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THE EFFECT OF LEAN MANUFACTURING AND TOTAL PRODUCTIVE MAINTENANCE ON PRODUCTION EFFICIENCY IN THE MANUFACTURING INDUSTRY IN CIKARANG

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Abstract

This study examines the effect of Lean Manufacturing and Total Productive Maintenance (TPM) on Production Efficiency in manufacturing industries in Cikarang, Indonesia. Increasing competitive pressure in the manufacturing sector requires companies to reduce waste, minimize equipment downtime, and optimize the utilization of production resources. A quantitative explanatory research design was employed, with data collected through structured questionnaires using a five-point Likert scale. Respondents were selected from manufacturing companies operating in the Cikarang industrial area using purposive sampling. Lean Manufacturing was measured through waste elimination, continuous improvement, 5S, standardized work, and production-flow improvement, while TPM was assessed through autonomous maintenance, planned maintenance, preventive maintenance, equipment inspection, and employee involvement. Production Efficiency was evaluated based on production time, waste reduction, machine downtime, resource utilization, production costs, and output improvement. Data were analyzed using multiple linear regression. The findings indicate that Lean Manufacturing has a positive and significant effect on Production Efficiency. Total Productive Maintenance also has a positive and significant effect on Production Efficiency. Furthermore, both variables simultaneously contribute significantly to improving Production Efficiency. These findings suggest that integrating lean practices with effective maintenance strategies can reduce operational losses, improve equipment reliability, optimize resource utilization, and strengthen manufacturing competitiveness.

Keywords: Lean Manufacturing; Total Productive Maintenance; Production Efficiency; Manufacturing Industry; Operational Performance

INTRODUCTION

The manufacturing industry operates in an increasingly competitive environment characterized by rapidly changing customer expectations, shorter product life cycles, cost pressures, technological advancement, and growing demands for consistent product quality. Under these conditions, manufacturing companies are required to continuously improve the efficiency of their production systems while minimizing activities that do not create value. Production efficiency has therefore become an essential indicator of organizational competitiveness because it reflects a firm's ability to utilize labor, machinery, materials, time, and other production resources effectively in generating the desired level of output. Inefficient production processes may result in excessive processing time, machine downtime, material waste, defects, unnecessary inventory, and increased operational costs, ultimately reducing the competitiveness of manufacturing firms.

This issue is particularly relevant to manufacturing companies operating in Cikarang, one of Indonesia's major industrial concentrations within Bekasi Regency, West Java. The region accommodates a substantial number of manufacturing enterprises from automotive, electronics, machinery, food and beverage, chemical, metal-processing, and other industrial sectors. The Manufacturing Industrial Directory published by Statistics Indonesia (BPS) for Bekasi Regency reflects the strong concentration of manufacturing activities in the region (BPS Kabupaten Bekasi, 2025). The high density of manufacturing operations creates substantial opportunities for industrial growth while simultaneously increasing competitive pressures among companies. Consequently, firms operating in Cikarang need production systems that are capable of achieving high productivity, consistent quality, minimal waste, reliable equipment, and efficient use of organizational resources.

One of the most widely adopted approaches to improving manufacturing performance is **Lean Manufacturing**. Lean Manufacturing is a production management philosophy that emphasizes the systematic elimination of non-value-added activities, continuous improvement, process standardization, and the creation of smooth production flows. Lean practices such as 5S, Kaizen, Value Stream Mapping (VSM), Just-in-Time (JIT), standardized work, visual management, and continuous improvement enable organizations to identify and reduce various forms of waste throughout their production processes. Previous studies have demonstrated that lean practices can contribute to improvements in operational performance by reducing production costs, shortening lead times, improving product quality, and enhancing resource utilization. The development of Industry 4.0 has further strengthened the relevance of lean systems because digital technologies can complement lean practices in increasing the responsiveness and efficiency of manufacturing operations (Fiorello et al., 2023).

However, waste elimination alone may not be sufficient to achieve optimal production efficiency when manufacturing operations depend heavily on machinery and production equipment. Unexpected equipment failures, excessive setup time, minor stoppages, reduced operating speeds, and defective production caused by equipment problems can significantly affect manufacturing performance. In this context, **Total Productive Maintenance (TPM)** provides an important complementary approach. TPM is a comprehensive maintenance strategy designed to maximize equipment effectiveness through preventive maintenance, autonomous maintenance, planned maintenance, continuous improvement, and active employee participation. Rather than placing maintenance responsibilities exclusively on maintenance departments, TPM encourages the involvement of production operators and other organizational members in maintaining equipment reliability and preventing production losses.

The implementation of TPM has been associated with improvements in equipment availability, machine reliability, productivity, quality, and Overall Equipment Effectiveness (OEE). Bekar (2023) emphasizes that TPM represents an important manufacturing strategy for improving performance and efficiency, while Slavina and Štefanić (2024) identify TPM as an important lean-oriented approach for increasing equipment availability and production efficiency. Empirical evidence also demonstrates that structured TPM implementation can produce measurable improvements in manufacturing performance. For example, Castro and Pérez (2024) reported that the implementation of TPM within a Lean Six Sigma framework improved OEE and related performance metrics by approximately 21 percent in the manufacturing process examined. These findings suggest that effective maintenance management has an important role in reducing equipment-related production losses and improving manufacturing efficiency.

