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Identify Critical Success Factors (CSFs) For Sustainable Lean Manufacturing Implementation in Indonesia Automotive

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ABSTRACT

The Indonesian automotive industry, known for its extensive supply chain and high resource consumption, demands operational strategies that promote both efficiency and sustainability. This study explores Sustainable Lean Manufacturing (SLM) as a strategic framework by identifying and prioritizing the Critical Success Factors (CSFs) necessary for its effective implementation. Using a mixed-method approach, the research applied the Delphi technique to gather expert consensus and the Analytical Hierarchy Process (AHP) to rank the identified CSFs. Data were collected through three rounds involving expert panels from various automotive firms with over a decade of experience in lean and sustainability practices. Nineteen CSFs were identified and grouped into six dimensions: Management and Leadership, Human Resources Development, Sustainable Production Process, Environmental Management, Supply Chain Management, and Safety and Well-being. Results show that Management and Leadership is the most influential dimension (51%), with Top Management Commitment ranked as the top CSF (0.2740). The study's methodological novelty lies in combining Delphi and AHP for sector-specific validation, filling the research gap on SLM in Indonesia's automotive industry. The findings offer a structured decision-making model for practitioners to implement SLM initiatives that align with both operational goals and sustainability regulations. Future research is encouraged to apply this model to other industries and adopt AI-based tools for adaptive strategy development.

Keywords: *Sustainable Lean Manufacturing, Critical Success Factors, Automotive Industry, Delphi AHP Method, Process Efficiency, Sustainability*

INTRODUCTION

The implementation of Sustainable Lean Manufacturing (SLM) in the automotive industry is closely related to the need to enhance operational efficiency while simultaneously reducing environmental impact. The automotive industry is recognized as one of the sectors with high resource consumption and a significant contributor to carbon emissions (Ben Ruben et al., 2019; Gama & Bonamigo, 2024; Hartini & Ciptomulyono, 2015; Kumar et al., 2022; Kumar & Mathiyazhagan, 2020; Lim et al., 2022). According to data from the Association of Indonesia Automotive Industries (gaikindo.or.id, 2020), there are more than 1,550 domestic companies involved in the production of automotive raw materials and components, consisting of 550 first-tier supplier companies and 1,000 second- and third-tier supplier companies. Specifically, the automobile industry in Indonesia currently has local assembly and manufacturing facilities with a production capacity of approximately 2.4 million units per year. This sector directly employs around 75,000 workers and indirectly provides employment to approximately 1.5 million people (gaikindo.or.id, 2024).

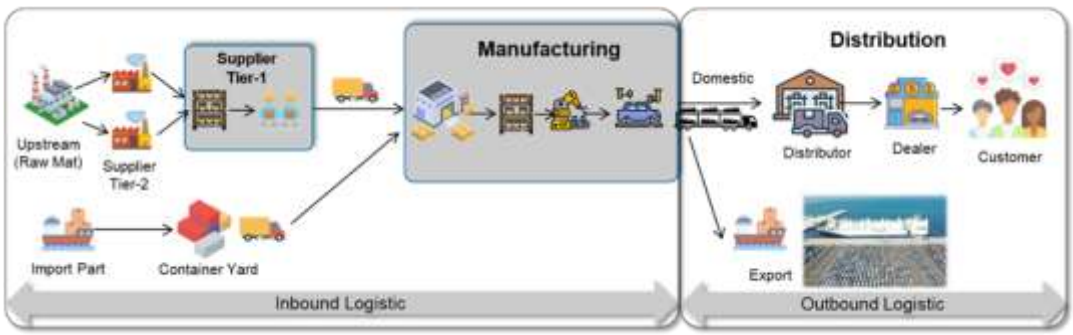

Figure 1. Automotive Industry Supply Chain in Indonesia (gaikindo.or.id, 2020)

The automotive industry supply chain is significantly more complex compared to other industries, as illustrated in Figure 1. The process begins with raw material and spare parts suppliers (upstream), sourced both domestically and through imports, which are delivered to first- and second-tier suppliers. These components are then processed and forwarded to manufacturing facilities. Once the production process is complete, the finished goods are distributed via external logistics networks for both domestic markets and export. This supply chain reflects the interconnection between manufacturers, suppliers, distributors, and consumers in supporting the continuity of the automotive industry.

