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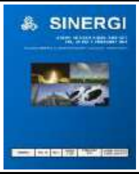

Positioning of quality systems in lean manufacturing: integrated approach vs independent implementation in the food industry

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Abstract
Despite the widespread adoption of Lean Manufacturing (LM), its effectiveness in the food industry remains underexplored, particularly regarding the integration of the Quality System (QS). The purpose of this research is to compare QS placement and LM implementation strategies in the food industry. This study utilized a comparative approach, analyzing empirical data from four food processing companies in Indonesia over six months, employing qualitative methods (expert interviews, document analysis) and quantitative analysis. Response Surface Methodology (RSM) with the Box-Behnken design was applied for optimization, while Principal Component Analysis (PCA) identified key variables influencing Lean Manufacturing success. Two implementation strategies were compared: phased implementation with a separate Quality System (Companies A and B) and simultaneous implementation with an integrated Quality System (Companies C and D). The findings revealed that Company A achieved the highest performance, with 88% in 5S and 85% in Just-In-Time (JIT), followed by Company B with 80% in JIT and 75% in 5S. In contrast, companies C and D exhibited lower performance. PCA results indicated that PC1 (80.40%) was associated with on-time delivery and sales growth, whereas PC2 (14.47%) was linked to rejection factors. Companies A and B excelled in PC1, while Companies C and D were more dominant in PC2. These findings suggest that phased implementation of LM tools is more effective than simultaneous application. This research not only addresses a critical gap in the literature but also provides practical insights for food industry practitioners seeking to enhance operational efficiency through Lean Manufacturing.

Keywords:
Comparative study;
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INTRODUCTION

The implementation strategy of Lean Manufacturing (LM) has not been fully understood by food companies, and this condition is further complicated by differing perceptions among previous researchers. Although Lean Manufacturing principles have been widely applied across various sectors, a significant gap remains in understanding how these principles can be effectively adapted to the unique challenges of the food industry, particularly regarding the integration of Quality Systems. Some studies suggest that the gradual implementation of LM facilitates the selection and evaluation of appropriate LM tools [1][2]. On the other hand, other research indicates that simultaneous application of LM tools can save processing time [3]. These differing views highlight the lack of clarity regarding the best LM implementation strategy in the food sector.

Meanwhile, although the LM concept has been widely applied in various industries, its effectiveness in the food processing sector remains uncertain [4]. Food products face unique challenges such as limited shelf life, susceptibility to spoilage, and dependence on seasonal raw materials [5], making LM implementation more complex [6]. Therefore, it is crucial to evaluate whether the LM concept introduced by Krafcik [7], initially applied in the automotive industry, can also be effectively implemented in the food industry.

Lean Manufacturing (LM) is a systematic approach to reducing waste in the production process without compromising efficiency and product quality. LM strategies are applied across various industries, including the food industry, to enhance operational efficiency and optimize resource utilization. LM strategies encompass various methods to improve productivity, such as just-in-time (JIT), continuous improvement (*Kaizen*), and value stream mapping (VSM). To support the implementation of these strategies, several LM tools are used, including *5S*, *Kanban*, and *Total Productive Maintenance* (TPM). However, the application of these tools in the food industry presents unique challenges, particularly in relation to quality systems (QS).

Quality System (QS) refers to a structured framework that ensures product quality and safety through standardized procedures, such as ISO 9001, HACCP, and GMP. In the context of Lean Manufacturing (LM), the position of QS remains a subject of debate—whether it should be integrated as an LM tool or function as an independent system that supports LM implementation. QS plays a crucial role in maintaining product consistency and compliance, particularly in the food industry, where safety and regulatory standards are critical. The relationship between QS and LM lies in their shared goal of improving efficiency and minimizing defects; however, while LM focuses on reducing waste and optimizing production flow, QS emphasizes quality assurance and risk management. Understanding this dynamic is essential for determining the most effective approach to positioning QS within LM in the food industry.

The Quality System (QS) in the food industry is not limited to ISO standards but encompasses various systems and regulations that ensure product quality and safety. Some commonly used standards include ISO 22000 as a food safety management system, ISO 9001 for quality management systems, and specific standards such as FSSC 22000 and BRCGS. Additionally, HACCP and GMP-based approaches are also part of QS, which are widely recognized in the global food industry.

In the implementation of Lean Manufacturing (LM), there are two key aspects that determine its approach. First, the relationship between LM and the Quality System (QS) can be either converged, where QS functions as a part of LM as a supporting tool, or separate, where QS operates independently and holds a higher priority than LM. Second, the implementation process of LM can be gradual, involving a progressive application with continuous evaluation and improvement, or simultaneous, where all LM elements are applied at once to achieve efficiency in a shorter time. The choice of strategy depends on the needs and characteristics of the industry implementing it.

Comparative efforts between literature and empirical data on LM implementation have been widely conducted in non-processing industries. However, the relationship between LM and QS has only been studied in recent empirical research. A recent study demonstrated significant lead time reduction using VSM in a Jordanian food factory [8]. Another study found that LM practices like JIT, TPM, and SPC improved operational efficiency and aligned with sustainability goals [9]. However, they also highlighted challenges in integrating LM with quality and waste minimization systems.

