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Analysis of production area layout design based on lean and green thinking in the micro, small, and medium enterprises (MSME) industry

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ABSTRACT

This research aims to analyze and design the layout of production areas based on Lean-Green (L&G) Thinking in Micro, Small and Medium Enterprises (MSMEs) Scale Companies. This research can help MSMEs increase their competitiveness in an increasingly competitive market by focusing on operational efficiency and sustainable production processes. Researchers used the Systematic Layout Planning (SLP) method and the ProModel® simulation tool to support this goal. The SLP method helps evaluate the current MSME layout system and identify areas that can be made more efficient by considering distance, time, and electrical energy consumption criteria. Meanwhile, simulation techniques help formulate appropriate lean-green strategies to increase process efficiency and minimize environmental impacts. Evaluation of the company's current layout resulted in an increase in operational efficiency of 1.55%, a reduction in inventory of 83%, and a reduction in electricity consumption of 26%. This research recommendation includes concrete steps to improve the layout of production areas that support MSMEs in becoming agents of change that combine operational efficiency with environmental responsibility.

1. INTRODUCTION

The Micro, Small, and Medium Enterprises (MSME) industry has a significant role in the global economy. However, resources are often wasted in the production process, and there are large environmental impacts [1], [2]. The application of lean and green (L&G) concepts is becoming increasingly relevant in supporting the sustainability of MSMEs. Numerous studies on the L&G concept conducted since the 2010s have indicated that this approach can foster an inclusive and sustainable industry by evaluating the effectiveness of strategies implemented by decision-makers and addressing consumer needs [3], [4], [5]. In general, the application of the lean concept comes from stake-holders and internal management [6], [7], [8], and green implementation comes from society and government [9]. Through the Ministry of Industry and Environment and Forestry, the government consistently encourages sustainable industrial development by implementing the Green Industry concept. The application of integrated L&G concepts within the industrial sector has been shown to enhance economic advantages and promote environmental sustainability over the long term by boosting process productivity, improving product quality, and managing environmental impacts [10], [11].

The cosmetics and personal care industry is the second priority, along with the pharmaceutical sector, in the National Development Master Plan. According to the Director General of SMEs at the Ministry of Industry, this industrial sector plays a crucial role in GDP growth, contributing approximately 1.92% [12].

There has also been a rise in large and small to medium-sized cosmetic industries, with 95% originating from MSMEs [13]. With this rapid growth, the sustainability of the cosmetics and personal care industry has become an important theme to highlight regarding the level of productivity, efficiency of energy consumed, handling of process and product waste, and so on [14], [15]. This study focuses on a cosmetics MSME in Depok, West Java, which is working to extend its Good Cosmetic Manufacturing Practices (CPKB) certificate. The company faces challenges in meeting the requirements for this extension, particularly in designing a production layout that enhances operational efficiency and minimizes environmental impact. The research will evaluate the production area layout, analyze workflow, and identify optimization opportunities using a lean-green approach. It will demonstrate how effective strategies can improve the company's operational efficiency and environmental sustainability. Since the end of 2019, this company has started a program based on L&G concepts in stages with 19 employees. The stages of program implementation can be seen in Fig. 1.

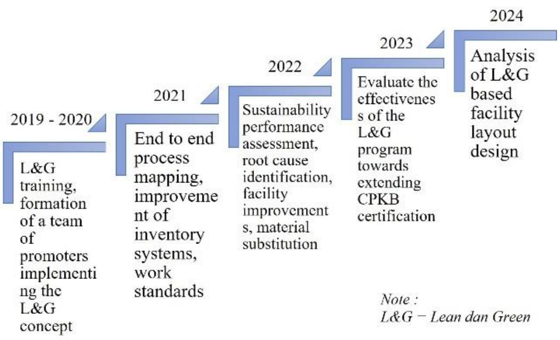

Fig. 1. Implementation map of L&G in pilot MSME

In the first stage, the company initiated a program to implement the L&G concept by providing training for workers to have the correct mindset towards the L&G concept (Fig. 1). Then, it continued with end-to-end process mapping and improvements using the L&G approach. After implementing the L&G concept for 4 years, a positive impact on the company's performance began to be seen as a result of several improvements, including clarity of processes and information flow. However, the results of these improvements have not been reflected in changes to the layout of the production area, where there is still a lot of waste in material flow, use of space, and use of other production resources. The company lacks the necessary knowledge and skills to conduct independent analyses of layout enhancements, and it also does not have a reference for a sustainable layout model, which is needed for the CPKB certification. This phenomenon is the basis for researchers to analyze production area layout design based on L&G Thinking.

