using the Operator Material Handling (OMH) cost metric.

Although previous studies had shown that integrating Lean Manufacturing with facility layout design could reduce transportation waste [23–25], most remained limited to qualitative or process-level evaluation. Addressing this gap, the present study proposed a data-driven Lean framework that integrated waste prioritization, structured Lean tool selection, detailed process analysis, and Blocplan-based facility layout optimization, with effectiveness quantitatively evaluated using the OMH cost metric. As a result, this study offered a replicable and empirically validated improvement model for labor-intensive food manufacturing SMEs. Therefore, this study aimed to reduce transportation waste through Lean-based facility layout optimization and to quantitatively evaluate the resulting operational and economic impacts.

2. Materials and Methods

2.1. *Lean manufacturing in SMEs*

Lean Manufacturing (LM) was an effective strategy for improving operational performance by eliminating non-value-added activities. Its adaptability led to widespread adoption across various scales of enterprises, including SMEs in Indonesia [26, 27]. Empirical studies consistently demonstrated the positive impact of Lean Manufacturing on productivity improvement and waste reduction across diverse SME contexts. [26] conducted a systematic literature review on Lean implementation in Indonesian SMEs, identifying key adoption trends and practical challenges. [28] validated a progressive Lean implementation model for SMEs in the metal products industry, showing that tools such as Value Stream Mapping (VSM) and continuous improvement practices significantly enhanced operational efficiency. Collectively, these findings confirmed Lean's suitability as a structured and measurable improvement framework for SMEs. However, most Lean implementation studies remained focused on general waste reduction outcomes, offering limited operational guidance on translating dominant waste identification into concrete process redesign decisions.

2.2. *Waste identification and prioritization.*

Accurate waste identification and prioritization were essential for targeted Lean improvements. Numerous international studies had applied systematic assessment frameworks based on the Seven Wastes and Value Stream Mapping to detect and rank inefficiencies in manufacturing systems [29–31]. To determine which waste types should be addressed first, the Borda Count method was commonly used to aggregate expert judgments and rank waste criticality, as demonstrated in recent studies integrating Value Stream Mapping with Borda-based prioritization. Prioritization was particularly important for SMEs with limited resources, as improvement efforts had to focus on interventions that delivered the greatest operational and competitive impact [32]. Once critical wastes were identified, appropriate Lean tool selection became essential. The Value Stream Analysis Tool (VALSAT) provided a structured mechanism for linking dominant waste categories to the most suitable Lean tools, ensuring that subsequent process analyses were systematically directed toward eliminating the most significant inefficiencies [14].

2.3. *Value stream mapping and process analysis.*

Value Stream Mapping (VSM) was a visualization tool used to map material and information flows from raw materials to finished goods, enabling the identification of bottlenecks, excessive waiting times, and non-value-added activities within production systems [33]. In small-scale food industries, VSM frequently revealed excessive manual transportation and handling activities, consistent with findings on Lean practices and barriers in food processing SMEs [34]. Process Activity Mapping (PAM) was commonly integrated with VSM to classify activities into value-added (VA), necessary non-value-added (NNVA), and non-value-added (NVA) categories, providing a quantitative basis for assessing time and movement losses [14]. Current Process Activity Mapping (CPAM) documented existing conditions, while Future Process Activity Mapping (FPAM) evaluated reductions in waste and cycle time following improvement implementation. The Value Stream Analysis Tool (VALSAT) complemented

VSM and PAM by supporting the selection of appropriate Lean tools, such as Root Cause Analysis (RCA) or facility layout optimization, based on dominant waste types identified within the value stream [14].

2.4. Root cause analysis.

Sustainable improvement required identifying the underlying causes of process inefficiencies. Root Cause Analysis (RCA) was a systematic approach used to trace contributing factors behind observed problems. The Fishbone (Ishikawa) diagram supported RCA by categorizing causes into key factors such as Man, Machine, Method, Material, and Environment, while structured questioning techniques such as 5W+1H helped deepen root cause identification [35]. The 5W+1H technique complemented RCA by translating identified causes into actionable improvement strategies. Within Lean-based improvement frameworks, the integration of Fishbone and 5W+1H bridged problem diagnosis and solution design, guiding targeted actions such as layout redesign, work standardization, and process sequencing.