Previous studies have not fully optimized the use of advanced statistical methods such as RSM and PCA, even though these methods are essential for identifying and grouping the dominant factors influencing the implementation of Lean Manufacturing (LM) in the food industry. RSM helps optimize important variables, while PCA provides a more comprehensive analysis of the factors affecting operational performance and product quality. The application of these two methods is expected to fill the gap in previous research, offering a deeper understanding of the challenges and opportunities in LM implementation in the food industry.

To carry out an in-depth and valid analysis of the actual situation, multiple case studies are used. The case study method is the most suitable method that focuses on the exploratory nature of research [10], where qualitative and quantitative data are used [11]. Cases that have occurred will provide in-depth information about the process for testing hypotheses and explaining cause and effect relationships [12]. This method is very helpful in making conclusions regarding causal relationships. This method is also suitable for use in analyzing certain phenomena that focus on events [13].

This study offers an advanced novel approach by comparing literature and empirical data related to the implementation of LM in the food industry. The uniqueness of this research lies in the use of advanced statistical methods, namely RSM and PCA, which have not been applied in previous studies. These methods are expected to fill existing research gaps and enrich the understanding of the evolution of the LM concept.

The objectives of this study are:

1. To analyze the implementation of LM in the food industry through a comparison of literature and empirical data.
2. To identify the appropriate positioning of the QS within the LM implementation strategy in the food industry.
3. To optimize the use of advanced analytical methods such as RSM and PCA to uncover the dominant factors influencing the effectiveness of LM implementation.

RSM is used to determine the most effective combination of LM tools for improving operational performance by analyzing the interaction between multiple variables, while PCA identifies the most influential LM tools and reduces data dimensionality.

METHOD

Material

To meet the research objectives, the research design was carried out through: (a) A comprehensive literature review regarding LM, operations management, food processing, and product characteristics. (b) Comparison of the effectiveness of LM implementation in four food companies. Companies with different characteristics were deliberately involved to show the relationship between LM and QS based on company perceptions about LM implementation [14].

Data were collected through structured interviews with key stakeholders in each company, supplemented by surveys distributed to employees involved in Lean Manufacturing practices. The survey used a 5-point Likert scale to assess perceptions of Lean tool effectiveness.

Before data collection, ethical approval was obtained from the institutional review board, and informed consent was secured from all participants, ensuring their anonymity and the confidentiality of their responses.

The choice of LM tool in this research was determined by the company which was then used as a reference for comparative studies. These LM tools were: Just In Time and the kanban system [15]; 5S [16]; TQM [17] and TPM [18]. These tools were chosen based on their relevance to the company's operational strategy and their effectiveness in improving efficiency and quality within the food industry.

The application of LM was the authority and strategy used by the company to obtain optimal results. There are two options, namely: a) a gradual LM process, where the implementation of QS was followed by the gradual implementation of lean practices. b) application of LM together with QS.

The effectiveness of LM implementation was measured based on the performance of LM implementation, which includes three key indicators: percentage (%) on-time delivery, indicating the ability to meet delivery schedules; performance based on % reject, reflecting the defect rate as an efficiency measure; and performance based on sales growth, assessing the impact of LM on business expansion. The performance of the four companies was compared over a two-year period (2021-2023) to evaluate whether their strategies were effective and optimal, providing a basis for recommendations to enhance LM implementation and validate findings against existing literature. This research design was illustrated in Figure 1.

Figure 1 illustrates the stages of the research, which began with the selection of four food companies (Plant A–D) for comparative analysis. Each company was then categorized based on the relationship between Lean Manufacturing (LM) and the Quality System (QS), whether implemented separately (*separate*) or in an integrated manner (*unity*). In the next stage, companies applied various LM tools, including Just In Time (JIT), Total Quality Management (TQM), Total Productive Maintenance (TPM), Kanban, and 5S, using two different approaches: gradual implementation (*step-by-step*) or simultaneous application (*together*). Finally, the effectiveness of LM implementation was evaluated using three key performance indicators: on-time delivery, reject cost, and sales growth.

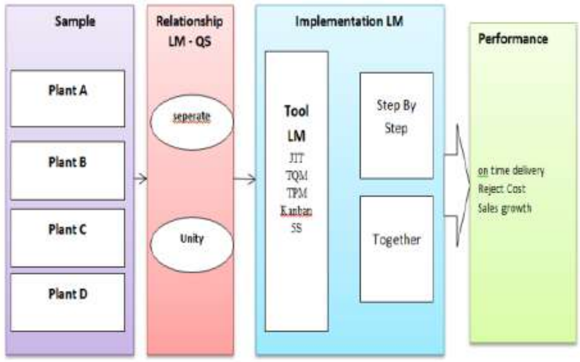

Figure 1. Design of the Study

Methods

This study employed a mixed-methods research design, integrating both qualitative and quantitative data to provide a comprehensive analysis of Lean Manufacturing implementation in the food industry. We mapped research on LM in the food industry from 2010-2023. The data were from Scopus and Web of Science collected using Harzing's Publish or Perish (Window GUI Edition) 7.31.3306.7768 and visualization using VOSviewer version 1.6.16.

The comparative study was conducted over two years (August 2021-2023), involving four different companies. Researchers had access to be directly involved in observation, documentation and data collection. Interviews, document reviews, and field observations before and after LM implementation were conducted in this research [19]. The combination of complementary data was called triangulation [20]. In addition, several strategies that ensure the reliability of research, as recommended by Powell et al [21], include detailed documentation, consistency of respondents' statements and the evidence used.