The rationale for this study is to address the critical need for effective layout design in Micro, Small, and Medium Enterprises (MSMEs) by demonstrating how the integration of Lean-Green strategies through systematic layout planning can significantly enhance operational efficiency and environmental sustainability, thereby filling a notable gap in the existing literature that predominantly focuses on larger enterprises. It is important to carry out this research by considering two main aspects. First, MSMEs, as pillars of the local economy, often require efficient operational strategies to compete globally [16], [17], [18]. Second, with increasing awareness of sustainability, MSMEs need to adopt environmentally friendly product practices to minimize negative impacts on the environment [19], [20], [21]. Not many studies specifically explore applying the L&G thinking concept in the layout of MSME production areas. By exploring and analyzing these aspects, it is hoped that this research can provide valuable insights for developing knowledge in industrial engineering and for MSMEs in increasing operational efficiency while supporting environmental sustainability efforts.

In responding to complex problems related to implementing the L&G thinking in the layout of MSME production areas, the problem-solving approach will use lean-green waste mapping [22] and systematic layout planning [23], [24]. The lean waste mapping will identify and eliminate waste in the production process, such as unnecessary work elements or movements, inventory buildup, or wasted waiting time [25], [26]. Meanwhile, green waste mapping focuses on reducing environmental impacts through energy efficiency, environmentally friendly materials, and better waste management [27], [28]. This combined approach can produce a holistic strategy for redesigning the layout of MSME production areas that is efficient and environmentally friendly [29], [30].

This study aims to investigate whether the application of a lean-green approach significantly contributes to operational and environmental improvements in MSMEs, with a specific focus on the research question: How can the unification of production layouts and waste management practices contribute to the enhancement of operational efficiency and sustainability in MSMEs? The main contributions of this research are described as follows:

1) Leveraging a lean-green approach by designing production area layout to increase MSME operational efficiency and reduce environmental impacts. To effectively implement this approach, a comprehensive methodology was employed, which included a thorough literature review to identify best practices and an in-depth analysis of waste identification.
2) Comparing conditions before and after implementing the lean-green strategy through in-depth analysis using a systematic layout planning and simulation approach. The measurement

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includes operational efficiency parameters such as cycle time, amount of inventory, labor productivity, and environmental impact parameters such as electricity consumption and waste management.

The article is organized as follows: Section 2 explains related work establishing the theoretical foundation. Section 3 describes the methodology, including data collection and model implementation steps. While Section 4 presents the results and discussion, including findings and their implications. Finally, Section 5 offers a conclusion summarizing the key insights, addresses the study's limitations, and suggests directions for future research.

2. RELATED WORK

There is significant interest in optimizing production layouts within the manufacturing sector, as evidenced by the 309 articles indexed in Scopus that include the keywords "production layout" and "manufacturing." Fig. 2 shows the co-occurrence map of 38 keywords (originally 312 from 309 articles) with minimum co-occurrence 2 times for each keyword. The co-occurrence network analysis revealed that the keyword 'MSME' was not present among the identified keywords. This indicates that the MSME sector has not been a primary focus in the literature related to 'production layout' and 'manufacturing', as indexed in Scopus.

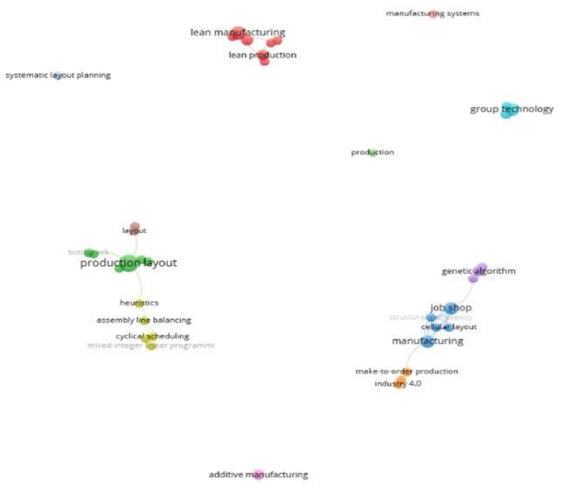

Fig. 2. Co-occurrence network of keywords from Scopus-indexed articles related to 'production layout' and 'manufacturing'

Table 1 shows the literature review on Systematic Layout Planning (SLP) as the main method in this research, which combines with simulation using ProModel®.