2.5. Facility Layout Optimization.

Facility layout directly influenced material flow, worker motion, and transportation time, making it a critical factor in minimizing waste within Lean systems [36]. Recent studies confirmed that effective layout design and optimization significantly reduced movement inefficiencies and improved operational performance in manufacturing and food-related facilities [37, 38]. Systematic Layout Planning (SLP) provided a structured framework for layout development based on flow relationships, space requirements, and adjacency needs. The Activity Relationship Chart (ARC) translated process interdependencies into proximity requirements and served as a key input for layout optimization algorithms such as Blocplan and Corelap [39]. Blocplan was a heuristic layout planning algorithm that generated optimized block layouts by considering material flow intensity and adjacency preferences. In the Lean context, Blocplan supported the reduction of transportation and motion waste by aligning the physical layout with process flow, thereby minimizing total material handling distance [40].

2.6. Performance Evaluation.

Evaluation of Lean implementation effectiveness was conducted by comparing process conditions before and after improvement. Future Process Activity Mapping (FPAM) and Future Value Stream Mapping (FVSM) were used to visualize post-improvement conditions and to quantify reductions in non-value-added activities and overall process time. Beyond time-based indicators, cost-based evaluation provided tangible evidence of efficiency gains. The Operator Material Handling (OMH) cost metric converted material movement distance and handling frequency into monetary values, enabling direct assessment of economic benefits achieved through reduced transportation effort and layout improvements.

2.7. Research gap and proposed framework.

The food processing industry faced specific operational challenges related to hygiene control, perishable materials, and limited production space. Previous studies showed that Lean principles could be effectively adapted to food and agro-based manufacturing systems, where

tools such as Value Stream Mapping (VSM), Root Cause Analysis (RCA), and facility layout redesign contributed to reducing transportation waste, process inefficiencies, and operational costs. However, most existing studies applied Lean tools in a fragmented manner, focusing on individual techniques rather than integrating waste prioritization, process diagnosis, and physical layout redesign into a unified improvement framework. Addressing this gap, the present study proposed a holistic Lean Layout Cost framework that integrated waste prioritization (Borda), tool selection (VALSAT), process visualization (VSM, CPAM, FPAM), root cause identification (RCA, Fishbone, 5W+1H), and systematic facility layout optimization (ARC and Blocplan), while quantitatively evaluating economic benefits using the Operator Material Handling (OMH) cost metric.

2.8. Research design.

This study employed a descriptive quantitative case study conducted at IKM Tempe Haji Emah, a traditional tempeh-producing SME in Bandung, Indonesia. Building on prior diagnostic findings that identified transportation as the dominant waste [7], this research focused on reducing transportation waste through the application of Lean Manufacturing tools and facility layout optimization, while quantitatively evaluating the resulting operational and economic improvements. The methodology integrated Lean tools in sequential stages, combining qualitative analysis (waste identification and root cause analysis) with quantitative evaluation (layout optimization and cost-based performance measurement).

2.9. Research Flow.

The research framework consisted of eleven integrated stages combining Lean Manufacturing tools with systematic facility layout optimization, as illustrated in Figure 1. The framework began with problem identification and data collection, followed by current state analysis, waste identification and prioritization, improvement design, and performance evaluation.

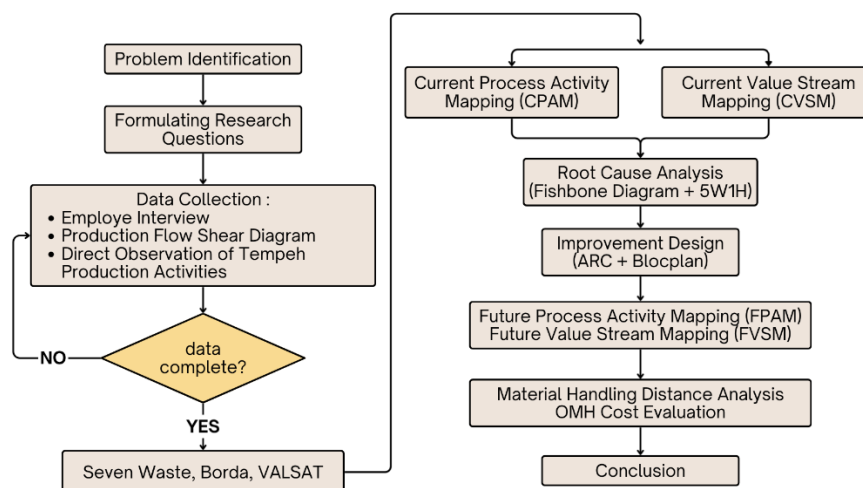


Figure 1. Research framework.

