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Lean Manufacturing Development Model for Production Cost Reduction in Small and Medium Industries (SMEs) of Tempeh Food with a Green Manufacturing Approach

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ABSTRACT

The Small and Medium Industry (SMEs) of tempeh food is a strategic sector in supporting food security and local economic empowerment. However, the main challenges faced are high production costs due to waste and low process efficiency. This research aims to develop a Lean Manufacturing model based on the Green Manufacturing approach to reduce production costs in a sustainable manner. The research method involves identifying the type of waste using the Value Stream Mapping (VSM) approach, analyzing the root of the problem with Fishbone diagrams, and designing solutions through the integration of lean and green principles, such as 5S, Kaizen, and environmentally friendly waste management. A case study was conducted on one of the tempeh SMEs in Sanan, Malang City, East Java, Indonesia. The results of the research showed that weekly production costs decreased from IDR 3,188,000 to IDR 2,998,250 (efficiency ±17%), defective products decreased from 4.7% to 1.5% (68% decrease), total processing time decreased from 2,605 minutes to 1,332 minutes (time savings ±14%). Waiting time is reduced by more than 50%. These findings show that the Lean-Green Manufacturing approach not only improves operational efficiency, but also encourages sustainable production practices that are relevant to the development of food SMEs in Indonesia

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1. INTRODUCTION

In the industrial field, achieving the target demand and getting optimal profits without spending excessive costs is one of the important key factors desired by every business actor. In fact, Indonesia itself is included in the country in Southeast Asia with a fairly large MSME business where as reported by Kominfo there are 3.79 million SMEs registered in Indonesia. Many SMEs are competing to promote a product with a new variety that they sell with the aim of making a profit. In this case, sometimes SMEs are not aware that small things can provide additional income if processed properly, one of which is utilizing production waste. To overcome the impact on environmental problems caused by industry, a concept was created that aims to overcome environmental problems. As the object of research on Small and Medium Industries (SMEs) tempe sanan. In the context of this research, the place to be researched is SMEs Kripik Tempe Amanah, this SMEs is a business engaged in food processing, especially the manufacture of tempeh and tempeh chips located in Sanan Gg. III, Purwantoro, Blimbing District, Malang City, East Java.

Small and Medium Industries (SMEs) in Indonesia, especially in the processed food sector such as tempeh, play a very vital role in the national economy. Tempeh, which is known as an affordable and nutritious source of plant-based protein, is widely produced by SMEs in various regions. However, most SMEs face major challenges related to operational efficiency and high production costs, which limit their competitiveness in domestic and international markets [1]. For this reason, efforts to increase efficiency and reduce production costs are needed so that SMEs can continue to exist and develop. Lean manufacturing, which focuses on reducing waste and improving the efficiency of the production process, has proven to be an effective method to lower production costs in many large industries [1].

This lean manufacturing concept can be adapted for SMEs, even though they face obstacles such as limited resources and technology [2]. The implementation of lean manufacturing in tempe SMEs will help identify and eliminate existing wastes in the production process, such as waste of raw materials, labor, and time, all of which can contribute to a significant reduction in production costs [3]. In addition, the green manufacturing approach that prioritizes resource efficiency, waste reduction, and the use of environmentally friendly technology is gaining more attention in the manufacturing industry.

Green manufacturing not only aims to reduce environmental impact, but can also contribute to the reduction of production costs through energy efficiency and raw materials [4]. The integration of lean manufacturing with green manufacturing, known as "Lean and Green", has the potential to increase industrial sustainability while lowering production costs [5]. However, the application of these two approaches to SMEs, especially in the tempeh food industry, requires special adaptation. Factors such as simple production processes, limited technology, and limited capital are challenges that must be overcome [6]. Therefore, this study aims to develop a lean manufacturing model that can be implemented in tempeh SMEs with a green manufacturing approach to effectively reduce production costs. This research aims to develop a Lean-Green Manufacturing model that can be applied practically to tempeh food SMEs to identify sources of waste, design process improvements, and reduce production costs without neglecting environmental aspects. This approach is expected not only to improve operational efficiency but also to strengthen the competitiveness of SMEs in a sustainable manner.

2. LITERATURE REVIEW

2.1 Small and Medium Industry (SMEs) Tempeh Food

Small and Medium Industries (SMEs) play an important role in supporting national economic growth, especially in the local food sector such as tempeh. Tempeh, as a typical Indonesian fermented product, is produced by many SMEs spread across various regions and is a source of livelihood for the community [7]. However, the challenge of production efficiency and waste management is still the main problem in the sustainability of tempeh food SMEs [8].

Figure 1. Tempe Sanan Artisans
(Source: Research Object 2025)

Tempeh artisans in the center of the tempeh industry in Sanan, Malang City continue to choose production amid the increase in the price of imported soybeans [9]. They continue to produce by reducing the size of tempeh from usual [10].