Table 1. Literature review on systematic layout planning (SLP)

Author	Year	Method	Main focus		Research scale			Research parameters			
			Lean	Green	Small	Med.	Large	Operation Efficiency	Energy Saving	Waste	Cost
Parveen *et al.* [5]	2011	Simulation	✔	✔			✔	✔		✔	
Lista *et al.* [23]	2021	SLP and VSM	✔				✔	✔			
Kovács [24]	2020	SLP	✔	✔	✔	✔		✔	✔		
Cervantes *et al.* [30]	2024	SLP and 5S	✔		✔	✔		✔			
Kumar & Mallerswari [31]	2022	SLP and Simulation	✔				✔	✔			
Liu *et al.* [32]	2020	SLP and Simulation	✔				✔	✔			
Zahid & Amran [33]	2022	SLP	✔				✔	✔			
Zuniga *et al.* [34]	2020	Simulation	✔				✔	✔			
Haryanto *et al.* [35]	2021	SLP	✔				✔	✔			
Laurent *et al.* [36]	2022	SLP and Simulation	✔				✔	✔			
Gozali *et al.* [37]	2023	SLP and Simulation	✔				✔	✔			✔
Mao *et al.* [38]	2023	SLP and Simulation	✔	✔			✔	✔	✔		
Dresanala *et al.* [39]	2023	SLP and Simulation	✔				✔	✔			
Salins *et al.* [40]	2024	SLP	✔				✔	✔			✔
Nurkamila *et al.*[41]	2024	SLP and OWAS	✔		✔			✔			
Current Study	2024	SLP and Simulation	✔	✔	✔	✔		✔	✔	✔	✔

MSMEs make various efforts to improve the efficiency of their operations. Redesigning the production area layout design based on lean and green thinking can be one way to enhance efficiency, reduce waste, and promote sustainability so that they are not only competitive but also contribute positively to the environment. Optimal production area layout can be part of applying the lean thinking concept to maximize productivity by minimizing movement waste and implementing the green thinking concept by optimizing resource efficiency.

Process and product layouts that minimize the movement and transport of materials are important considerations in implementing lean and green in redesigning the layout of a production area. This research explores the integration of Lean-Green (L&G) strategies in Micro, Small, and Medium Enterprises (MSMEs) using Systematic Layout Planning (SLP) and simulation techniques. It stands out from previous studies focusing on larger companies or specific industries like healthcare and textiles, which often overlook MSMEs in sustainability discussions. While earlier research has used case studies and qualitative methods to examine energy savings and lean principles, this study takes a systematic and quantitative approach, measuring factors like inventory reduction, energy consumption, and overall operational efficiency. It highlights a gap in the literature, as most studies do not adequately address the unique challenges MSMEs face in adopting sustainable practices.

Additionally, this research aims to improve operational efficiency and environmental impact through a customized L&G framework, differing from prior works focusing on efficiency or sustainability alone. This comprehensive approach enhances the understanding of L&G integration in MSMEs and offers practical insights to help these enterprises become more competitive and environmentally responsible in a challenging market. Previous studies that fully utilized the Systematic Layout Planning (SLP) methodology have demonstrated significant outcomes, including enhanced operational efficiency, reduced production cycle times, and optimized space utilization [23], [24], [35]. When compared to previous research, such as that by Lista *et al.* [23], Cervantez *et al.* [30], Zuniga *et al.* [34], which highlighted the benefits of layout optimization without addressing environmental impacts, and Kumar & Mallerswari [31], which focused primarily on larger industries, this research underscore the unique challenges and opportunities faced by MSMEs. Notably, while Kovacs [24] reported energy savings, they did not correlate these with waste indicators and cost impact, as concerned aspects of our research. Thus, this study not only fills a significant gap in the existing literature by demonstrating that MSMEs can achieve substantial operational and environmental improvements but also provides practical insights for enhancing competitiveness in an increasingly demanding market.

3. RESEARCH METHODS

In designing the layout of production areas in MSMEs by applying a lean-green thinking approach, researchers designed a research flow chart, as shown in Fig. 3.

We employed a systematic approach to analyze and optimize the production layout of MSMEs by applying Lean-Green concepts. The following are the detailed steps regarding data processing and the formulations utilized, according to Fig. 3.

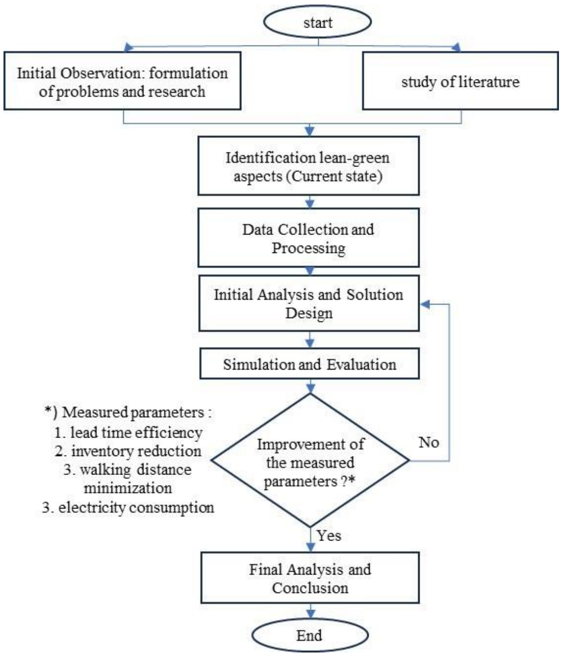

Fig. 3. Research steps

a. Literature Study. A comprehensive literature review was conducted to understand the principles of Lean Manufacturing and Green Manufacturing. It included an analysis of relevant previous research to identify best practices within small and medium-sized industries.
b. Identify Lean-Green Aspects in Production Area Layout. Following the conceptual understanding, specific aspects of the production area layout that had not been optimized were identified. It involved analyzing workflow space utilization and identifying waste that could be minimized.
c. Data Collection. Data related to operational efficiency and environmental impact of the MSME production layout were collected. This data encompassed: production cycle time, production flow, amount of semi-finished product inventory, energy consumption, and quantity of waste generated.
d. Data Processing. The collected data were processed using process flow mapping, systematic layout planning steps, and Promodel.