With the adoption of lean manufacturing and a focus on sustainability, the automotive industry strives not only to enhance operational efficiency but also to reduce environmental impact aligning with global trends toward greener and more environmentally friendly industries. Research conducted by Hartini et al. (2020) emphasizes that Value Stream Mapping (VSM) integrated with sustainability such as sustainable-VSM enables companies to assess not only operational performance and reduce costs by eliminating non-added value activities, but also environmental and social performance, thereby enhancing long-term competitiveness (Abhishek & Pratap, 2020; Batwara et al., 2023; Hernandez Marquina et al., 2021; Lee et al., 2021; Salwin et al., 2021).

However, despite the evident benefits of lean manufacturing in terms of productivity improvements and cost reductions, studies addressing Sustainable Lean Manufacturing (SLM) remain limited. According to Sunmola et al. (2024), the integration of both approaches can lead to significant improvements in manufacturing performance by considering sustainability without compromising efficiency. The study also highlights that implementing lean green practices helps companies not only improve efficiency but also meet the increasing market demand for environmentally conscious supply chains. Therefore, integrating lean manufacturing with sustainability principles has become a priority for many companies to achieve better production efficiency while reducing waste and negative environmental impacts.

Eskandari et al. (2022) suggest that integrating lean production with sustainability can improve both operational and social performance; however, without in-depth analysis of the critical success factors, such efforts often fall short of optimal results. Furthermore, Hartini et al. (2020) point out that selecting relevant indicators must involve industry practitioners to ensure the effectiveness and practical feasibility of implementing SLM at the plant level. A lack of awareness regarding these success factors can lead to failure in maintaining long-term efficiency and commitment to sustainability.

Identifying the Critical Success Factors (CSFs) in implementing SLM is essential, as a clear understanding of these key factors is crucial for achieving optimal outcomes (Hernandez Marquina et al., 2021; Khan et al., 2022; Vrchota et al., 2021). In this context, the study proposed by Debnath et al. (2023) contributes to identifying the main success factors that can facilitate SLM implementation in the furniture industry. The importance of identifying CSFs in SLM implementation is growing, particularly in response to global environmental challenges and increasing demands from stakeholders to maintain competitiveness and sustainability. However, existing studies on the identification of CSFs in SLM implementation remain very limited, and no research has specifically focused on the automotive industry even though, according to gaikindo.or.id (2020), the automotive supply chain in Indonesia is extensive and involves a large number of companies. Thus, identifying the CSFs for the implementation of Sustainable Lean Manufacturing will assist the automotive industry in developing more efficient and adaptive strategies in response to market changes and sustainability-related regulations.

This study explores Sustainable Lean Manufacturing (SLM) as a strategic framework by identifying and prioritizing the Critical Success Factors (CSFs) necessary for its effective implementation. Compared to previous studies such as Debnath et al. (2023), which focused on identifying CSFs in the furniture industry using the Best-Worst Method (BWM), and Hartini et al. (2020) or Eskandari et al. (2022), which emphasized sustainability assessment tools and frameworks across industries without a sector-specific deep dive, the novelty of this research lies in its industry-specific focus and methodological robustness. This study is the first to comprehensively identify, validate, and prioritize 19 CSFs for Sustainable Lean Manufacturing (SLM) implementation in Indonesia's automotive industry, using a multi-round Delphi method combined with Analytical Hierarchy Process (AHP). It involves a broad spectrum of practitioners from large to small automotive companies, providing a sector-wide consensus model. Unlike general or conceptual frameworks in prior studies, this research delivers a validated, hierarchical decision-making model tailored to the complexity and scale of Indonesia's automotive supply chain, offering practical, prioritized guidance for implementation at multiple organizational levels.