A general description of the company as a comparative study can be seen in Table 1. These four companies were selected based on variations in operational scale, product types, and prior experience in Lean Manufacturing implementation. Additionally, they belong to the same management group and are currently undergoing an experimental implementation of LM. The author also works at the headquarters, ensuring ease of access and data transparency in this study.

Implementation

The implementation stage was divided into: (i) LM relationship with QS, (ii) LM implementation and (iii) performance analysis. The results of these factors were used as a reference for the application of LM in the food industry. The LM-QS relationship explains the relationship between two variables (LM-QS) in the four companies.

The relationship was defined as follows.
Separate: QS was not a part/tool of LM. QS was seen as a quality system whose position was parallel to LM and QS's position is more prioritized than LM.
Converge: QS was a set of LM tools, while LM was the company's main priority.

All four companies selected and used LM tools. Use of LM tools depends on company policy. At this stage, the comparative study focuses on implementation: (a) Step by Step; selecting an LM tool through stages (choosing one tool to be applied with QS. If successful, you may add another LM tool. (b) Simultaneously, where QS was part of an LM tool that was used together with other LM tools. Sometimes, five LM tools (JIT, TQM, TPM, Kanban, 5S) were used simultaneously. The selection of LM-QS relationships and their application are presented in Table 2.

In the final stage, performance analysis was carried out based on the following indicators: a) on-time delivery (%) which shows the timeliness of delivery, b) Reject Cost (%) which refers to costs incurred due to product defects and expiration. c) Sales Growth (%) within 6 months compared to the highest achievement in 2023.

Statistics

The application of Response Surface Methodology and Box-Behnken Design was to optimize the performance of the LM tool. Performance was measured based on achieving standards set by the company internally. The variable measurement was based on a 1–5 Likert scale, where 1 = strongly disagree/very ineffective, 2 = disagree/ineffective, 3 = neutral, 4 = agree/effective, and 5 = strongly agree/very effective, according to the questionnaire design.

We involved 100 respondents, consisting of 80 participants from companies A, B, C, and D, along with consultants specializing in Lean Manufacturing.

Table 1. General Overview of Companies

Plant	Location	Product	Expire	Revenue/year Billion IDR	Certification
A	Surabaya	Bread	< 1 month	64	HACCP
B	Bandung	Chocolate	>1 year	114	ISO, HACCP
C	Tangerang	Wafer Cream	>1 year	146	ISO, HACCP
D	Medan	Cake	<1 month	78	HACCP

Table 2. Lean Manufacturing Implementation

Plant	Relationship LM-QS	LM Tool	Method	Implementation
A	separate	5S1tth; JIT2th	Gradual (Step by Step)	LM tools adjust to the characteristics of QS. In the first year, the implementation of QS was along with 5S and added with JIT implementation.
B	Separate	JIT1th; 5S2th	Gradual (Step by Step)	LM tools adjust to the characteristics of QS. The JIT was implemented simultaneously with QS, in the first year while 5S was implemented in the second year.
C	Converge	JIT, TQM, TPM, 5S, Kanban	Together	QS (TQM) was a LM tool. All LM tools were simultaneously applied.
D	Converge	TQM, 5S, JIT, Kanban	Together	QS (TQM) was LM tool, the four LM tools were implemented simultaneously.

Plant A: performance optimization was measured using three (3) variable factors, namely implementation time, JIT, and 5S.
Plant B: performance optimization is measured using three (3) variable factors, namely implementation time, JIT, and 5S.
Plant C: performance optimization was measured using six (6) variable factors, namely implementation time, JIT, 5S, TQM, TPM, and Kanban.
Plant D: performance optimization was measured using five (5) variable factors, namely implementation time, JIT, 5S, TQM, and Kanban.
To evaluate the performance of the four companies, Principal Component Analysis (PCA) was conducted based on three main variables: percentage of rejects, sales growth, and on-time delivery. Company performance data was obtained from the 2021-2023 period. This PCA analysis aims to identify the principal components that contribute most to the variation in company performance and to simplify the complexity of the data into a few significant principal components.

RESULTS AND DISCUSSION

Integration of Quality Systems and Lean Manufacturing: Trends and Challenges

The visualizations in Figure 2 was generated using VOSviewer software based on the data presented in Table 3. VOSviewer is a tool used to map relationships between keywords or variables in a research field based on bibliometric data. In this study, the mapping was conducted to understand the patterns and trends of Lean Manufacturing (LM) research in the food industry from 2010 to 2023.

Based on the mapping results of previous researchers in 2010 - 2023, the role of QS (TQM) which was forced to become an LM indicator caused the crucial role of QS in the food industry to be reduced by the LM strategy. So many companies separate QS from LM. However, on the other hand, QS becomes an LM tool (if referring to the initial concept of LM formation). Figure 2 helps in mapping QS placement and research hypotheses.

Figure 2a presents the mapping of correlations between variables frequently studied in LM research in the food industry. The size of the nodes represents how often a variable has been studied, while the connecting lines indicate the strength of the relationships between variables. This visualization helps identify key research variables, the interconnections between frequently studied concepts, and potential research gaps that remain unexplored. Additionally, the colors in the mapping represent groups of closely related variables, providing insights into research topics that are commonly studied together in LM implementation in the food industry. Referring to Figure 2a, we map the papers based on research objectives: (i) placement of QS in LM implementation (ii) how to implement LM.