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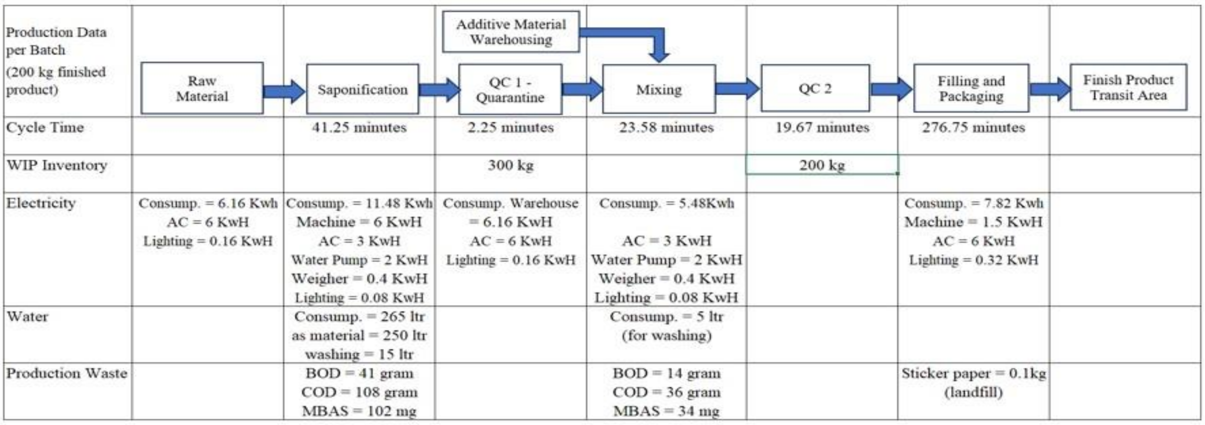
e. Quantitative Analysis and Solution Design. Quantitative analysis will be carried out to evaluate the differences before and after implementing Lean-Green strategies. Based on the findings from the analysis, solutions and strategies were designed to enhance operational efficiency and environmental sustainability.
f. Design Evaluation. Post-implementation, an evaluation was conducted to measure the impact of changes made to the production area layout. At this stage, comparisons before and after implementation were assessed to determine improvements in efficiency and reductions in environmental impacts.
g. Result Analysis. The collected data were thoroughly analyzed using descriptive and inferential statistical methods to conclude the effectiveness of the Lean-Green strategy in the production layout of MSMEs.

4. RESULTS AND DISCUSSION

4.1. Case problem

The researchers observed the pilot cosmetic companies in the Cinere area, Depok City, and collected data on production cycle time, production flow, the amount of semi-finished product inventory, the amount of energy consumption, the amount of waste at one of which was produced as simplified in Fig. 4. The current production layout presents several significant issues including inefficient workflow patterns, which lead to unnecessary movement and delays in production processes. The company also struggles with high inventory levels, which ties up valuable resources and increases the risk of obsolescence. Furthermore, the lack of environmentally friendly practices in the production layout exacerbates negative environmental impacts, such as excessive energy consumption and waste generation.

The researcher also described a map of the current production facility layout as visualized in Fig. 5. The data processing process begins with identifying L&G Waste. The research team took detailed operating time data and grouped it into Value Added (VA) and Non-Value Added (NVA). Through brainstorming with production managers, the main types of waste were identified in Table 2. The current/Future Value Stream Mapping was developed in Fig. 6. To visualize the production process data (including production cycle time, inventory lead time, number of human resources) and waste identification.