As shown in Figure 1, the study began with problem identification through direct observation and informal interviews to capture inefficiencies in the tempeh production process. Waste identification was then conducted using a structured questionnaire based on the Seven Waste framework [14]. Waste prioritization was performed using the Borda Count method to

determine the most critical waste type [29], validating transportation waste as the dominant issue in line with prior diagnostic findings [7]. Based on the prioritized waste, appropriate Lean tools were selected using the Value Stream Analysis Tool (VALSAT) [41].

Process analysis was carried out using Process Activity Mapping (PAM) and Value Stream Mapping (VSM) to develop Current Process Activity Mapping (CPAM) and Current Value Stream Mapping (CVSM), enabling the classification of activities into value-added (VA), necessary non-value-added (NNVA), and non-value-added (NVA), as well as the visualization of material flow and transportation waste. Root causes of transportation waste were identified through Root Cause Analysis (RCA) using Fishbone diagrams and the 5W+1H method [35]. Improvement actions included developing an Activity Relationship Chart (ARC) and optimizing the facility layout using the Blocplan heuristic algorithm to minimize material handling distance while maintaining process adjacency requirements [21]. The effectiveness of the proposed improvements was evaluated using Future Process Activity Mapping (FPAM) and Future Value Stream Mapping (FVSM). Finally, operational impacts were quantified through Operator Material Handling (OMH) cost evaluation by converting reductions in material handling distance into cost savings (IDR 387 per meter).

2.10. Waste Assessment and Lean Tool Application.

Waste identification was conducted using a structured questionnaire based on the Seven Waste framework. Expert judgments were collected from experienced operators and analyzed using the Borda Count method to confirm transportation as the dominant waste, consistent with prior diagnostic findings [7]. Following waste prioritization, Lean tool selection was performed using VALSAT, resulting in the selection of Process Activity Mapping (PAM), Value Stream Mapping (VSM), and Root Cause Analysis (RCA) for detailed process diagnosis [35]. Current Process Activity Mapping (CPAM) and Current Value Stream Mapping (CVSM) were developed to document material flow, activity classification (VA, NNVA, NVA), and transportation characteristics. Root causes of transportation waste were identified using RCA supported by Fishbone diagrams and the 5W+1H approach, leading to layout redesign as the primary improvement strategy. Facility layout optimization was conducted using the Systematic Layout Planning (SLP) framework, supported by Activity Relationship Charts (ARC) and optimized using the Blocplan algorithm [36]. Improvement effectiveness was evaluated by comparing total material handling distance and was quantified economically using the Operator Material Handling (OMH) cost metric.

3. Results And Discussion

3.1. Waste identification and prioritization.

The waste identification employed the Seven Waste framework, implemented through a structured questionnaire in which operators and supervisors performed pairwise comparisons of waste categories. The responses were aggregated using the Borda Count method to determine waste priority, confirming transportation as the dominant waste in the production system at IKM Tempe Haji Emah. This waste was mainly associated with frequent manual movements of soybeans between soaking, grinding, and fermentation stages, and it formed the basis for selecting Lean analysis tools in the subsequent phase [33, 34]. The results of waste

prioritization using the Borda Count method are presented in Table 1, which shows that transportation waste had the highest ranking among all identified waste types.

Table 1. Borda ranking of identified waste types.