2.2 *Lean Manufacturing in the Context of SMEs*

Lean Manufacturing is a systematic approach to identify and eliminate waste in the production process without sacrificing customer value [11]. This concept emphasizes operational efficiency, cost reduction, and improved product quality. The application of lean in SMEs can increase productivity and competitiveness, although it requires adjustments to small-scale resources and capacities [12]. Lean principles such as **Value Stream Mapping (VSM), 5S**, **Kaizen**, and **Just In Time (JIT)** have proven to be effective in reducing wasted time, materials, and energy on the production line [12]. However, the success of lean implementation in SMEs is highly dependent on human resource training and management commitment [12]. Transformation of Tempe Sanan SMEs with Lean Management and Value Stream Mapping (VSM) for Production Process Efficiency [13]

2.3 *Green Manufacturing: Synergy with Lean*

Green Manufacturing is a production approach that emphasizes energy efficiency and minimization of environmental impact throughout the product life cycle [14]. This approach can be synergized with Lean Manufacturing, known as **Green Lean**, which not only eliminates waste from a cost perspective, but also from an environmental perspective [15].

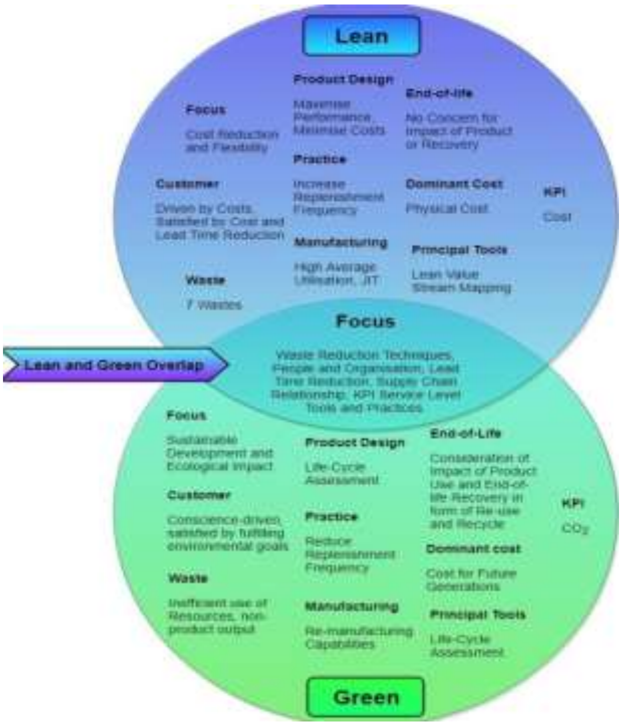

Figure 2. Relationship between lean and green approaches

In the context of tempeh SMEs, green manufacturing integration can be implemented through reducing water and energy use during the fermentation process, managing solid and liquid waste, and reusing soybean waste as animal feed or organic fertilizer [16].

2.4 *Reduction of production costs through a lean-green model*

Production costs in tempeh food SMEs often swell due to unrealized waste in the production process, such as overproduction, defects, and waiting time [17]. The integrated application of the lean-green manufacturing model can help identify points of waste and establish sustainable improvement measures. For example, replacing wood fuel with biogas from fermented waste can reduce energy costs while reducing emissions [18]. Several studies state that the simultaneous implementation of the lean-green model can result in an increase in efficiency of up to 30% and a reduction in operational costs of 15-25% in the food sector. In the context of SMEs, this approach must be designed adaptively according to the technological and managerial capacity they have.

2.5 Development of Lean-Green Model for Tempe SMEs

The lean-green manufacturing development model for tempeh food SMEs must pay attention to the aspects of locality, production culture, and environmental awareness of industry players. This model ideally consists of a phase of identifying waste, mapping the production process, determining green performance indicators (green KPIs) [19], and measuring the impact of implementation on costs and the environment [20]. Several tools such as **Life Cycle Assessment (LCA)** and **Environmental Value Stream Mapping (EVSM)** can be used to evaluate the environmental performance of the tempeh production process [21]. In addition, the role of collaboration between the government, academics, and industry players is important in fostering and developing a lean and environmentally friendly tempeh production system [22].

3. METHODS

This study uses a qualitative-quantitative approach (mix-method) with a case study on one of the tempeh food SMEs in Sanan City, Malang, East Java, Indonesia. This method is designed to identify waste in the production process, analyze the root causes, and develop relevant and applicable Lean-Green Manufacturing models. Research methods are research steps when conducting research or finding a solution to find a way out so that it can run in a structured, systematic manner and make it easier to draw conclusions from research results. The method in this study starts from data collection. The data needed by the researcher include: primary data and secondary data. Primary data is data obtained directly from SMEs or data that occurs in the field obtained from interview techniques, especially with the authorities with this research. The secondary data is data obtained from SMEs in a ready-made form. The data obtained is in the form of qualitative and quantitative data

3.1 Research Stages

The stages of this research method are arranged as follows:

A. Identify the Production Process

Field observations and interviews were conducted to map the flow of the tempeh production process, from the receipt of raw materials to the distribution of the final product [23].

B. Value mapping (VSM)

VSM is used to identify value-added and non-value-added activities in the production chain [24].

C. Identify the type of waste and the root of the problem 7 waste (young) approach in Lean: overproduction, waiting, transportation, overprocessing, inventory, motion, and defect [17]. The root of the problem analysis was carried out using the Fishbone Diagram (Ishikawa).