Meanwhile, Figure 2b maps the development of LM research in the food industry from 2010 to 2023. The colors in this visualization represent changes in research trends, where newer concepts typically appear in red, while older concepts appear in green or blue. Through this mapping, the evolution of LM approaches in the food industry can be observed, including shifts in research focus from certain methods to others and the emergence of new approaches that are increasingly being studied. This analysis provides a comprehensive understanding of LM research development and serves as a foundation for future research directions.

Figure 2b provides an understanding of the LM evolution process. LM development was dominated by non-processing companies such as: textiles, electronics, automotive, furniture, etc. Developments in processing industries such as food, pharmaceuticals and chemicals had not seen their dominance. LM continues to develop in terms of paradigm, philosophy and implementation to gain efficiency and productivity.

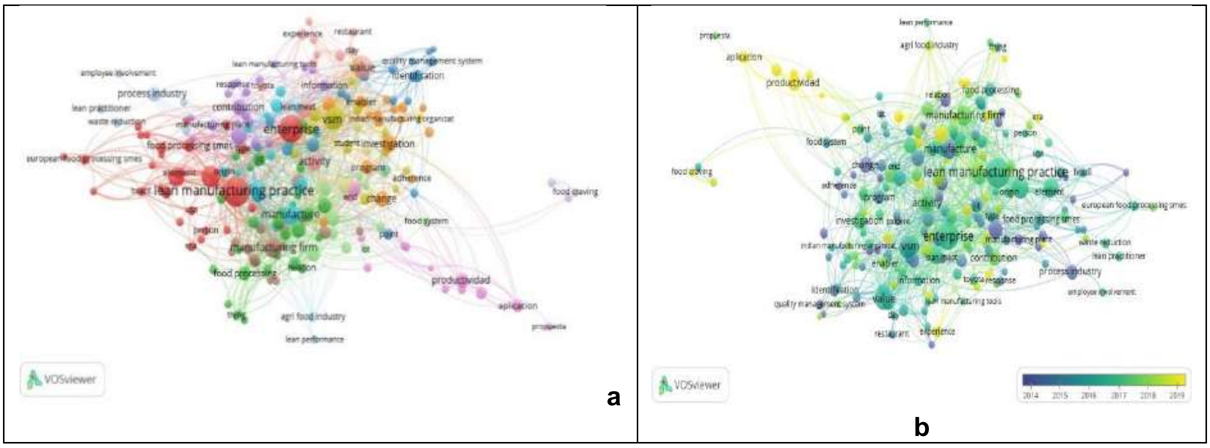

Figure. 2. Mapping of previous research for the period 2010-2023 using VosViewer. Mapping of research based on correlation between variables (a). Mapping based on LM development from the period 2010-2023 (b).

LM was a derivative of sustainable manufacturing so its evolution must follow developments. In 2018 until now, LM has been collaborated with the nature of Agile manufacturing to gain agility in responding to customer desires.

The placement of QS separately from LM turned out to be higher (41%) compared to the placement of QS as an indicator of LM (30%). Implementing LM gradually (step by step) also showed greater results (39%) than simultaneous implementation (0.16% + 2% = 18%). We show the complete results in Table 3.

This study reveals that in the food industry, QS is more frequently separated from LM (41%) rather than being used as an LM tool (30%), due to QS's crucial role in maintaining product quality and safety. A step-by-step LM approach (39%) is also proven to be more effective than simultaneous implementation (18%), avoiding confusion between QS and LM. These findings support previous studies in non-food sectors [22, 23, 24, 25] but challenge the assumption that the relationship between QS and LM can be directly applied to the food industry [26]. This research provides significant contributions to understanding a more contextual integration strategy for QS and LM in the food sector.

The placement of QS into an LM tool and the relationship between the two have been researched previously. Collaboration in manufacturing fields such as automotive, electronics, textiles, furniture, etc. provides strong evidence that these two concepts support each other and can be used simultaneously. The application of LM in the food industry has produced different conditions. The food industry has tried to implement LM simultaneously with QS, confusion has occurred in implementing the LM.

Table 3. The research mapping of the application of LM in the food industry for the period 2010-2023

Number	Description	Quantity paper	%
1	Number of papers	1000	100
	Scopus indexed papers	650	65
	papers indexed by Web of Science	350	35
2	QS variable was separate from LM	410	41
	LM implementation (step by step)	390	39
	LM implementation (simultaneously)	20	2
3	QS variable becomes LM tool	300	30
	LM implementation (simultaneously)	158	16
	Does not explain the implementation	142	14
4.	Others	290	29

Note: % based on total number of papers (1000 papers)

An in-depth study of the literature review also shows results that are not much different [9].

Performance Metrics

The performance metrics of the four companies were analyzed, revealing distinct differences in the effectiveness of Lean Manufacturing tools employed. We prove the results of this literature mapping with an in-depth case study in a food company with high researcher involvement. Recommendations for the application of LM in food companies are proposed based on comparative studies. Data regarding performance analysis was presented first to determine the effectiveness of the various strategies implemented by the company which supports the performance analysis of this study (Figure 3).