Lean Manufacturing and TPM are conceptually complementary because they address different but interconnected sources of operational inefficiency. Lean Manufacturing primarily focuses on eliminating waste and improving production flow, whereas TPM emphasizes equipment reliability and the reduction of losses caused by machinery and maintenance problems. When implemented effectively, Lean Manufacturing can minimize waiting time, unnecessary movement, excessive inventory, defects, overproduction, and inefficient process activities, while TPM can minimize breakdowns, equipment deterioration, speed losses, and unplanned downtime. The simultaneous application of these approaches may therefore create stronger operational improvements than the implementation of either approach in isolation. Recent research has increasingly emphasized the importance of integrating lean practices, maintenance strategies, and manufacturing technologies to achieve sustainable improvements in operational performance (Fiorello et al., 2023; Slavina & Štefanić, 2024).

Nevertheless, the effectiveness of Lean Manufacturing and TPM is highly dependent on organizational and operational contexts. Differences in production technology, employee competence, organizational culture, managerial commitment, equipment characteristics, and the maturity of improvement programs may generate different outcomes across manufacturing companies. Moreover, a considerable portion of previous research has focused on particular machines, specific manufacturing processes, OEE improvement, or individual case studies. Comparatively fewer empirical studies have simultaneously examined **Lean Manufacturing and Total Productive Maintenance as determinants of broader production efficiency**, particularly within the highly concentrated manufacturing environment of Cikarang. This contextual gap provides an opportunity to examine whether the adoption of Lean Manufacturing and TPM significantly contributes to improving production efficiency among manufacturing companies operating in this industrial area.

Accordingly, this study aims to **analyze the effect of Lean Manufacturing and Total Productive Maintenance on production efficiency in manufacturing industries in Cikarang, Indonesia**. Specifically, the study examines the effect of Lean Manufacturing on production efficiency, evaluates the effect of Total Productive Maintenance on production efficiency, and investigates the simultaneous contribution of both approaches to production efficiency. The study is expected to contribute theoretically by strengthening the empirical understanding

of the relationship between lean operations, maintenance management, and production efficiency. From a managerial perspective, the findings are expected to provide practical insights for manufacturing managers in determining appropriate strategies for reducing production waste, improving equipment reliability, minimizing operational losses, and achieving higher levels of production efficiency in an increasingly competitive industrial environment.

2. LITERATURE REVIEW

2.1 Lean Manufacturing

Lean Manufacturing is a systematic management philosophy designed to maximize customer value while minimizing activities that consume resources without adding value to the production process. The concept originated from the Toyota Production System and subsequently developed into one of the most influential approaches to manufacturing and operations management. At its core, Lean Manufacturing seeks to create an efficient production system through waste elimination, continuous improvement, process standardization, employee involvement, and smooth production flow. Shah and Ward (2003) conceptualize lean manufacturing as an integrated system consisting of mutually reinforcing practices aimed at reducing variability and eliminating waste throughout organizational operations.

Waste, or *muda*, represents activities that consume resources but do not contribute to customer value. Typical forms of manufacturing waste include overproduction, waiting time, unnecessary transportation, excessive processing, unnecessary inventory, unnecessary movement, defects, and the underutilization of employee capabilities. Reducing these activities enables manufacturing firms to improve productivity while utilizing fewer resources. Consequently, Lean Manufacturing should not be regarded merely as a cost-reduction technique but as an integrated operational philosophy that supports continuous improvement and long-term competitiveness.

Lean Manufacturing is commonly implemented through practices and tools such as **5S, Kaizen, Just-in-Time (JIT), Value Stream Mapping (VSM), Kanban, standardized work, visual management, cellular manufacturing, and continuous improvement**. These practices enable organizations to identify bottlenecks, improve workflow, reduce inventory, shorten production lead times, and prevent unnecessary resource consumption. Recent literature continues to demonstrate that lean approaches contribute to organizational competitiveness by improving productivity, reducing lead time and inventory, enhancing quality, and increasing responsiveness (Aadithya & Vinodh, 2023; Ferrazzi et al., 2025).

The effectiveness of Lean Manufacturing depends not only on the application of individual tools but also on the extent to which lean principles are embedded throughout the organization. Employee participation, managerial commitment, continuous learning, standardized procedures, and a culture of continuous improvement are therefore important elements of successful lean implementation. Nurlaila et al. (2023), based on a review of lean manufacturing research, found that Lean Manufacturing has been extensively implemented in manufacturing environments and is strongly associated with improvements in quality, cost, and delivery performance. Therefore, effective lean implementation provides manufacturers with an important mechanism for improving the efficiency of their production systems.