METHOD

Based on a previous study by Debnath et al. (2023), which specifically examined the identification of Critical Success Factors (CSFs) in the implementation of Sustainable Lean Manufacturing (SLM) in the furniture industry using the Best-Worst Method (BWM), the method is noted for its efficiency since it only requires determining the best and worst factors, without the need to evaluate all factors based on expert opinions. This method is effective when the number of criteria or factors is relatively small and applied to a single company. However, according to Debnath et al. (2023), the limitation of the BWM method lies in the lack of consensus among experts when the number of experts involved increases, the method can lead to bias in determining the best and worst factors.

In the context of this research, the large number of companies in the automotive industry and the diversity in industry scale ranging from local to foreign investment enterprises necessitate the involvement of a representative expert panel from various scales and types of companies. Therefore, the Delphi method is considered more suitable for this study to establish consensus among experts. This approach is expected to yield evaluation results that are applicable across different scales within the automotive industry. In addition, the Analytical Hierarchy Process (AHP) method is used to identify the hierarchical structure of the CSFs and to support general decision-making across all levels of the automotive industry in Indonesia. The research methodology used in this study is illustrated in the flowchart in Figure 2 and is explained as follows:

Literature Review Stage

After determining the research topic, an initial literature review is conducted focusing on:

1. Lean manufacturing and sustainability practices across various industries to identify research gaps.
2. Studies discussing success factors or indicators related to the Critical Success Factors (CSFs) in the implementation of Sustainable Lean Manufacturing (SLM).

Expert Panel Identification Stage, with the following criteria:

1. Having worked or been involved in the automotive industry for more than 10 years.
2. Holding a leadership or decision-making role, with relevant knowledge or experience in Lean Manufacturing and Sustainability practices.

Identification of CSFs Using the Delphi Method – Round 1

The first round of data collection involves:

1. Developing a questionnaire form based on initial literature data.
2. Distributing the questionnaire; experts rate or assign levels of importance to each CSF.
3. Analyzing expert responses from the first round.

Ranking of CSFs Using the Delphi Method – Round 2

The second round of data collection and processing involves:

1. Providing feedback and round-1 results to experts through a Focus Group Discussion (FGD).
2. Allowing experts to review and revise their responses.
3. Analyzing the results to identify factors or sub-dimensions with consensus agreement.

3. **CSFs Hierarchy Identification and Evaluation Using Analytical Hierarchy Process (AHP) – Round 3**

In the third round, the hierarchy of CSFs is identified through:

1. Constructing the CSFs hierarchy consisting of the main goal, key criteria or dimensions, and success factors under each dimension.
2. Redistributing questionnaires to experts to perform pairwise comparisons among the dimensions.
3. Verifying and validating the consistency of the data.

Results and Conclusion Stage

The analysis produces weights and rankings for each CSF in the implementation of SLM, along with conclusions and recommendations for future research. Based on the steps and methodology outlined above, the research flow is illustrated in the flowchart shown in Figure 2 below.