D. Integration of lean and green tools

Tools such as 5S, Kaizen, and waste management are applied according to the principles of Green Manufacturing to reduce waste and environmental impact [18].

E. Model development and validation

The Lean-Green Manufacturing model is compiled and validated through process improvement simulations as well as cost and efficiency impact analysis.

3.2 Research Method Flow Drawing

The following is a picture of the stages of the research method:

Figure 3. Research Method Flow

In the initial stage, direct observation was carried out on all tempeh production activities starting from the receipt of raw materials (soybeans), the soaking process, boiling, fermentation, to packaging. The main goal of this stage is to understand the process flow and record potential inefficiencies that occur at each stage of production. This method combines operational efficiency (lean) with environmental sustainability (green), and is designed to provide practical and applicative solutions at the scale of food SMEs, especially the tempeh industry which often has limited resources but has great potential for improving production processes.

4. RESULTS AND DISCUSSION

4.1 Data Collection

Data collection in this study was carried out systematically to obtain accurate and relevant information related to the production process, waste, costs, and environmental impacts arising from tempeh production activities on the Small and Medium Industry (IKM) scale. The data collection method was compiled to support the development of Lean Manufacturing models that are integrated with the Green Manufacturing approach.

A. Field studies and direct observation

Observation was carried out directly to the location of Tempe SMEs to observe the flow of the production process from the receipt of raw materials to the final packaging. This activity aims to:

- Identify the stages of the production process.
- Record the processing time and wait time at each workstation.
- Analyze activities that are Value Added and Non-Value Added
- Document activities that indicate waste, such as overproduction, waiting, defect, transportation, motion, overprocessing, and excess inventory.

B. Structured interviews

Interviews were conducted with business owners and production workers as many as three people using a structured question guide. The aim is to obtain qualitative information related to:

- Is there an unnecessary process in the production process?
- What percentage of products fail in one production process?
- Are there workers who do not do their work during the production process?
- How long does it take to deliver raw materials to the production site?
- Is there any excess inventory at the time of production?
- Is there any excess expenditure during the production process?
- Are there any movements that are not required during production?
- Is it still using electricity at the time of production?
- Are you satisfied with the packaging at this point?
- Does production produce pollution?
- Are there workers who work optimally during the production process?
- Are there any products that are not sold in one production process?

The results of this interview will later be given a score (1-5), where 1 is the lowest and 5 is the highest. From the value that has been collected, it will later be multiplied by the VALSAT multiplier factor to determine the right method to experience waste that occurs during the production process.

C. Quantitative data logging

Quantitative data is collected to conduct cost analysis and impact measurement of lean & green improvement. The data collected includes:

- Daily/weekly production amount.

- LPG consumption (number of cylinders per week).
- Volume of water use.
- Weekly operational costs (raw materials, energy, packaging, labor).
- Number of defective products per week.
- The amount of plastic and organic waste generated.

Data are recorded during a 7-day consecutive observation period to ensure the accuracy of the weekly average.

D. Documentation and field photos

Data collection is also supported by visual documentation in the form of photos of workflows, production tools, workplace layouts, and waste conditions. This documentation helps in Value Stream Mapping (VSM) mapping and process validation.

E. Literature studies and secondary data

As a complement, secondary data is collected through

- Literature study related to Lean Manufacturing, Green Manufacturing, and food SMEs.
- Statistical data from government agencies or industry offices related to the number of tempeh SMEs and their production patterns.

4.2 *Data Processing*

After all primary and secondary data is collected through observation, interviews, quantitative recording, and field documentation, the next step is data processing. This stage aims to analyze the actual condition of tempeh SMEs, identify waste, and simulate potential improvements through Lean and Green Manufacturing approaches.

A. Production pipeline mapping using VSM

The first step in data processing is to create a value stream map. This map depicts all stages of the tempeh production process, from the receipt of raw materials to the packaging of finished products, accompanied by information on process time, waiting time, and identification of value-added (Value Added/VA) and non-value-added (Non-Value Added/NVA) activities.