Production Data per Batch (200 kg finished product)	Raw Material	Saponification	QC 1 - Quarantine (Additive Material Warehousing)	Mixing	QC 2	Filling and Packaging	Finish Product Transit Area
Cycle Time		41.25 minutes	2.25 minutes	23.58 minutes	19.67 minutes	276.75 minutes	
WIP Inventory			300 kg		200 kg		
Electricity	Consump. = 6.16 Kwh AC = 6 KwH Lighting = 0.16 KwH	Consump. = 11.48 Kwh Machine = 6 KwH AC = 3 KwH Water Pump = 2 KwH Weigher = 0.4 KwH Lighting = 0.08 KwH	Consump. Warehouse = 6.16 KwH AC = 6 KwH Lighting = 0.16 KwH	Consump. = 5.48Kwh AC = 3 KwH Water Pump = 2 KwH Weigher = 0.4 KwH Lighting = 0.08 KwH		Consump. = 7.82 Kwh Machine = 1.5 KwH AC = 6 KwH Lighting = 0.32 KwH	
Water		Consump. = 265 ltr as material = 250 ltr washing = 15 ltr		Consump. = 5 ltr (for washing)			
Production Waste		BOD = 41 gram COD = 108 gram MBAS = 102 mg		BOD = 14 gram COD = 36 gram MBAS = 34 mg		Sticker paper = 0.1kg (landfill)	

Fig. 4. Mapping of L&G data in the production process flow

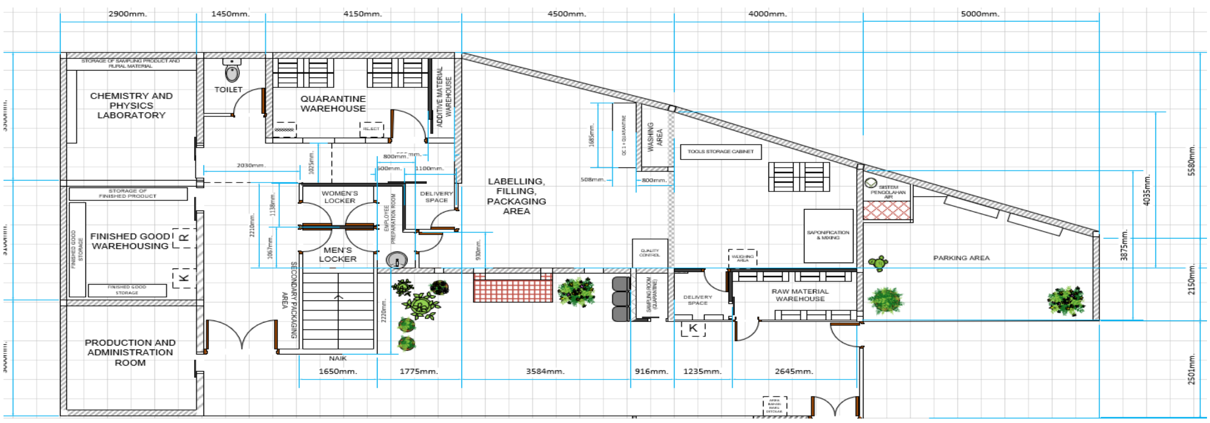


Fig. 5. Production facility layout mapping – current conditions

Table 2. Identification of L&G waste mapping

No	Workstation	Waste type	Waste description
1	Saponification & Mixing	*Unnecessary process and moving/transportation*	The raw material and additive material warehouse are separate. The distance between them is 6 m, while the distance between the mixing and additive material warehouse is 12m. The separate location of the warehouses causes two types of waste: waste in the back-and-forth weighing process and waste in steps.
2	Saponification	*Excessive Inventory*	The basic inventory of facial soap is 2 drums (2 x 1 drum measuring 150 kg), even though the daily requirement is 180 kg --> there is an inventory of 120 kg.
3	Saponification & Mixing	*Energy In-efficiency*	Machines and equipment operate at full capacity during working hours, regardless of whether production is taking place.
4	Raw Material & Additive Material Warehouse	*Energy In-efficiency*	The additive materials warehouse is separate (quite far) from the main raw materials warehouse. The additive materials warehouse has 1 AC unit with 0.75 KW power, which is excessive for a 7m2 room.