Researchers had access to be directly involved in observation, documentation and data collection. Interviews, document reviews, and field observations before and after LM implementation were conducted in this research [19]. The combination of complementary data was called triangulation [20]. In addition, several strategies that ensure the reliability of research, as recommended by Powell et al. [21], include detailed documentation, consistency of respondents' statements and the evidence used. Figure 3 shows the performance of the four companies in terms of on time delivery, reject costs and sales growth. The color scale represents performance levels, where green indicates the lowest values and red the highest. For on-time delivery and sales growth, green signifies lower performance and red higher performance, whereas for the percentage of defective products, green represents better performance (lower defects) and red worse performance (higher defects). Intermediate values are depicted with gradient colors such as blackish red or blackish green, reflecting their position within the respective scales.

On time delivery at company B showed an improvement and its achievement in the 24th month was almost perfect (close to 100%), followed by company A and the reverse condition was seen in companies C and D (Figure 3a).

The results of interviews with factory managers and supervisors at factory B show: a) the implementation of JIT supports distribution effectiveness, b) the selection of an LM tool was intended to be more focused in dealing with obstacles c) the implementation of JIT was intended to meet market demand with guaranteed quality. In this performance analysis, the implementation of factory B strategy was found to be more effective.

The "Reject Cost" performance indicator shows that success can be seen from the reduction in costs caused by product defects and product returns (Figure 3b). Plant A succeeded in reducing reject costs gradually from 9% to 3% through implementing one tool (5S) in the first year and JIT in the second year. Factory B succeeded in reducing reject costs from 6% to 3.9%. In contrast, Factories C and D never succeeded in reducing their reject costs. Factory A implements a more effective strategy in reducing rejection costs. Factory managers and supervisors admit that: a) 5S LM tools which were synonymous with sanitation really help QS in avoiding product contamination. b) The product's lifespan was quite short, and must be supported by strong quality to anticipate damage due to processing and contamination by microorganisms. c) after successful implementation of 5S, JIT is implemented in stages.

The performance indicator "Sales Growth" shows an increase in the number of sales compared to 2020. Factory A was more effective as shown by a continuous increase in sales percentage. Factory B experienced a decline in sales growth after 5S was implemented. Meanwhile, factory C and factory D experienced different conditions (Figure 3c). Factory manager A admitted that this happened because a) the use of JIT tools was implemented when 5S had been firmly embedded in the company. b) the implementation of JIT had to be carried out because the product life was relatively short.

Interviews conducted with factory managers C and D yielded similar findings: a) the company experienced confusion as to whether the LM tool should be implemented simultaneously or the quality system should be seen as part of the LM tool. b) Overlapping priorities of LM tools cause companies to be unable to focus on main problems. c) Confusion continues to the evaluation and problem-solving stage.

This study highlights the importance of a phased strategy in implementing Lean Manufacturing (LM) to improve efficiency and performance, particularly in industries with short product shelf lives, such as the food industry. Factory A successfully reduced rejection costs and significantly increased sales by first implementing 5S, which focuses on sanitation to prevent contamination, before proceeding with Just-In-Time (JIT) to optimize distribution efficiency. In contrast, other factories that did not adopt a phased approach showed suboptimal performance, with some even experiencing a decline in sales growth.

The findings support the hypothesis that phased implementation of Lean tools leads to higher performance metrics, as evidenced by Company A's superior results in both 5S and Just-In-Time (JIT) practices compared to Companies C and D, which employed simultaneous implementation.

These findings reinforce the importance of flexibility in LM implementation tailored to the specific challenges of the industry [27][28] while challenging previous research claims that simultaneous LM implementation is universally effective across all sectors [29]. This study contributes by emphasizing that the success of LM depends on system readiness and structured strategies [30].

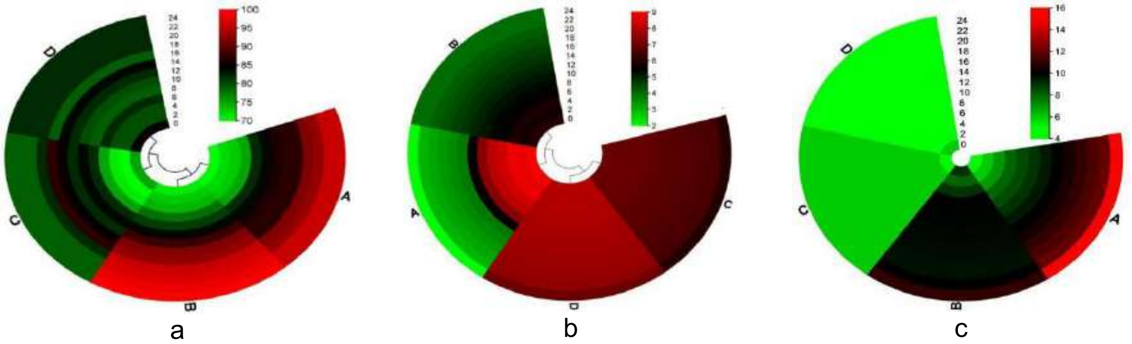

Figure 3. The Performance of LM Implementation. Percentage (%) on time delivery (a). performance based on % reject (b), and performance based on sales growth (c).

Comparative Analysis of Implementation Strategies

The effectiveness of LM implementation varies depending on the strategy and industrial context. To optimize LM performance, a comparative analysis is necessary to understand how tools such as 5S, Just-in-Time (JIT), Total Quality Management (TQM), Total Productive Maintenance (TPM), and Kanban interact in different operational environments. This section explores these strategies using RSM with Box-Behnken Design, providing insights into their impact on performance outcomes.