Waste Type	Rating							Weight	Average	Ranking
	1	2	3	4	5	6	7			
Overproduction	0	0	1	2	2	3	0	17	0,103	6
Waiting	0	2	3	3	0	0	0	31	0,188	2
Transportation	0	3	3	1	1	0	0	32	0,194	1
Inappropriate Processing	0	1	3	1	2	1	0	25	0,152	4
Unnecessary Inventory	0	0	0	2	2	3	1	13	0,079	7
Unnecessary Motion	0	2	2	3	1	0	0	29	0,176	3
Defect	0	0	1	2	3	2	0	18	0,109	5
Total								165	1	28

3.2. Lean tool selection using VALSAT.

The Value Stream Analysis Tool (VALSAT) framework was applied to support the selection of appropriate Lean analytical tools for addressing transportation waste. Tool selection was based on three considerations: suitability to the production process, practicality for small-scale facilities, and potential contribution to waste reduction [14]. The scoring results indicated that Process Activity Mapping (PAM) was the most relevant tool, followed by Value Stream Mapping (VSM) and Root Cause Analysis (RCA). This combination enabled complementary analysis, where VSM provided a holistic view of material and information flows [33], PAM captured detailed non-value-added activities, and RCA facilitated structured identification of underlying causes [35]. The VALSAT framework was used to assess the suitability of various Lean tools in addressing different types of waste. The scoring matrix is presented in Table 2, where each tool was evaluated against the Seven Waste categories based on its level of effectiveness.

Table 2. VALSAT scoring Matrix.

Waste Type	Process Activity Mapping	Supply Chain Response Matrix	Production Variety Funnel	Quality Filter Mapping	Demand Amplification Mapping	Decision Point Analysis	Physical Structure
Overproduction	1	3		1	3	3	
Waiting	9	9	1		3	3	1
Transportation	9						
Inappropriate Processing	9		3	1		1	1
Unnecessary Inventory	3	9	3		9	3	
Unnecessary Motion	9	1					
Defect	1			9			

The effectiveness of various Lean tools was quantitatively evaluated using the VALSAT scoring approach. As shown in Table 3, Process Activity Mapping achieved the highest score, indicating its strong relevance for identifying and reducing transportation waste, followed by

the Supply Chain Response Matrix and Demand Amplification Mapping as supporting analytical tools [14].

Table 3. Comparison of lean tool effectiveness.

Waste Type	Score	Process Activity Mapping	Supply Chain Response Matrix	Production Variety Funnel	Quality Filter Mapping	Demand Amplification Mapping	Decision Point Analysis	Physical Structure
Overproduction	0.103	0.103	0.309		0.103	0.309	0.309	
Waiting	0.188	1.691	1.691	0.188		0.564	0.564	0.188
Transportation	0.194	1.745						
Inappropriate Processing	0.152	1.364		0.455	0.152		0.152	0.152
Unnecessary Inventory	0.079	0.236	0.709	0.236		0.709	0.236	
Unnecessary Motion	0.176	1.582	0.176					
Defect	0.109	0.109			0.982			
Total	100%	6.830	2.885	0.879	1.236	1.582	1.261	0.339
Ranking		1	2	6	5	3	4	7

3.3. Process Activity Mapping (PAM) and Current Process Activity Mapping (CPAM).

Process Activity Mapping (PAM) was applied to obtain a detailed representation of the existing production flow from raw material preparation to packaging. Each activity in the Current Process Activity Map (CPAM) was classified into Operation (O), Transportation (T), Inspection (I), Delay (D), and Storage (S), and further grouped as Value-Added (VA), Non-Value-Added (NVA), or Necessary but Non-Value-Added (NNVA) to assess time distribution and overall process efficiency [33, 34]. The CPAM results are presented in Table 4, highlighting the distribution of activity types and their corresponding time consumption. It was observed that operation activities accounted for the majority of total processing time, whereas transportation activities, although smaller in proportion, represented non-value-added time that contributed to overall inefficiency [34].

Table 4. Summary of CPAM results (activity type and time distribution).

Activity Code	Quantity	Time (s)	Time (m)	Time (j)
Operation	26	216185	3603	60,05
Transportation	12	4529	75	1,26
Inspection	1	100	2	0,03
Delay	0	0	0	0
Storage	0	0	0	0
Total	39	220814	3680	61,34

The results indicated that operation and transportation activities dominated the total process time, with transportation alone reaching 1.26 hours per cycle, reflecting substantial non-value-added (NVA) time caused by inefficient layout and repeated manual handling between stations. Activities were then categorized into VA, NVA, and NNVA for further analysis [33]. As shown in Table 5, value-added (VA) activities accounted for the majority of total processing time (58.34 hours), whereas non-value-added (NVA) and necessary non-value-

added (NNVA) activities contributed 0.59 hours and 2.41 hours, respectively. Although relatively small, NVA activities represented pure waste and highlighted opportunities for process improvement [34].