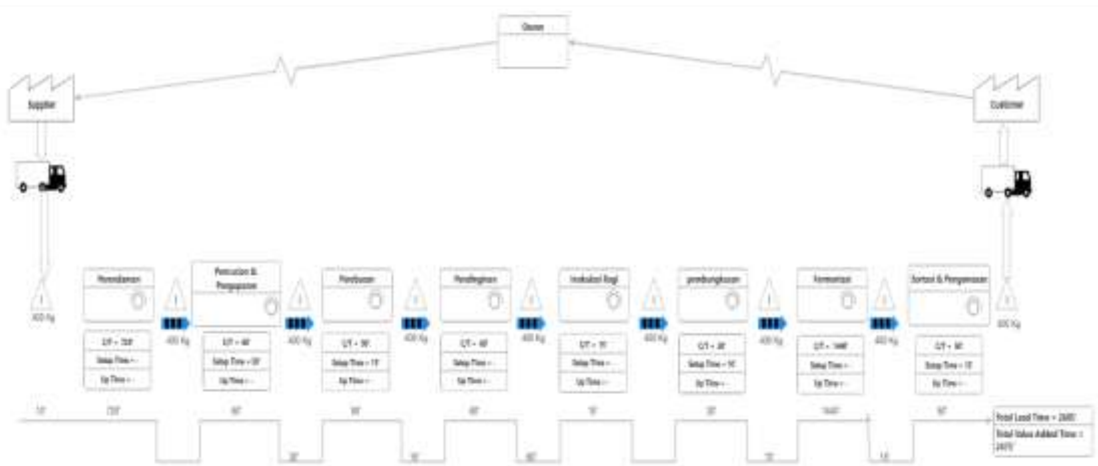

Figure 4. CSM Tempe Process Picture (Source: Processed Data 2025)

The CSM (Current State Mapping) shows that there are nine processes from the delivery of raw materials (soybeans) to tempeh packaging where from all processes it is obtained a lead time of 2,605 minutes and a total value added time of 2,475 minutes.

B. Waste analysis with lean manufacturing principles

After the VSM is created, the data is analyzed to identify the types of waste based on the Lean Manufacturing approach. This analysis includes:

- Waiting (fermentation and cooling waiting time)
  1. Lead time higher than Value Added Time
  2. Some processes just wait without any value-adding process.
- Defect (product fails due to unstable process), Overprocessing (inefficient washing or packaging process)
  1. Some processes have high times such as fermentation and immersion.
- Transportation & Motion (ineffective movement of materials or workers)
  1. The waste that has been identified is then described in Table 1.

Table 1. Waste production process

Types of Waste	Location/Process	Evidence/Indications	Estimated Losses
Overproduction	Production is not to order	Unsold leftover products (2×/week)	IDR 300,000/week
Waiting	Cooling & fermentation	Waiting for a natural process with no added value	-
Transportation	Between production stations	Distance ±20 meters between processes	IDR 100,000/week
Overprocessing	Washing & Packing	3x wash, plastic overwrap	IDR 75,000/week
Inventory	Soybean stocks are piling up	Not in accordance with production capacity	IDR 220,000/week
Motion	Final packaging	Unergonomic working position	IDR 60,000/week
Defect	Fermentation	The product fails due to unstable temperature	IDR 280,000/week

C. VALSAT

After interviews with three sources and direct observations, the next step is to determine the right method to overcome waste using VALSAT.

Table 2. VALSAT Table

Waste	Sources			Average
	Anna's mother	Mother Nature	Mrs. Trinil (chair)	
Inapropriate processing	3	3	2	2,7
defect	2	2	2	2,0
waiting	3	3	1	2,3
transportation	1	1	3	1,7
unnecessary inventory	2	2	1	1,7
unnecessary overhead	2	1	2	1,7
unnecessary motion	1	1	2	1,3
power and energy	2	2	3	2,3
innapropriate design	1	1	3	1,7
enivironmental pollution	1	3	3	2,3

human potential	2	3	1	2,0
overproduction	3	3	3	3,0

After obtaining the value of each waste that occurred based on interviews with three sources, then the results of the value obtained will be multiplied by the VALSAT multiplier factor to determine the appropriate handling method.

Table 3. VALSAT Matrix Multiplication

Waste	PAM	OSCEM	SCRM	VATP	SCRM	QFM	DPA	PSM	PVF	DAM
inappropriate processing	24,0	8,0	8,0	8,0	8,0	2,7	8,0	24,0	8,0	2,7
defect	2,0	18,0	2,0	2,0	2,0	18,0	2,0	2,0	6,0	18,0
waiting	21,0	7,0	2,3	2,3	2,3	2,3	2,3	7,0	2,3	2,3
transportation	1,7	1,7	1,7	5,0	5,0	1,7	5,0	1,7	1,7	5,0
unnecessary inventory	5,0	5,0	15,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0
unnecessary overhead	5,0	5,0	5,0	15,0	5,0	15,0	5,0	1,7	1,7	5,0
unnecessary motion	12,0	1,3	4,0	1,3	1,3	1,3	1,3	4,0	1,3	1,3
power and energy	2,3	7,0	2,3	7,0	2,3	2,3	2,3	2,3	2,3	2,3
inappropriate design	1,7	1,7	1,7	5,0	1,7	1,7	1,7	1,7	1,7	1,7
environmental pollution	2,3	2,3	2,3	21,0	7,0	2,3	2,3	7,0	2,3	2,3
human potential	18,0	6,0	6,0	2,0	2,0	2,0	6,0	6,0	6,0	2,0
overproduction	9,0	3,0	9,0	3,0	3,0	3,0	27,0	9,0	27,0	9,0
Total	104,0	66,0	59,3	76,7	44,7	57,3	68,0	71,3	65,3	56,7
Ranking	1	3	8	2	10	7	5	4	6	9

Table 3 is obtained from the value multiplier of the results of interviews with the resource persons with multipliers H (9), M(3), and L(1), after which the highest ranking score is obtained namely PAM (Production Activity Mapping) and VATP (Value Analysis Time Profile) which will be the method for handling waste that occurs.