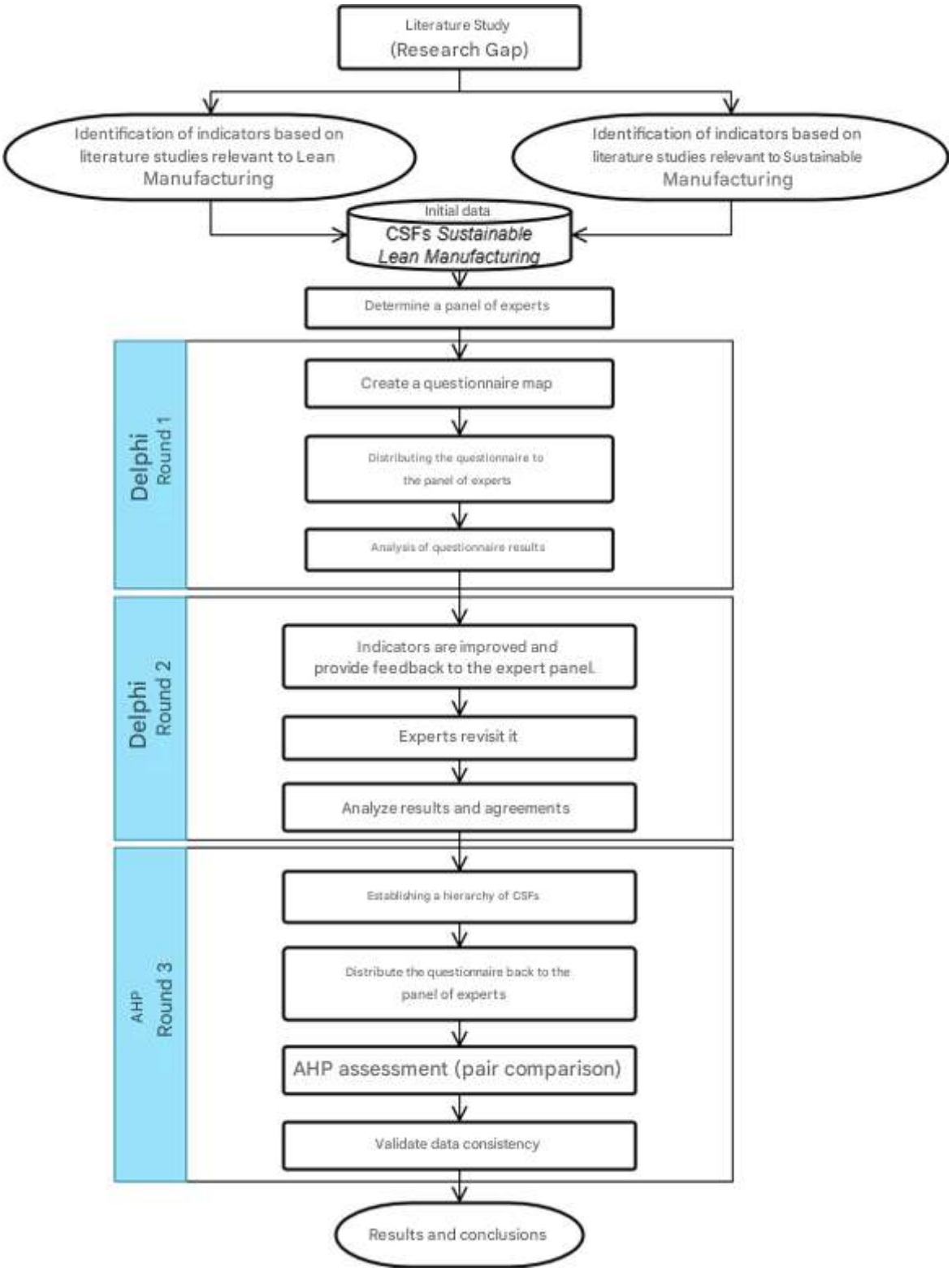

Figure 2. Research Methodology Flowchart

This research was conducted at PT. TMMIN, a four-wheeled vehicle manufacturing company located in Jakarta and Karawang, West Java, Indonesia. PT. TMMIN operates with over 150 component companies across its supply chain; however, this study focuses on selected suppliers representing large, medium, and small-scale industries, as well as companies with both local and foreign ownership (Foreign Direct Investment) to provide a comprehensive overview of Sustainable Lean Manufacturing implementation in Indonesia's automotive industry. The industry classification follows Ministry of Industry Regulation No. 64/2016. Data collection was carried out at PT. TMMIN and selected suppliers from December 2024 to March 2025. The initial stage of this study involved a comprehensive literature review to identify critical success factors (CSFs) for implementing Sustainable Lean

Manufacturing (SLM), using keywords such as lean manufacturing, sustainability, and CSFs. This process resulted in the identification of 18 key success factors, including Top Management Commitment, Employee Involvement, Training and Education, Adoption of Disruptive Technology, Sustainable Supply Chain Management, Continuous Improvement (Kaizen), Value Stream Mapping, Environmental Impact Assessment, Government Policy Support, Sustainable Resource Utilization, Sustainability Performance Indicators, Sustainable Supplier Selection, Safety and Ergonomics Integration, Carbon Emission Reduction, Sustainable Waste Management, Employee Well-being, Customer Responsiveness, and Sustainable Inventory Management each supported by findings from various academic sources.