Table 5. Recapitulation of CPAM activity values.

Activity Type	Quantity	Time (s)	Time (m)	Time (h)
VA	13	210,011	3,5	58.34
NVA	5	2,125	35	0.59
NNVA	21	8,678	145	2.41
Total	39	220,814	3,68	61.34

The CPAM results showed that value-added (VA) activities accounted for approximately 95.1% of total process time, while non-value-added (NVA) and necessary non-value-added (NNVA) activities contributed 4.9%, largely driven by transportation and waiting. This high proportion of VA indicated that the production process was relatively efficient. However, compared to previous studies where NVA typically ranged between 10–30% in traditional manufacturing systems, the lower NVA value in this study suggested a more streamlined process [34]. Nevertheless, the presence of transportation-related waste indicated that further improvements were still required, particularly through facility layout optimization. Despite the high proportion of VA time, this study focused Lean improvements on transportation-related NVA due to its significant impact on cycle time, operator workload, and material flow continuity. These findings formed the basis for the subsequent Root Cause Analysis (RCA) and 5W+1H, followed by layout redesign using the Blocplan algorithm to reduce transportation waste and enhance workflow efficiency [40].

3.4. Root Cause Analysis (RCA)

Root Cause Analysis (RCA) was performed using a Fishbone (Ishikawa) diagram to identify the underlying causes of transportation waste, as shown in Figure 2 [35]. The results confirmed that layout inefficiency was a primary driver of excessive transportation. In this study, RCA findings were not only diagnostic but were directly translated into spatial improvement parameters through the development of an Activity Relationship Chart (ARC) and subsequent Blocplan-based layout optimization [36, 40].

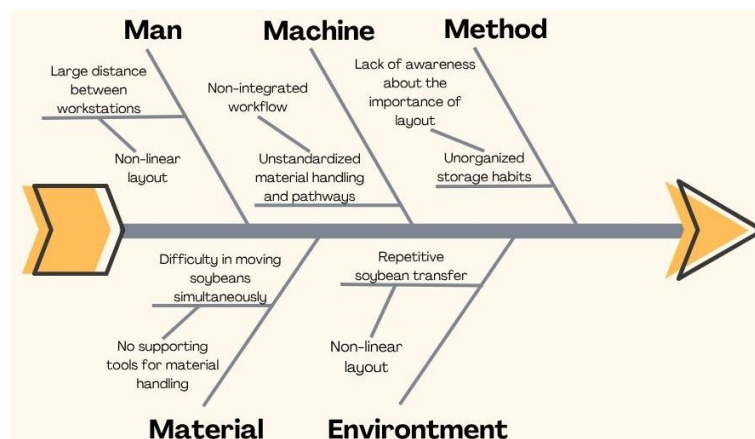


Figure 2. Fishbone Diagram of Transportation Waste

The Fishbone analysis identified five key contributing factors: long distances and non-linear layout (Environment), unstandardized material flow (Method), disorganized work habits (Man), lack of material handling aids (Machine), and repetitive soybean movements (Material). Collectively, these factors generated excessive operator movement and transportation time, confirming layout inefficiency as the root cause of transportation waste [35]. Consequently, the next phase focused on layout optimization using the Activity Relationship Chart (ARC) and the Blocplan algorithm to improve material flow and reduce handling distance [36, 40]. The Current State Value Stream Map (CVSM) is presented in Figure 3, illustrating the overall production flow, material movement, and transportation activities within the system. The labels A, B, C, and so on represented sequential workstations in the tempeh production process, from raw material preparation to final product packaging [33]. A Future State Map (FSM) was then developed to represent the desired condition after implementing Lean improvements and layout redesign. The FSM eliminated unnecessary backtracking and aligned material flow sequentially with production steps, as shown in Figure 4. In the FSM, the letters A–F indicated sequential process stages in the production system, from raw material receiving to final product shipment [33, 37]. This visualization supported the identification of physical improvement opportunities in the facility layout.