Company A implemented LM using 5S followed by JIT. The implementation of JIT had a performance impact of 85% in months 13 - 18. However, there was a significant decrease in performance ($p<0.05$) in months 22 - 24. The lowest performance < 60% is seen in months 7-9 (Figure 4b). The implementation of 5S was not much different from JIT. 5S provided the highest performance impact of 88% in months 12-19. It decreased periodically until the 24th month (<72%). The lowest performance was shown in the 1st month at <72%. Complete results can be seen in Figure 4a.

Implementation of JIT in company B provided the highest performance of 80% in the 10-20th month. However, there was a gradual decline in the following months, the decline continued until month 24 (70%). JIT implementation was very bad at the beginning of the month (month 1-2) (Figure 4d). The implementation of 5S had an impact on increasing performance (75%) in the 12-18thmonth, although there was a consistent decline until the 24th month (55%). The lowest performance is shown by 5S activities in months 1-3. We show the complete results in Figure 4c

The implementation of JIT, 5S, TQM, TPM, and Kanban in Company C was carried out simultaneously. Overall, it was only able to have an impact on performance of 60%. JIT consistently provides performance (55%) from the beginning to the 24th month (Figure 4e). The same phenomenon also occurs in the implementation of 5S (Figure 4f) and TQM (Figure 4g). The best implementation of TPM occurs in the 10-15th month which had an impact on performance of 50% in the 12-15th month (Figure 4h). A different phenomenon was shown by kanban which experienced a decline in performance reaching <54% in the 12-15th month (Figure 4i). The sequence of LM tool effects that have the largest impact on performance was JIT, TQM, 5S, TPM and the lowest was the Kanban system.

Simultaneous implementation of JIT, 5S, TQM, and Kanban in company D was only able to produce performance of 54%. JIT only had an effect on performance of 40% in months 8-16, then there was a decline of up to 20% in month 24 (Figure 4j). Results that were not much different are shown by 5S activities (Figure 4k). The effect of TQM on performance reached its peak in months 8-18 at 40%, but the decline in TQM reached 30% in month 24 (Figure 4l). The kanban system reached its peak influence on performance (42%) in months 11-13, then there was a drastic decline (27%) in the 24th month (Figure 4j). The LM activities that have the greatest influence were JIT, 5S, TQM, and the lowest was the kanban system.

Based on the research findings, it was found that Companies A and B demonstrated a more optimal implementation compared to Companies C and D. Company A, which implemented LM gradually with 5S followed by JIT, achieved optimal performance, especially between the 12th and 19th months, although there was a performance decline after the 22nd month. Company B also showed good performance improvement with the implementation of JIT and 5S, but the decline occurred more quickly by the 24th month.