In this stage, expert panelists were selected based on specific criteria, including having over 10 years of experience in the automotive industry, holding leadership or decision-making positions, and possessing knowledge and experience in Lean Manufacturing, Sustainability, or a combination of both. The selected experts come from various industrial scales large, medium, and small representing companies such as PT. TMMIN, PT. AII, PT. SID, PT. BMM, and AKTI, with roles including General Manager, Assistant General Manager, President Director, Vice President Director, and Academic Senate Chair. This diverse composition provides a comprehensive representation of the complexities within the Indonesian automotive industry. In the first round of data collection using the Delphi method, the initial 18 critical success factors (CSFs) for implementing Sustainable Lean Manufacturing (SLM) were grouped into six main dimensions to facilitate analysis, followed by the development of a Likert scale questionnaire distributed to expert panelists. Based on the geomean analysis, three factors with values below 3.500 namely Sustainable Supplier Selection, Customer Responsiveness, and Sustainable Inventory Management were excluded. Additionally, experts proposed five new factors considered crucial for successful SLM implementation: Top Management Knowledge & Capability, Internal Company Policy, Reward & Appreciation, Supplier Development, and Manpower Utilization, reflecting their practical insights and professional experience. In the second round of data collection, feedback from the first round was presented to the experts through a Focus Group Discussion (FGD), allowing them to re-evaluate and reach consensus. As a result, 19 validated CSFs grouped into six main dimensions were finalized. In the third round, these CSFs were assessed using the AHP method by collecting expert judgments through pairwise comparisons, aggregating responses, constructing comparison matrices, calculating normalized weights, and checking consistency ratios. The resulting priority weights serve as the basis for identifying the most influential factors in implementing Sustainable Lean Manufacturing in Indonesia's automotive industry.

RESULTS AND DISCUSSION

Weight Analysis of the Main Dimensions

In this study, the main dimensions are categorized into six areas: *Management and Leadership*, *Human Resources Development*, *Sustainable Production Process*, *Environmental Management*, *Supply Chain Management*, and *Safety and Well-being*. Based on the data analysis, the weights of these six main dimensions are presented in Table 1.

Table 1. Weights and Rankings of the Six Main Dimensions in SLM Implementation

No	Dimension	Weight
1	Management and Leadership (ML)	0.51
2	Safety and Well-being (SW)	0.20
3	Human Resources Development (HC)	0.16
4	Supply Chain Management (SC)	0.06
5	Sustainable Production Process (SP)	0.04
6	Environmental Management (EM)	0.02

Source: Data processed

Based on the results, the dimension with the highest weight is *Management and Leadership*, accounting for 51% of the total evaluated dimensions. This is followed by *Safety and Well-being* (20%), *Human Resources Development* (16%), *Supply Chain Management* (6%), *Sustainable Production Process* (4%), and finally *Environmental Management* (2%). The high weight of the *Management and Leadership* dimension reflects its critical role as the primary determinant in implementing Sustainable Lean Manufacturing (SLM) in companies. Without strong commitment and company policies that support SLM activities, successful implementation is unlikely. The second highest weight, *Safety and Well-being*, signifies its foundational importance especially in

manufacturing companies to ensure a safe working environment and employee well-being before advancing to broader sustainability and environmental initiatives.