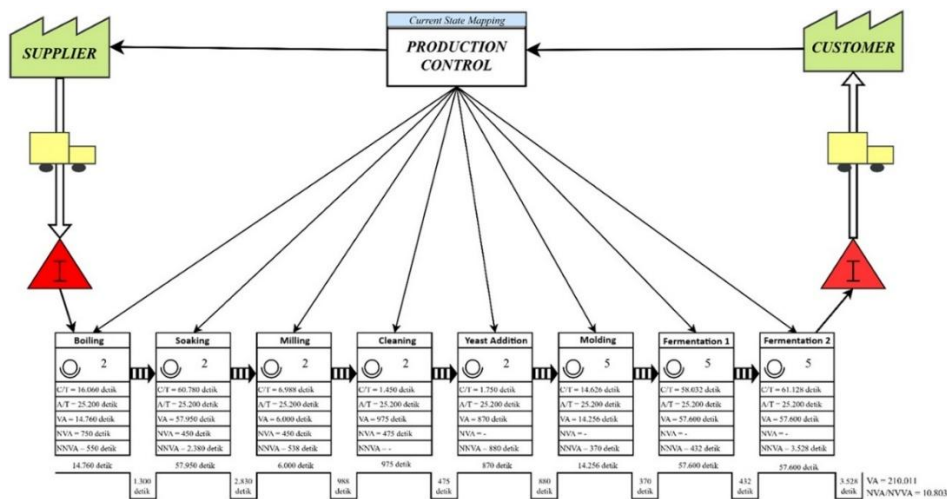


Figure 3. Current state value stream map.

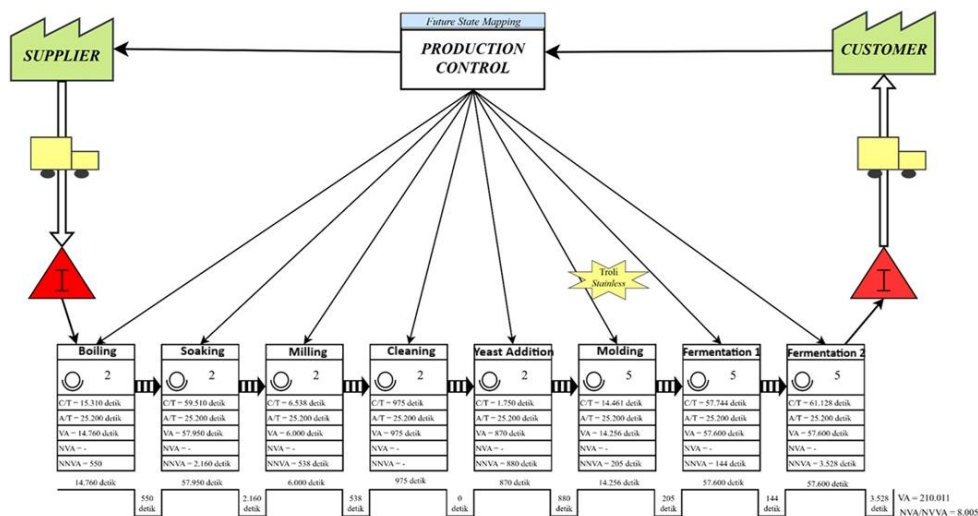


Figure 4. Future State Value Stream Map. A = Raw material receiving, B = Processing, C = Assembly, D = Inspection, E = Packaging, F = Finished goods shipping.

3.5 Root cause analysis summary.

Consistent with previous findings, Root Cause Analysis (RCA) revealed that excessive transportation was mainly caused by manual material handling, disorganized workstation arrangement, and narrow workspaces with cross flows [35]. These findings served as the basis for developing the new layout configuration. To mitigate the identified transportation waste, the Blocplan algorithm was employed as the primary layout optimization tool within the Systematic Layout Planning (SLP) framework [36, 40]. The algorithm utilized three main inputs: (1) From-To Chart data, (2) Activity Relationship (Closeness) Chart, and (3) production sequence derived from the Future State Map [33, 39]. The existing facility layout showed a functional arrangement of production areas, which resulted in material backtracking and inefficient flow between processes, as illustrated in Figure 5. After the layout redesign, the proposed facility layout was developed using the Blocplan method, as shown in Figure 6. The new layout aimed to improve material flow and reduce unnecessary transportation. Subsequently, the total material handling distance was remeasured to quantify efficiency gains [40].