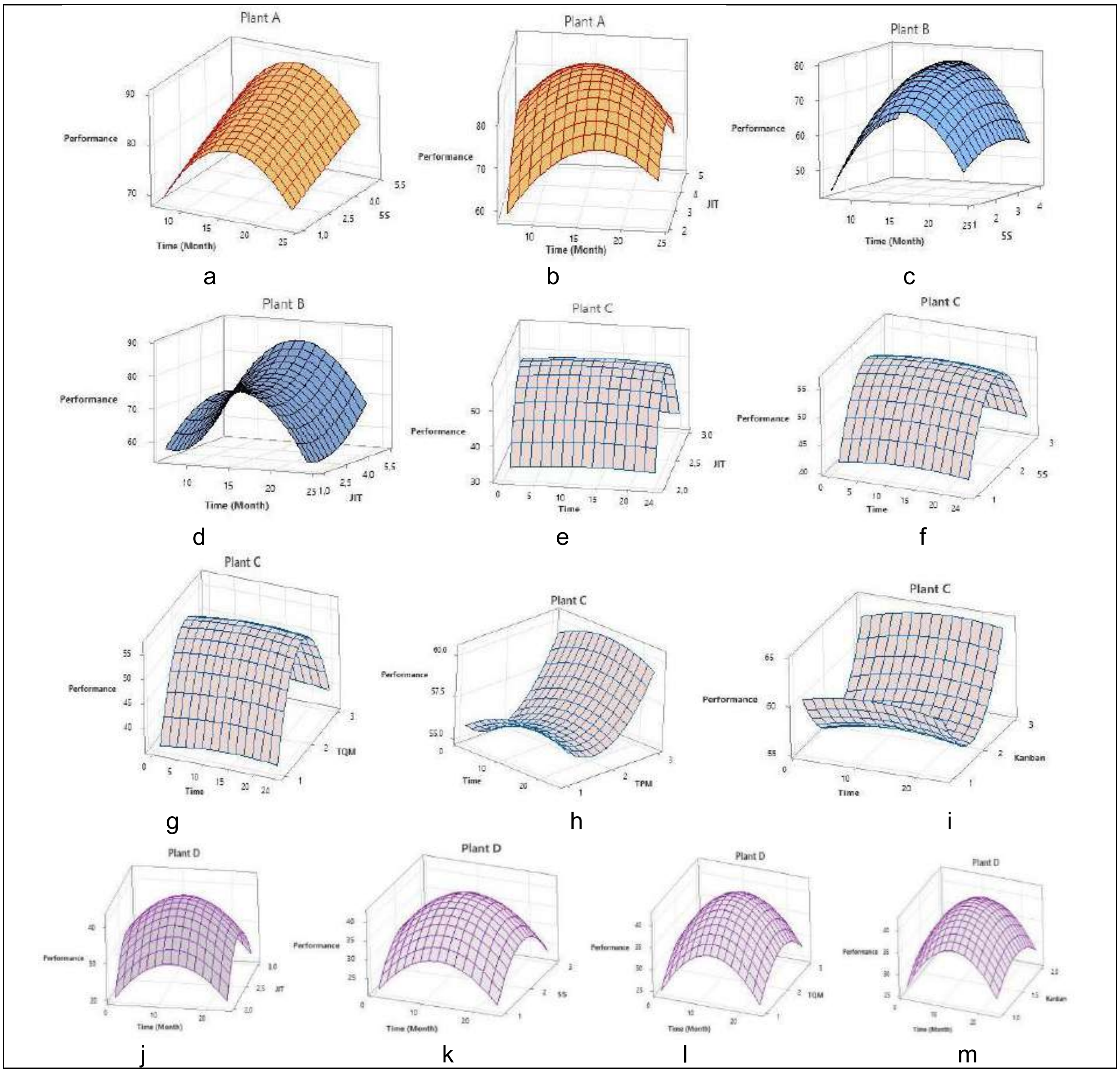

Figure 4. Response Surface Methodology and Box-Behnken Design for LM performance optimization. Surface plot of performance vs 5S (a), JIT in company A (b), 5S in company B (c), JIT in company B (d), JIT in 5S in company C (e), 5S in company C (f), TQM in company C (g), TPM 5S in company C (h), Kanban in company C (i), JIT in company D (j), 5S JIT in company D (k), TQM JIT in company D (l), and Kanban JIT in company D (m).

Meanwhile, Companies C and D, which implemented LM simultaneously, including JIT, 5S, TQM, TPM, and Kanban, only reached performance levels of around 60-54%, with a sharp decline observed in Kanban. These findings support previous research indicating that the gradual implementation of LM, with a clear focus and tailored tools, is more effective than simultaneous implementation [31], which tends to be confusing and difficult to sustain.

Key Factors Influencing Success

In this analysis, PCA was used to evaluate the implementation of various tools in each company based on on-time delivery, sales growth, and rejection rates. By identifying the variables with the most dominant influence, this analysis provides a comprehensive overview of the key factors determining the success of the implemented strategies.

According to the PCA results (Figure 5a and 5b), the most significant component was the first one (PC1), which had an eigenvalue of 2.41198 and explained 80.40% of the variation in the whole. With an eigenvalue of 0.43404, the second component (PC2) contributed 14.47% more to the variance's explanation, for a cumulative total of 94.87%. The remaining 5.13% was supplied by the third component (PC3), which has an eigenvalue of 0.15398. The biggest positive contributions for PC1 were from sales growth (0.6014) and on-time delivery (0.5929), whereas reject (-0.53553) had a negative influence. Reject (0.84178) was the main element in PC2.

Companies A and B demonstrated exceptional proficiency in implementing Lean Manufacturing (LM) methods, as determined by the findings of the PCA (Figure 5a). Their dominance in on-time delivery and sales growth was demonstrated by their locations in the upper right quadrant of the biplot, where their PC1 values were high at 80.40%. Conversely, firms C and D demonstrated inferior performance, especially with regard to high reject rates, as seen by the negative values in PC2 (14.47%). Their places, distant from the biplot's center, showed serious problems with quality that affected how well they performed as a whole. In summary, firms A and B outperformed in critical LM areas, but companies C and D needed to improve especially in lowering reject rates to increase the efficacy of their LM implementation.

Based on PC1 and PC2, the two primary components of the data structure, the cluster plot with confidence analysis offered crucial insights (Figure 5b). With an eigenvalue of 2.41198, the first principal component (PC1) could account for 80.40% of the variation in the data. The results showed that PC1 was the most important dimension for differentiating the data features, especially those that were affected by factors like sales growth and on-time delivery, which had strong positive coefficients on this component (0.6014 and 0.5929, respectively).

Companies A and B were positioned along PC1, indicating that their profiles were comparable with respect to the features that this dimension described. With an eigenvalue of 0.43404, the second principal component (PC2) was able to account for 14.47% of the variation in the data. Despite having a lesser impact than PC1, PC2 was still significant since it improved comprehension of the variations in the data. Affects like reject, which had a positive coefficient on PC2 (0.84178) and a negative coefficient on PC1 (-0.53553), were evident in the dominating companies C and D on PC2. This showed that, in contrast to Companies A and B, Companies C and D had unique qualities, with refuse serving as a major differentiator.

The results from PCA highlight the key factors influencing the performance of Lean Manufacturing (LM) implementation across companies. PCA identified that Companies A and B excelled in on-time delivery and sales growth, with their positions on PC1, which accounts for 80.40% of the data variation. This shows how PCA effectively highlights the relationship between LM tools and performance outcomes. In contrast, Companies C and D, marked by high reject rates, were positioned negatively on PC2. PCA thus provides valuable insights into the effectiveness of LM strategies, emphasizing the importance of focusing on specific performance drivers for optimal results [32].

The separation of QS from the LM concept is a crucial step in the evolution of LM, which is currently considered more suitable for application in the food industry. This research shows that separating QS from LM can be an effective solution to address various failures experienced by food companies in implementing LM. This emphasizes that LM needs to be applied with a flexible approach, tailored to the characteristics and readiness of each industrial sector [33]. By separating QS from LM, companies can focus on improving process efficiency without being hindered by the difficulties of integrating both concepts, leading to more sustainable long-term improvements in performance and quality [34].