D. PAM (Production Activity Mapping)

Production Activity Mapping is a mapping technique used to describe and analyze detailed activities in the production process in detail. The main objective is to identify the types of activities in the process, including value-added operations and non-waste-based activities, such as transportation, inspection, storage, and delays.

Table 4. PAM Table.

Tempe							
No	**Activity**	**Machine**	**Dist (M)**	**Time (Min)**	**Man**	**Category**	**Note**
1	Soybean Shipping	Engine	5	10	1	Transport	VA
2	Soybean Opening	Scissors	-	2	1	Operation	NNVA
3	Soy pouring	-	0,5	5		Operation	NNVA
4	soy soaking	Pan	-	720		Waiting	VA
5	Soybean Raised	Sieve	-	5		Operation	NVA

6	Soybean pouring	-	0,5	5		Transport	NVA
7	Soybeans washed and peeled	Pan	-	60	1	Operation	VA
8	Soybean Removal	Sieve	-	5		Operation	NVA
9	Soybean pouring	-	0,5	5		Transport	NVA
10	boiled soybeans	Pan	-	-	1	Operation	VA
11	Waiting for the soybeans to ripen	-	-	90		waiting	VA
12	Soybean Raised	Sieve	-	5		Operation	NVA
13	Soybean pouring	-	0,5	5		Transport	NVA
14	Chilled soybeans	Tampah	-	60		waiting	VA
15	Yeast pouring	-	1	15	1	Operation	VA
16	Put the lid on top of the tempeh	Plastic	-	30		Transport	NNVA
17	Waiting for the tempeh to be finished	-	-	1440		waiting	NNVA
18	Tempeh sorting	-	-	15	1	Operation	VA
19	Tempeh Packaging	-	1	35		Operation	VA
Jumlah			9	2512	6		

Source : processed data

Table 4. shows that there are some activities that do not provide added value and some that provide added value. From the table, there are 53% of activities in the form of operations, 26% of activities in the form of movements, and 21% of activities in the form of delays. This analysis will be used to build a future state mapping based on what waste occurs and how to deal with it.

E. Value Analysis Time Profile (VATP)

Value Analysis Time Profile is a tool or method in value analysis that maps the time duration of each step in a production process or service from the customer's perspective. The goal is to identify the most time-consuming steps and determine which ones are truly value-added and which are wasted in terms of time.

Table 5. VATP Table

Activity	Cost Rate (Rp/Hour/Kg)	Materials (Rp)	Duration (Hours)	Begin	Cost (Rp.)	End	Accumulation Cost (Rp.)
Soybean Shipping	10.000	2.740.000	0	0	2.750.000	0	2.750.000
Immersion	0	0	12	12	0	0	2.750.000
Washing & Stripping	0	0	1	13	0	24	2.750.000
Boiling	198.000	0	1,5	14,5	297.000	25	3.047.000
Cooling	23500	0	1	15,5	23.500	26,5	3.070.500
Yeast inoculation	0	70.000	0,25	15,75	17.500	27,5	3.088.000
Packaging	0	0	0,5	16,25	0	27,75	3.088.000
Fermentation	0	0	24	40,25	0	28,25	3.088.000
Sorting	0	0	0,3	40,55	0	52,25	3.088.000
Packaging	200.000	0	0,5	41,05	100000	53,05	3.188.000

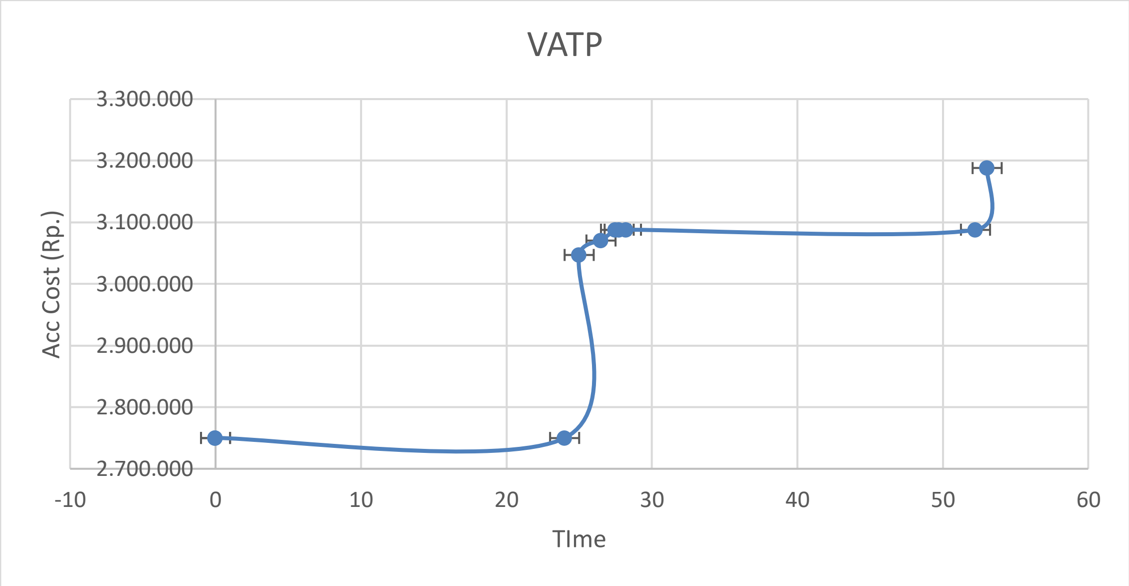

Figure 5. Value Analysis Time Profile before repair

Table 5. and Figure 5 show the results of the analysis of time to costs during the production process, with the result that during the 53.05 hours of the production process, the required cost is Rp. 3,188,500. The data from this analysis will also be used in building Future State Mapping.