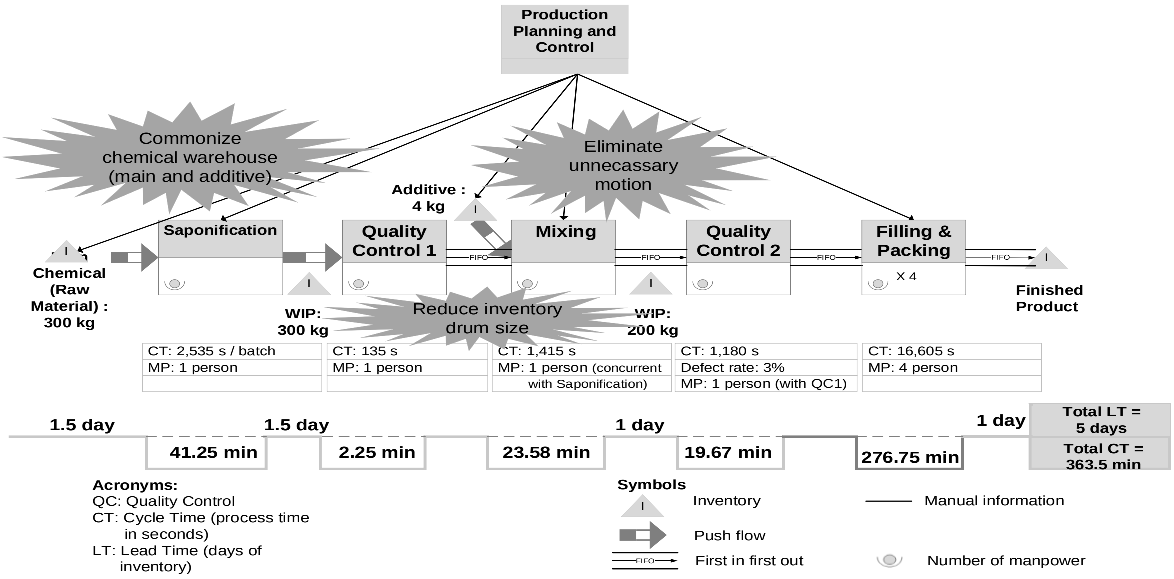


Fig. 6. Current/future value stream mapping

4.2. Result

The next step is to analyze the material flow and process linkages using the SLP method, with the Activity Relationship Chart (ARC) tools in Fig. 7 and the Activity Relationship Diagram (ARD) in Fig. 8. In Fig. 5, several rhombuses show the connection between 2 workstations, with the degree of connection shown through letter and color codes. The ARC created is the basis for creating the ARD in the next step (Fig. 6).

Fig. 7 makes it easier for researchers and management to visualize the relationships between workstations in the production section. The additive material warehouse, separate from the raw material warehouse, makes things difficult for warehouse workers. One worker handles both warehouses. Apart from that, the location of the additive material warehouse is quite far from the saponification and mixing processes, making it difficult for production operators to collect raw materials. Several proposed improvements can increase operational efficiency and improve environmental impacts, as outlined in Table 3

Based on the identification of L&G Waste, analysis of material flow and process linkages, and several proposed improvements, a layout simulation for the production process was carried out using ProModel® software (Fig. 9). The simulation results of improvements to achieving the Company's L&G performance indicators if the proposed improvements are implemented are mapped in Table 4.

Data on production cycle times, energy consumption, and types of waste produced are the main focus of efforts to improve operational efficiency and environmental sustainability. The research results show that identifying value-added (VA) and non-value-added (NVA) activities is key to identifying potential waste of time and energy in production. By understanding the comparison between activities that provide added value and those that do not, companies can make improvements to reduce inefficient time and optimize energy use.

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Table 3. Activity relationship chart (ARC)

No.	Workstation	Waste type	Improvement/recommendation activities
1	Saponification and Mixing Raw Material Warehouse & Additive Material Warehouse	*Unnecessary process and moving*	1. Eliminate unnecessary movements in weighing materials in the process: a. Saponification: six times back and forth movement → changed to two times → saved 150 seconds b. Mixing process: two back-and-forth movements → changed to one time → saved 30 seconds 2. Move the additive materials warehouse to the raw materials warehouse area (relay-out of rooms and shelves). This improvement has the potential to result in a cycle time reduction of 180 seconds or the equivalent of a 1% increase in efficiency (180 seconds/18,580 seconds). However, this activity requires dismantling and reassembling the room for Rp. 1 million.
2	Saponification	*Excessive Inventory*	Changing the drum size from 150 kg to 100 kg to minimize the amount of inventory
3	Saponification and Mixing	*Energy In-efficiency*	Updating work standards with orders to shut down machines and equipment immediately after use. Saving electricity/month = 3.4 kW h/*batch* = ± 151 kW h/month = Rp. 0,2 million/month
4	Raw Material Warehouse & Additive Material Warehouse	*Energy In-efficiency*	Eliminate one air conditioning unit by consolidating the air conditioning usage between the additive material and raw material warehouses. Saving electricity/month = 4.35 kW h/*batch* = ± 192 kW h/month = Rp. 0.3 month/month Besides, the estimated income from selling used AC is Rp. 1 million

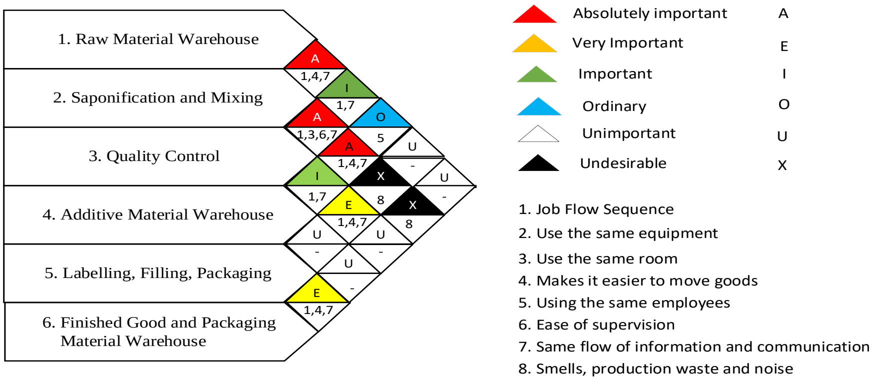

Fig 7. Activity relationship chart (ARC)