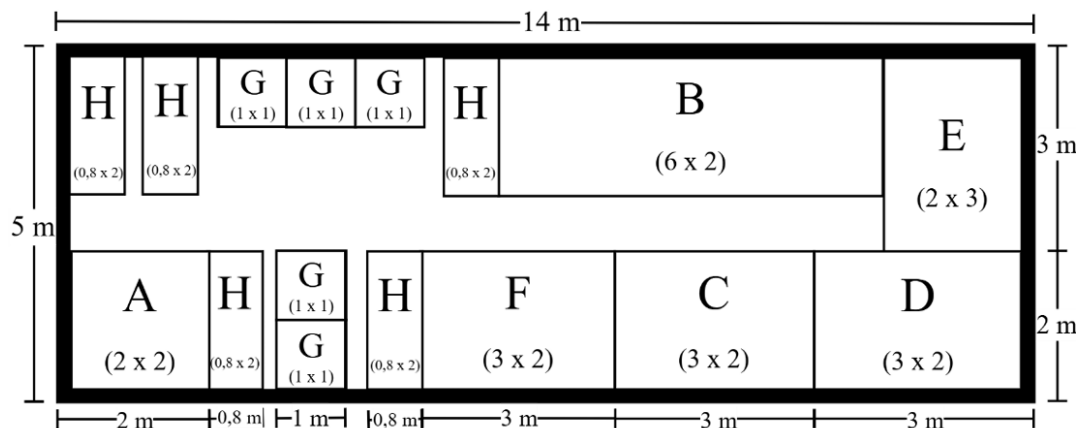


Figure 5 . Existing facility layout.

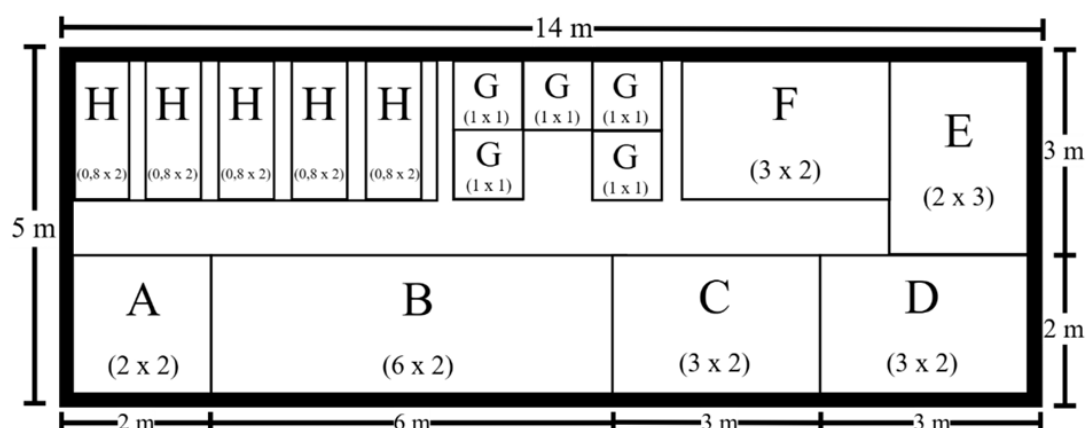


Figure 6. Proposed facility layout using blocplan method.

4.6. Evaluation of material handling distance reduction.

The effectiveness of the proposed facility layout generated using the Blocplan algorithm was evaluated by comparing total material handling distances before and after improvement [40].

Material handling distance was a key performance indicator in Lean-based layout redesign, as it directly represented transportation waste and operator movement within the production system [33, 34].

Table X compares material flow distances under existing and improved layouts. Under the current condition, total material handling distance reached 710 meters per production cycle, reflecting frequent back-and-forth movements between workstations. This result was consistent with the CPAM findings, which identified transportation as a major contributor to non-value-added activities [33].

Following layout implementation, the total material handling distance decreased to 575 meters, resulting in a net reduction of 135 meters or 19.01%. This improvement was achieved by repositioning highly interrelated workstations closer to each other, particularly within soybean preparation, molding, and fermentation processes [36, 40]. The most notable reductions occurred in material transfers between soybean storage and boiling, as well as between molding and fermentation stages.