F. Environmental impact analysis with a green manufacturing approach

The data was also analyzed from an environmental perspective using the Green Manufacturing method. Some of the parameters of the environment that are processed include:

- Energy consumption before and after repairs,
- Clean water usage per week,
- Solid waste volume
- Organic waste

From this data processing, it was obtained that the application of the 4R principle (Reduce, Reuse, Recycle, Replace) was able to produce:

- Reduce
  1. Optimizing raw materials so as to reduce waste that must be disposed of and can reduce the cost of raw materials
  2. Reduce water use at the washing and stripping stages so that it can save water, reduce the volume of liquid waste, and reduce waste treatment costs
  3. Reduce consumption by optimizing processes that require large amounts of energy so that they can reduce CO_2 gas emissions.
  4. Reduce lead times so that it can reduce storage costs and speed up production flow.
- Reuse
  1. Relatively clean water can be filtered and reused for other non-production purposes, thereby reducing clean water consumption and reducing waste volume.
  2. Using reusable containers (washable and reusable) so that it can reduce packaging waste and save the cost of buying new packaging.

- Recycle
  1. Organic waste from the process that produces waste that can be reprocessed can be used into fertilizer, fuel, or raw materials so that it can create an environment with zero waste
  2. Packaging waste can be collected and recycled for other purposes, reducing the burden on landfills.
- Replace

  If the volume of solid or liquid waste is too large and cannot be reused, it can be processed by means of Anaerobic Digestion (making it into methane) or by incineration (burning waste to produce heat/electrical energy) so that it is possible to create new energy that can replace the fuel that has been used.

G. Creation of Future State Mapping

From the data that has been analyzed and processed, it is found that ways to improve or reduce existing waste using Future State Mapping. Future State Mapping will be a map that illustrates ways to reduce or even eliminate waste that still occurs in the production process. Calculations based on PAM, VATP, and green manufacturing (4R) tools can be a reference for what must be done to reduce existing waste. In the tempeh production process, reductions and improvements are made in several production processes in tempeh. In the soaking process, the time needed to soak is reduced to 50% from the previous time, this is done to minimize time wasted due to ineffective work.

Furthermore, parallel processing is carried out for the washing & peeling, boiling, and cooling processes, this is done because too much water is used and movements are carried out if the three processes are carried out separately.

The next step is to standardize yeast inoculation, packaging, and sorting & packaging, this is done to reduce the time required and also reduce the waste produced.

Finally, by conducting experiments on the fermentation process, this still has to be researched many times whether the time of 1440 minutes cannot be changed or can still be reduced but does not reduce the value of the product. It is estimated that if the large time can be reduced and does not reduce the value of the product, then the time for fermentation can be reduced to 720 minutes from 1440 minutes.

H. Kaizen Recommendations

In addition to recommendations for making Future State Mapping, recommendations for improvement based on Kaizen principles were also added. In this kaizen recommendation, more emphasis will be placed on the addition of tools or replacement of tools that are considered possible to reduce existing waste as shown in Table 6.

Table 6. Kaizen Recommendation Table

Area	Proposed improvements
Cooling	Add parallel processes such as labeling
Fermentation	Use multi-level shelves and automatic temperature sensors
Packaging	Use eco-friendly & appropriate wrappers
Transportation	Cellular layout rearrangement
Boiling	Use an energy-efficient or biomass stove

Apart from the table's kaizen recommendations, there are kaizen recommendations based on Green Manufactur such as Table 7.

Table 7. Recommendations for Kaizen improvement based on Green Manufacturing

Area	Solution	Types of Principles	Benefit
Energy	Use an energy-efficient or biomass stove	Replace	Reduce CO_2 emissions, and reduce LPG consumption
Water	Reuse for further washing	Reuse	Reduces water consumption by 30%
Plastic	Replace with banana leaves	Replace	Reduce plastic waste
Organic waste	Processed into fertilizer or animal feed	Recycle	Reducing organic waste

From the two tables, they will later be included in the Future State Mapping to be a reference in handling existing waste.

I. Future State Mapping

After getting some recommendations for improvement to be implemented, the next step is to describe or map the improvements so that it can be seen whether the recommended improvements are likely to be successful or not.