Sub-Dimension Weight Analysis within the Management and Leadership Dimension

Based on the data analysis in the previous chapter, the weights of the sub-dimensions under the *Management and Leadership* dimension are presented in Table 4.2 as follows:

Table 2. Weights of Sub-Dimensions within the Management and Leadership Dimension

No	Sub-Dimension	Weight
1	Top Management Commitment (ML1)	0.54
2	Top Management Knowledge & Capability (ML4)	0.27
3	Sustainability Performance Indicators (ML3)	0.09
4	Internal Company Policy (ML5)	0.06
5	Government Policy and Regulation Support (ML2)	0.05

Source: Data processed

The sub-dimension *Top Management Commitment* received the highest weight at 54%, followed by *Top Management Knowledge & Capability* at 27%, *Sustainability Performance Indicators* at 9%, *Internal Company Policy* at 6%, and *Government Policy and Regulation Support* at 5%. This result indicates that, according to expert opinions, *Top Management Commitment* is the most critical factor in the successful implementation of SLM activities. This commitment must be supported by the *knowledge and capability of top management*, enabling them to provide effective guidance and direction for implementing SLM practices within the company.

Sub-Dimension Weight Analysis within the Safety & Well-being Dimension

Based on the data analysis in the previous chapter, the weights of the sub-dimensions under the *Safety & Well-being* dimension are shown in Table 4.3 as follows:

Table 3. Weights of Sub-Dimensions within the Safety & Well-being Dimension

No	Sub-Dimension	Weight
1	Safety an Ergonomics Integration (SW1)	0.68
2	Employee Well-being (SW2)	0.32

Source: Data processed

The results indicate that the sub-dimension *Safety and Ergonomics Integration* holds a weight of 68%, compared to *Employee Well-being* with a weight of 32%. According to expert opinion, this implies that the implementation of workplace safety and the ability to work comfortably with proper ergonomic practices is a critical success factor. It serves as a foundation before undertaking operational efficiency activities within the context of Lean Manufacturing, as well as contributing to environmental and social goals within the context of Sustainability.

Sub-Dimension Weight Analysis within the Human Resources Development Dimension

Based on the data analysis in the previous chapter, the weights of the sub-dimensions under the *Human Resources Development* dimension are presented in Table 4.4 as follows:

Table 4. Weights of Sub-Dimensions within the Human Resources Development Dimension

No	Sub-Dimension	Weight
1	Employee Training and Education (HR2)	0.44
2	Employee Involvement (HR1)	0.41
3	Reward & Appreciation (HR3)	0.15

Source: Data processed

The sub-dimension *Employee Training and Education* was identified as having the highest weight at 44%, followed closely by *Employee Involvement* at 41%, while *Reward & Appreciation* was weighted at 15% as a supporting factor in the successful implementation of SLM. According to expert opinions, the nearly equal weights of *Employee Training and Education* and *Employee Involvement* suggest that these two criteria should be

implemented in tandem. Actively involving all employees, along with providing training and education on sustainability and lean manufacturing, are key success factors in the effective application of Sustainable Lean Manufacturing.

Sub-Dimension Weight Analysis in the Supply Chain Management Dimension

Based on the previous chapter's data analysis, the weights of the sub-dimensions in the *Supply Chain Management* dimension are shown in Table 5 below:

Table 5. Sub-Dimension Weights in the Supply Chain Management Dimension

No	Sub-Dimension	Weight
1	Sustainable Supply Chain Management (SC1)	0.65
2	Supplier Development (SC2)	0.35

Source: Data processed

The results show that *Sustainable Supply Chain Management* holds a higher weight (65%) compared to *Supplier Development* (35%). According to expert opinions, this indicates that applying sustainable supply chain management by managing the supply chain using lean principles to minimize waste and non-value-adding processes, and enhancing flexibility and sustainability is a crucial factor. *Supplier Development* also supports the comprehensive implementation of SLM throughout the supply chain.