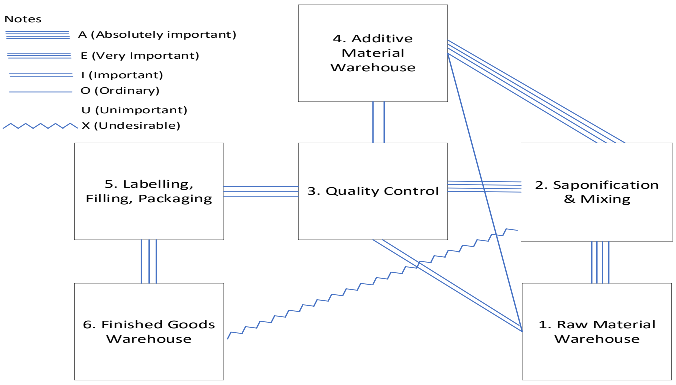

Fig. 8. Activity relationship diagram (ARD)

Table 4. Comparison of L&G performance

No	Improvement indicators	Before condition	After condition	%
1	Cycle Time	21.810 second	21.470 second	Improve efficiency 1.55 %
2	Inventory	120 kg	20 kg	Reduce inventory 83%
3	Distance	77 m	65 m	Improve 15%
4	Electricity Consumption (AC & Machine)	1335 KwH/month	993 KwH/month	Save energy consumption 26%
5	Potential Cost Reduction	± Rp. 1.900.000 / month	± Rp. 1.390.000 / month	± Rp. 510.000 / month

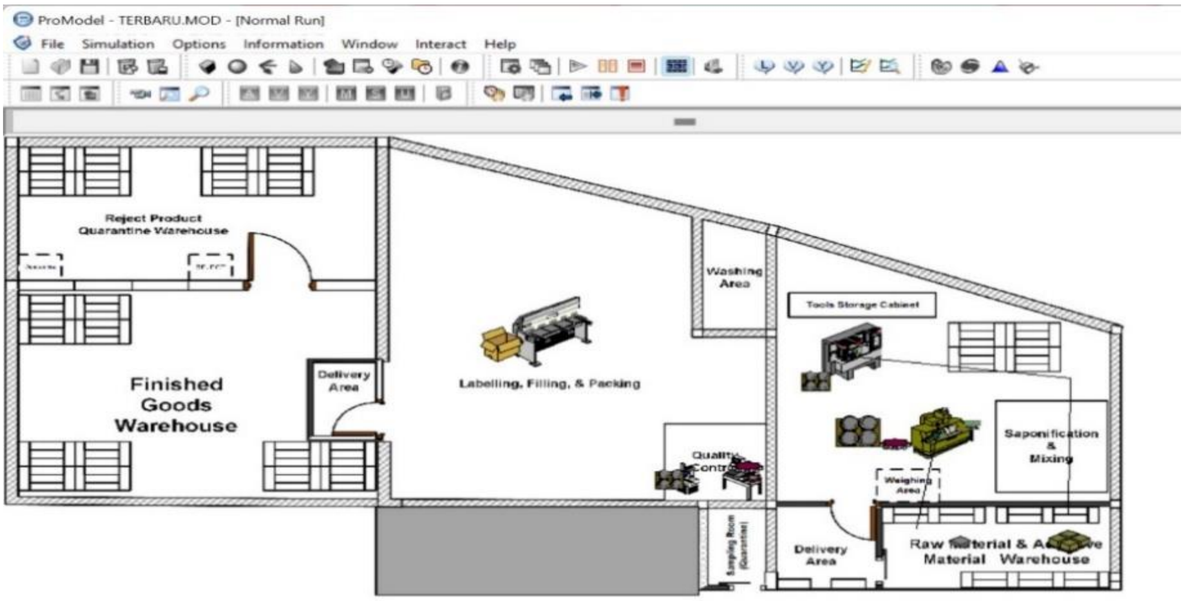

Fig. 9. Production process simulation with Promodel 6

4.3. Discussion

The findings of this research align with previous studies that emphasize the importance of waste reduction and environmental sustainability in enhancing operational efficiency. In this study, we integrated Lean-Green (L&G) strategies within Micro, Small, and Medium Enterprises (MSMEs) using the Systematic Layout Planning (SLP) method and simulation techniques. The findings related to the layout improvement, as illustrated in Fig. 7 and detailed in Table 4, indicate a marked enhancement in operational efficiency following the implementation of the redesigned production area layout. A critical modification involved unifying the raw material and additive material warehouses, significantly reducing the distance required for material transport and streamlining the workflow. This strategic consolidation not only improved accessibility but also reduced excessive work-in-progress (WIP) inventory by allowing for more efficient inventory management practices. Specifically, the change in drum size from 150 kg to 100 kg has effectively minimized excess inventory, optimizing storage space and reducing holding costs.