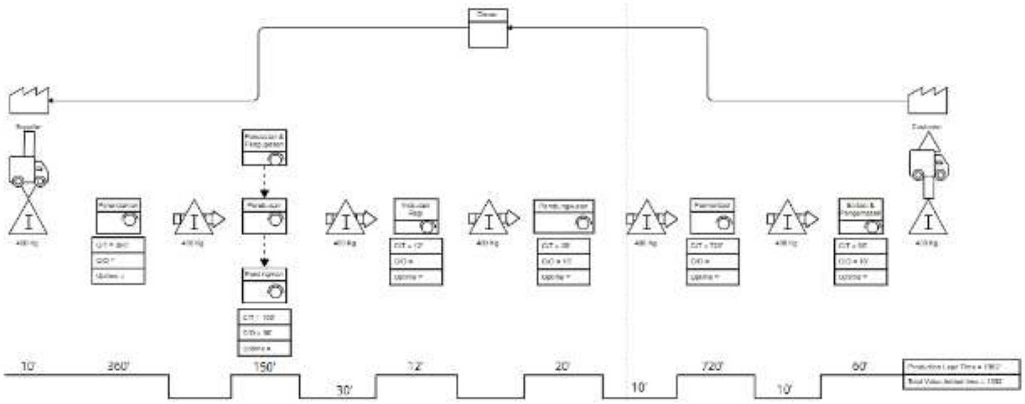

Figure 6. Future State Mapping Model of the Tempe Process

J. Simulation lean Improvement

Based on the Future state mapping that has been made, a simulation of improvement scenarios is carried out by applying Lean principles, such as:

- Layout rearrangement (reduced motion and transport)
- uses Parallel processing for some processes such as washing and immersion.
- Conducting engineering studies to reduce soaking and fermentation time by making some modifications
- Implement a pull system to regulate the flow between processes

Table 8. Simulation table for waste repair in the production process

Process	CT before (′)	CT After (′)	Batch	Repair
Perendaman	720	360	400	Optimization of process time
Washing & Stripping	60	45	400	Process parallel
Boiling	90	60	400	Process parallel
Cooling	60	45	400	Process parallel
Yeast inoculation	15	12	400	Standardization
Packaging	30	20	400	Standardization
Fermentation	1440	720	400	Eksperimen
Sorting & packaging	90	60	400	Standardization

Source : processed data

From the simulation shown in Table 8, the following results can be obtained:

- Weekly production costs decreased from IDR 3,188,000 to IDR 2,998,250 (efficiency ±17%),
- Defective products fell from 4.7% to 1.5% (68% decrease),
- The total processing time was reduced from 2,605 minutes to 1,332 minutes (time savings ±14%).
- Wait time reduced by more than 50%

K. Environmental impact analysis with a green manufacturing approach

From the application of the 4R principle, the results are obtained that:

- Reduction of LPG by 30% (8.7 → 5 cylinders/week),
- Clean water efficiency of 32%,
- A 70% reduction in plastic waste,
- Reduction of organic waste through reduction of defective products and reuse.

L. Waste Analysis after Repair

After the repair simulation is carried out, it is then checked whether or not the existing level of waste has decreased by checking using PAM and VATP.

M. PAM (Production Activity Mapping)

Table 9 shows the results of the repair simulation that has been performed

Table 9. PAM table after repair

Tempe							
No	Activity	Machine	Dist (M)	Time (Minute)	Man	Category	Ket
1	Soybean Shipping	engine	5	10	1	Transport	VA
2	Soybean Opening	scissors	-	2		Operation	NNVA
3	Soy pouring	-	0,5	5	1	Operation	NNVA
4	soy soaking	kuali	-	360		Waiting	VA
5	Soybeans washed and peeled	kuali	-	45		Operation	VA
6	Wet waste removal	Sieve	-	5		Operation	NNVA
7	Water draining	-	-	10		Operation	NNVA
8	Water filling	Selang	-	10		Operation	NNVA
9	boiled soybeans	Pan	-	-	1	Operation	VA
10	Waiting for the soybeans to ripen	-	-	60		waiting	VA
11	Soybean Raised	Sieve	-	5		Operation	NVA
12	Soybean pouring	-	0,5	5		Transport	NVA
13	Chilled soybeans	tampah	-	45		waiting	VA
14	Yeast pouring	-	1	12		Operation	VA
15	Put the lid on top of the tempeh	Plastic (reuseable)	-	20	1	Transport	NNVA
16	Waiting for the tempeh to be finished	-	-	720		waiting	NNVA
17	Tempeh sorting	-	-	60	1	Operation	VA
18	Tempeh Packaging	-	1			Operation	VA
	Jumlah		8	1374	6		

The PAM table above shows that there is a significant reduction in time with the improvements made, with evidence that there is a decrease in total production time from 2,512 minutes to 1,374 minutes. In addition, there was an increase in the number of "operations" that occurred from 10 operations to 11 operations, with a decrease in the number of "transports" from five transfers to three transfers. This shows that the improvements made can be said to be successful in reducing production time

N. Value Analysis Time Profile (VATP)

Table 10. shows the results of the repair simulation that has been carried out.