Simultaneous application of LM (plants C and D) apparently brings confusion when applied in the food industry. Optimal results were actually obtained by separating QS from LM as proven by plants A and B. In this case, these findings are at odds with research conducted by Baqleh et al. [8]. Failures in implementing the LM concept must be overcome so that it can be applied simultaneously, namely: a) Selecting the right LM tool to pair with QS [35]. b) Define QS and LM in detail to avoid overlapping concepts [36].

Company A's success can be attributed to its smaller operational scale, which allowed for more flexible Lean implementation, as well as its prior experience with quality management systems that facilitated the integration of Lean principles. These findings align with the work of Raut et al. [37], who noted that gradual implementation of Lean tools is more effective in environments characterized by high variability and strict quality requirements.

Practically, this research provides recommendations for implementing LM so that it does not overlap with the role of QS. Company managers are expected to be able to choose the right LM tool related to the characteristics of food products (product age, raw materials, risk of contamination/damage, etc.). In the short term, managers can implement recommendations from research, namely: selection of LM tools, implementation process, and placement of QS separately from LM. If it does not provide optimal results, continuous analysis can be carried out while still separating QS from LM activities.

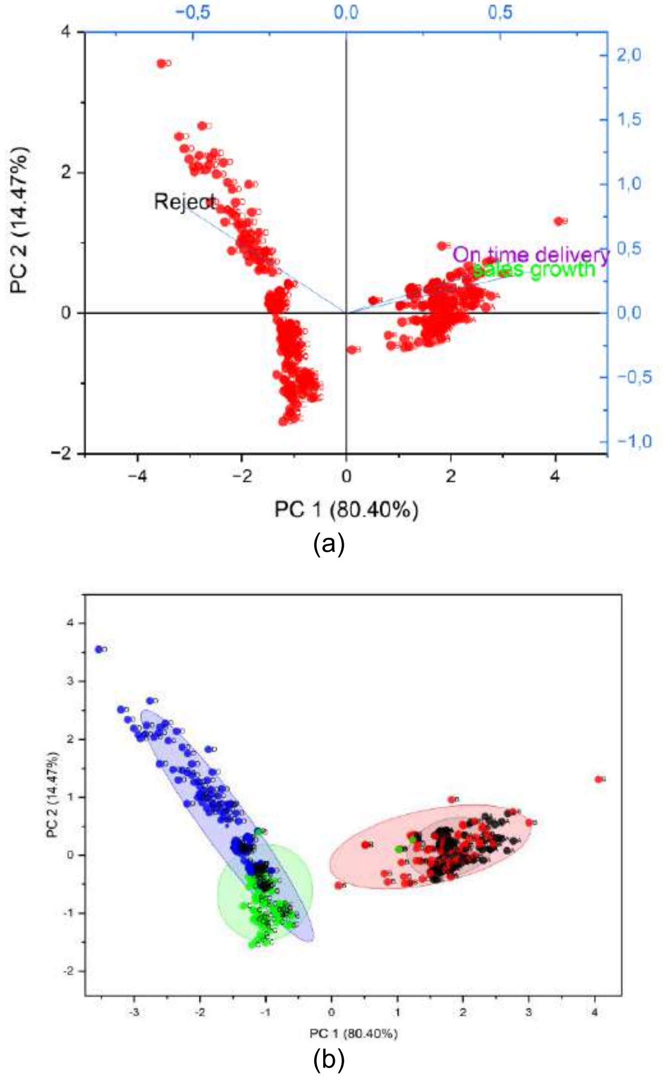

Figure 5. Results of Principal Component Analysis:
(a) Biplot and (b) Cluster Plot with Confidence Interval

Limitation

Although this study provides valuable insights, it should be acknowledged that the sample size is limited to four companies, which may not fully represent the diversity of the food industry. Future research should use a larger sample to confirm these findings.

Implications of Findings for Practice and Future Research

This study suggests that food companies should consider a phased approach to Lean Manufacturing implementation, particularly in contexts where quality systems are critical. Future research should explore the long-term impact of this strategy on operational performance.

CONCLUSION

The comparison results of the literature review with comparative studies of LM implementation in the food industry show the same results, QS is not a barrier to implementing the LM concept. Food companies must be able to position QS separately from the LM concept which is widely known. Implementing LM in stages will help companies evaluate appropriate LM tools that can be optimized in company conditions.

Company A performed best in terms of 5S (88%) and JIT (85%), with Company B coming in second with 80% for JIT and 75% for 5S. Companies C and D, on the other hand, showed worse performance levels. The findings of the Principal Component Analysis (PCA) showed that PC1 (80.40%) was mostly linked to sales growth and on-time delivery, whereas PC2 (14.47%) focused on rejection criteria. While Companies C and D were more noticeable in PC2, Companies A and B fared better in PC1. The results indicate that adopting all of the Lean Manufacturing (LM) tools at once was not as beneficial as using them gradually. Better control over performance factors and customization to particular operational requirements were made possible by this method.

Suggestions for further research are to increase the number of research samples, then analyze using the Structural Equation Model Partial Least Square (SEM-PLS) test to emphasize the influence of the LM variable (f^2) and the predictive value of LM on QS (Q^2)

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