The reduced material handling distance indicated that the proposed layout successfully aligned workstation arrangement with the actual production sequence. By minimizing unnecessary transportation and cross-flow movements, the redesigned layout supported smoother material flow and reduced operator workload [37, 38]. These findings demonstrated that integrating Lean Manufacturing tools with systematic layout planning using the Blocplan algorithm was effective in reducing transportation waste in labor-intensive food SMEs [34, 40]. The improvement in material flow performance provided a basis for further evaluation using cost-based indicators. Accordingly, the next section quantified the economic impact of the reduced material handling distance through Operator Material Handling (OMH) cost analysis.

4.7. Integrated results analysis and discussion.

The Seven Waste and Borda analysis confirmed transportation as the most critical inefficiency in the tempeh production system, obtaining the highest score (32), while unnecessary inventory ranked lowest (13). This indicated that excessive material movement was the dominant source of non-value-added activities. This study extended waste identification results into operational improvement by applying VALSAT to guide Lean tool selection and by implementing an integrated set of methods comprising Process Activity Mapping (PAM), Value Stream Mapping (VSM), Root Cause Analysis (RCA), and facility layout optimization using the Blocplan algorithm [33, 35, 40]. Unlike diagnostic-focused studies, improvement effectiveness was evaluated using both process-based indicators and economic measures through the Operator Material Handling (OMH) cost metric.

The VALSAT results identified Process Activity Mapping (PAM) as the most relevant tool (score = 6.830) [41]. Comparative analysis between CPAM and FPAM showed a reduction in total process time from 220,814 to 218,016 seconds. Non-value-added activities were eliminated, while necessary non-value-added activities were reduced, and value-added activities remained unchanged, indicating efficiency gains without disrupting core production. Transportation performance improved most significantly, with transportation time reduced by approximately 57% (from 4,529 to 1,951 seconds). This confirmed that layout redesign effectively minimized transportation waste by shortening travel distances and improving material flow continuity [33, 40]. Overall, integrating Lean Manufacturing tools with systematic facility layout optimization provided measurable operational and economic

benefits. The proposed Lean Layout Cost framework bridged diagnostic analysis and solution implementation, offering a practical and replicable improvement model for labor-intensive food SMEs.

The findings of this study were consistent with previous research in Lean Manufacturing and facility layout optimization. Prior studies [33, 34] reported that transportation waste was often a dominant inefficiency in labor-intensive production systems, particularly in SMEs. The application of Value Stream Mapping had also been shown to effectively identify and reduce non-value-added activities [33].

Compared to earlier studies, this research provided a more comprehensive approach by integrating diagnostic tools with quantitative layout redesign using the Blocplan algorithm [39, 40]. While previous works primarily focused on waste identification and qualitative improvements, this study demonstrated measurable performance enhancement, including a 57% reduction in transportation time and improved material flow efficiency.

5. Conclusion

This study concluded that integrating Lean Manufacturing tools with systematic facility layout optimization improved operational efficiency in traditional tempeh production. Transportation was identified as the most critical waste, and the layout redesign significantly reduced inefficiencies. Transportation time decreased by 57% and material handling distance by 19%, while non-value-added activities were eliminated without affecting value-added processes. The integration of Lean analysis and Blocplan-based layout redesign provided measurable operational and economic benefits for labor-intensive food SMEs. The proposed Lean Layout Cost framework offered a practical approach to reducing transportation waste and improving productivity under limited resource conditions.

Acknowledgments

The author would like to thank the management and workers of IKM Tempe Haji Emah for their cooperation and support during the data collection process. The author also acknowledged Universitas Widyatama for providing academic support for this research.

Author Contribution

Conceptualization: Tiaradia Ihsan; Methodology: Tiaradia Ihsan; Data Collection: Tiaradia Ihsan; Data Analysis: Mila Oktaviani and Tiaradia Ihsan; Data Verification: Rendiyatna Ferdian; Writing – Original Draft Preparation: Tiaradia Ihsan; Writing – Review and Editing: Tiaradia Ihsan and Rendiyatna Ferdian; Supervision: Tiaradia Ihsan.

Competing Interest

The authors declare that they have no competing interests regarding the publication of this paper.

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