Sub-Dimension Weight Analysis in the Sustainable Production Process Dimension

Based on the previous chapter's data analysis, the sub-dimension weights for the *Sustainable Production Process* are presented in Table 4.6 below:

Table 6. Sub-Dimension Weights in the Sustainable Production Process Dimension

No	Sub-Dimension	Weight
1	Continuous Improvement / Kaizen (SP1)	0.76
2	Adoption of Disruptive Technology (SP3)	0.15
3	Value Stream Mapping Implementation (SP2)	0.09

Source: Data processed

The dominant weight of *Continuous Improvement / Kaizen* (76%) reflects its importance in the success of SLM implementation. Experts interpret this as the vital role of continuous improvement practices (Kaizen) to detect and reduce waste points throughout the production process.

Sub-Dimension Weight Analysis in the Environmental Management Dimension

Based on the previous chapter's data analysis, the sub-dimension weights for the *Environmental Management* dimension are shown in Table 7. below:

Table 7. Sub-Dimension Weights in the Environmental Management Dimension

No	Sub-Dimension	Weight
1	Environmental Impact Assessment (EM1)	0.56
2	Sustainable Waste Management (EM4)	0.26
3	Sustainable Resource Utilization (EM2)	0.10
4	Carbon Emission Reduction (EM3)	0.08

Source: Data processed

Environmental Impact Assessment is the most critical sub-dimension in this category, with a weight of 56%. According to experts, it serves as a benchmark for sustainability success by evaluating environmental impacts from production processes, minimizing emissions and waste, and supporting sustainability through waste management, optimal resource utilization, and reduced environmental impacts.

Overall Evaluation of Critical Success Factors / Sub-Dimensions

The overall score of each sub-dimension is calculated by multiplying its local weight by the global weight of its corresponding main dimension. The results are presented in Table 4.8 below:

Table 8. Ranking of All Critical Success Factors

Rank	Critical Success Factor / Sub-Dimension	Score
1	Top Management Commitment (ML1)	0.2740
2	Safety and Ergonomics Integration (SW1)	0.1397
3	Top Management Knowledge & Capability (ML4)	0.1397
4	Employee Training and Education (HR2)	0.1372
5	Employee Involvement (HR1)	0.0653
6	Employee Well-being (SW2)	0.0643
7	Sustainability Performance Indicators (ML3)	0.0456
8	Sustainable Supply Chain Management (SC1)	0.0383
9	Continuous Improvement / Kaizen (SP1)	0.0330
10	Internal Company Policy (ML5)	0.0305
11	Government Policy and Regulation Support (ML2)	0.0241
12	Reward & Appreciation (HR3)	0.0230
13	Supplier Development (SC2)	0.0208
14	Environmental Impact Assessment (EM1)	0.0131
15	Adoption of Disruptive Technology (SP3)	0.0067
16	Sustainable Waste Management (EM4)	0.0061
17	Value Stream Mapping Implementation (SP2)	0.0040
18	Sustainable Resource Utilization (EM2)	0.0023
19	Carbon Emission Reduction (EM3)	0.0020

Source: Data processed

Among the 19 sub-dimensions (critical success factors) for implementing SLM in Indonesia's automotive industry, *Top Management Commitment* ranks highest, followed by *Safety and Ergonomics Integration* in second place and *Top Management Knowledge & Capability* in third.

CONCLUSION

This study developed a decision-making model to identify and prioritize 19 Critical Success Factors (CSFs) for implementing Sustainable Lean Manufacturing (SLM) in Indonesia's automotive industry, categorizing them into six key dimensions, with Management and Leadership receiving the highest priority weight. The top five CSFs include Top Management Commitment, Safety and Ergonomics Integration, Top Management Knowledge and Capability, Employee Training and Education, and Employee Involvement. Experts emphasized the foundational importance of Lean principles and leadership over environmental concerns in early SLM stages. For future research, it is recommended to apply and validate the model across diverse manufacturing sectors, examine the longitudinal impact of CSFs, integrate advanced modeling approaches such as AI for adaptive decision-making, and incorporate employee and stakeholder perspectives to deepen the understanding of human-centric success factors in sustainable transformation.

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