Table 10. Table VATP tempeh process after repair

Activity	Cost Rate (Rp/Hour/Kg)	Materials (Rp)	Duration (Hours)	Begin	Cost	End	Accumulation Cost
Soybean Delivery	10.000	2.764.000	0	0	2.774.000	0	2.774.000
Immersion	0	0	6	6	0	12	2.774.000
Washing & Peeling	0	0	0,75	6,75	0	12,75	2.774.000
Boiling	110.000	0	1	7,75	110000	13,75	2.884.000
Cooling	11750	0	0,75	8,5	8812,5	14,5	2.892.813
yeast inoculation	0	70.000	0,2	8,7	14000	14,7	2.906.813
packaging	0	0	0,33	9,03	0	15,03	2.906.813
Fermentation	0	0	12	21,03	0	27,03	2.906.813
Sorting	0	0	1	22,03	0	28,03	2.906.813
Packaging	60.000	0	0,25	22,28	15000	28,28	2.921.813

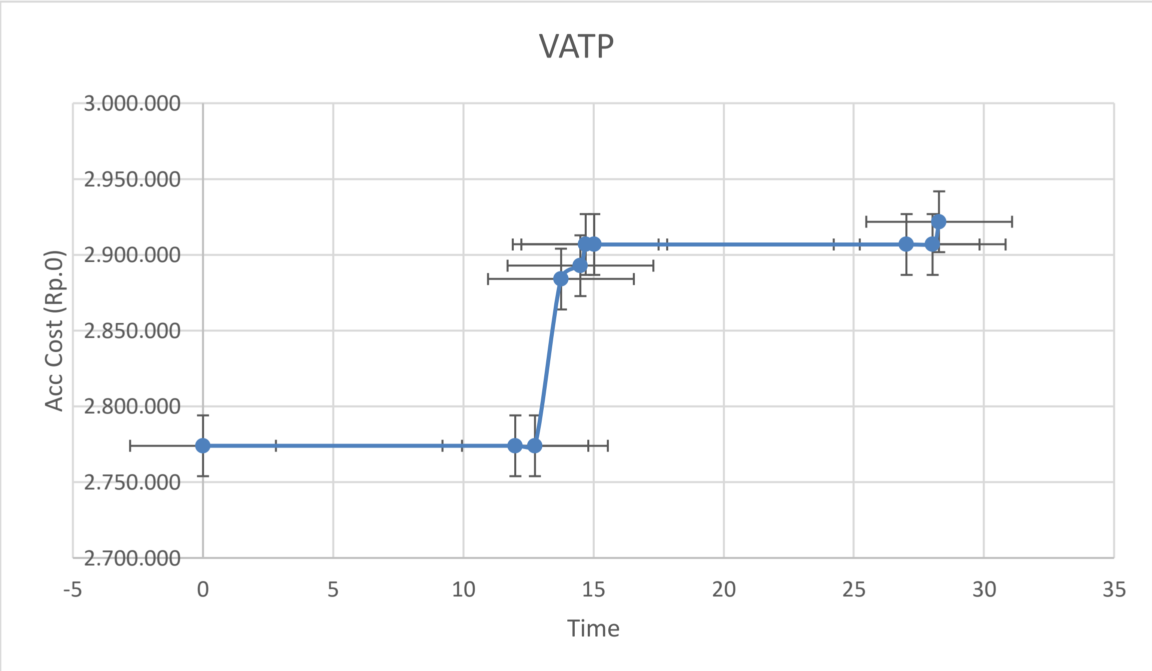

Figure 7. Scatter Plot VATP after repair

After the repair, it can be seen in Table 10 and Figure 7 that there was a decrease in Cost of Rp. 266,188 or around 8.35%. This shows that the improvements made have an impact on reducing waste in the tempeh production process and reducing costs during production.

5. CONCLUSION

This research develops a Lean-Green Manufacturing model for tempeh food SMEs as a solution to reduce production costs while maintaining environmental sustainability aspects. The results of the research showed that weekly production costs decreased from IDR 3,188,000 to IDR 2,998,250 (efficiency ±17%), defective products decreased from 4.7% to 1.5% (68% decrease), total processing time decreased from 2,605 minutes to 1,332 minutes (time savings ±14%). Waiting time is reduced by more than 50%. By implementing lean manufacturing, SMEs can identify and eliminate various types of waste in the production process such as overproduction, waiting, transportation, overprocessing, inventory, motion, and defects. This has the potential to reduce operational costs and improve production efficiency. From the application of the 4R principle, the results were obtained that: Reduction of LPG by 30% (8.7 → 5 cylinders/week), Clean water efficiency by 32%, Reduction of plastic waste by 70%, Reduction of organic waste through reduction of defective products and reuse. In addition to improving efficiency, the integration of green manufacturing concepts focuses on waste reduction, energy efficiency, and environmentally friendly use of resources. This Lean-Green approach is very relevant to the condition of SMEs that have limited resources, so that it can be implemented without large investments but still provides added value in terms of economy and environment. The use of the Lean-Green Manufacturing approach is able to overcome low yields, waste of resources, and production waste, thereby supporting the competitiveness of tempeh SME products in the market while reducing negative impacts on the environment. The follow-up recommendation is to implement the proposed model comprehensively with continuous supervision to achieve maximum efficiency and sustainability of the industry.

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