Moreover, this layout modification has resulted in energy savings by enabling the elimination of one air conditioning unit in the additive material warehouse, as the proximity of the two warehouses allows for more efficient climate control. The integration of these warehouses has contributed to a more sustainable operation by reducing energy consumption associated with cooling. Additionally, implementing updated work standards, which mandate the immediate shutdown of machines and equipment after use, further supports energy efficiency initiatives. This practice conserves electricity and enhances overall operational performance by ensuring that resources are utilized judiciously. Collectively, these improvements under-score the effectiveness of the Systematic Layout Planning (SLP) methodology in achieving significant benefits in production efficiency, inventory mana-gement, and energy sustainability within the MSME. The final results demonstrated a 1.55% increase in cycle time efficiency, an 83% reduction in inventory, a 15% distance shortening, and a 26% decrease in electricity consumption.

The findings of this research contribute to the development of theories related to Lean-Green

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manufacturing and sustainable production practices. This study fills a knowledge gap by providing empirical evidence on the effectiveness of Lean-Green strategies in MSMEs, an area that has received limited attention in the existing literature. The results support and expand upon existing theories of L&G manufacturing by demonstrating how their integration can lead to improved operational efficiency and reduced environmental impacts. This research confirms the notion that Lean-Green practices are not only applicable to large enterprises but are also beneficial for MSMEs. The study introduces new variables related to operational efficiency and environmental sustainability, such as production cycle time, inventory, distance, electricity consumption, and generated waste, which can serve as a foundation for future research. These variables may prompt further investigation into their interrelationships and impact on overall business performance.

4.4. Managerial implications

This research provides critical insights into applying Lean-Green concepts in Micro, Small, and Medium Enterprises (MSMEs) production layouts. The practical implications of this study are significant for practitioners and decision-makers in industrial engineering and management. First, practitioners are encouraged to adopt Lean-Green strategies to enhance operational efficiency and sustainability. It can be achieved through targeted training programs that equip employees with the necessary skills and knowledge to implement Lean principles and environmentally sustainable practices effectively. Second, the SLP method demonstrated in this research is a valuable tool for MSMEs to evaluate and redesign their production layouts. Decision-makers should utilize SLP to identify inefficiencies and develop strategies that optimize workflow, reduce cycle times, and minimize energy consumption, improving overall operational performance. Third, managers should invest in data management systems that facilitate the collection of relevant operational metrics, such as production cycle time, inventory, work distances, and energy usage. This data-driven approach will enable continuous improvement initiatives and provide a basis for evaluating the effectiveness of Lean-Green strategies. Finally, establishing a culture of continuous improvement is vital for the long-term success of MSMEs. Managers should encourage employees to identify areas for enhancement and propose innovative solutions, fostering a sense of ownership and commitment to sustainability initiatives.

5. CONCLUSION

This study effectively addresses a significant research gap by exploring the implementation of Lean-Green strategies specifically within Micro, Small, and Medium Enterprises (MSMEs), a sector often overlooked in existing literature. The main contribution of this research lies in developing a systematic framework that integrates Lean and Green principles with the Systematic Layout Planning (SLP) method, demonstrating that MSMEs can achieve notable improvements in operational efficiency and sustainability. The research methodology involved several key steps: a comprehensive literature review to identify best practices, identifying Lean-Green aspects relevant to production layouts, data collection from a pilot MSME in the cosmetic industry, implementation of the redesigned layout, and subsequent evaluation of the results. This structured approach yielded significant outcomes, including a 1.55% increase in operational efficiency, an 83% reduction in inventory, a 15% distance shortening, and a 26% decrease in electricity consumption.

The research has certain limitations that should be acknowledged. Firstly, the model developed is context-specific, which may limit its applicability to other industries beyond the cosmetic sector studied. Additionally, variations in organizational characteristics, such as size, structure, and operational practices, may influence the effectiveness of the proposed model. These factors could affect the generalizability of the findings, suggesting that further research is needed to validate the results across different contexts and industries.

The future scope of this research includes several key areas for further investigation. Firstly, it is recommended that subsequent studies validate the proposed framework across a wider range of industries and geographical locations to enhance its generalizability. Additionally, future research should explore the long-term impacts of Lean-Green practices on the performance of Micro, Small, and Medium Enterprises (MSMEs). It is also important to examine the challenges faced during implementing these practices. Lastly, investigating the role of technology in facilitating Lean-Green strategies could provide valuable insights for both practitioners and researchers in the field.

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