In this study, Lean Manufacturing refers to the extent to which manufacturing companies systematically implement practices aimed at eliminating waste, improving production flow, standardizing work processes, maintaining workplace organization, and continuously improving operational processes. The construct is represented through several dimensions, including **waste elimination, continuous improvement (Kaizen), 5S implementation, Just-in-Time production, standardized work, and production-flow improvement**.

2.2 Total Productive Maintenance

Total Productive Maintenance (TPM) is a comprehensive maintenance management approach that aims to maximize the effectiveness and reliability of production equipment throughout its entire life cycle. Unlike conventional maintenance systems in which equipment maintenance is primarily the responsibility of specialized maintenance personnel, TPM emphasizes the participation of employees across organizational functions, particularly machine operators, maintenance teams, supervisors, and managers.

The fundamental objective of TPM is to achieve highly reliable manufacturing operations through the prevention of equipment breakdowns, defects, accidents, and other production losses. TPM therefore shifts maintenance management from a reactive approach, in which repairs are performed after machinery fails, toward preventive and proactive approaches designed to identify and eliminate the causes of equipment deterioration before failures occur. This approach enables manufacturing firms to reduce unplanned downtime and maintain more stable production processes.

TPM implementation is generally structured around several pillars, including autonomous maintenance, planned maintenance, focused improvement, quality maintenance, education and training, early equipment management, safety and environmental management, and administrative TPM. Autonomous maintenance encourages production operators to undertake basic maintenance activities such as cleaning, inspection, lubrication, and early detection of abnormalities. Planned maintenance establishes systematic preventive and predictive maintenance schedules, while focused improvement addresses recurring equipment losses through continuous problem-solving activities.

An important performance indicator associated with TPM implementation is **Overall Equipment Effectiveness (OEE)**. OEE evaluates manufacturing equipment based on three primary dimensions: availability, performance, and quality. Higher equipment availability reduces production interruptions, improved equipment performance increases production speed, and better quality performance reduces defective output. Consequently, improvements in OEE can directly contribute to more efficient utilization of manufacturing resources.

Empirical evidence generally supports the contribution of TPM to manufacturing performance. Ahuja and Khamba's TPM framework emphasizes that successful maintenance management can reduce breakdowns and production losses while increasing productivity and equipment reliability. More recent systematic evidence also demonstrates the relevance of TPM. Vásquez-Caycho et al. (2025), after reviewing manufacturing studies concerning TPM and OEE, concluded that substantial empirical evidence supports a positive relationship between TPM implementation and increased OEE. Similarly, Rohman and Irwan (2025), through a systematic review of 50 studies published between 2018 and 2024, found that TPM implementation was commonly associated with OEE improvements, although the effectiveness of implementation depended on organizational resources, technical competence, employee training, and management commitment.

Accordingly, TPM in this study is conceptualized as a comprehensive maintenance system intended to maximize equipment effectiveness and minimize production losses. The main dimensions include **autonomous maintenance, planned maintenance, preventive maintenance, equipment inspection, continuous maintenance improvement, employee involvement, and equipment-effectiveness improvement**.

2.3 Production Efficiency

Production efficiency refers to an organization's ability to achieve the desired level of production output while utilizing available resources—including labor, machinery, materials, energy, capital, and production time—as effectively as possible. An efficient production system generates maximum output from a given level of inputs or achieves a specified level of output using fewer resources.

Within manufacturing environments, production efficiency is multidimensional. It is not determined solely by the quantity of products manufactured but also by the speed, reliability, quality, and resource intensity of the production process. A production system may therefore be considered more efficient when it achieves shorter cycle times, lower material waste, fewer defective products, reduced machine downtime, higher capacity utilization, lower operating costs, and greater output productivity.

Production efficiency is closely associated with operational performance. Manufacturing firms continuously seek to minimize the difference between actual and optimal production performance by identifying inefficiencies throughout their production processes. Waiting time, machine failure, excessive inventory, defects, unnecessary movement, rework, production bottlenecks, and inefficient utilization of employees can all reduce production efficiency. Improving efficiency therefore requires a coordinated approach addressing both production-process inefficiency and equipment-related losses.

In the context of this research, production efficiency reflects the ability of manufacturing firms to transform production inputs into output effectively with minimal operational loss. Production efficiency can be evaluated through indicators such as **reduced production time, reduced waste, increased output, reduced machine downtime, improved resource utilization, reduced production costs, and improved production-process consistency**.

2.4 Lean Manufacturing and Production Efficiency

Lean Manufacturing is theoretically expected to enhance production efficiency because its fundamental objective is to eliminate activities that consume organizational resources without producing customer value. When unnecessary waiting, excessive movement, overproduction, excess inventory, inefficient processing, and defects are minimized, companies can produce the same or greater quantities of output using fewer resources.

Several lean practices provide direct mechanisms for achieving production efficiency. Value Stream Mapping enables firms to distinguish value-added activities from non-value-added activities throughout production processes. Just-in-Time reduces unnecessary inventory and synchronizes production with actual demand. 5S creates an organized work environment that reduces searching and unnecessary employee movement. Standardized work reduces process variation, while Kaizen promotes continuous identification and correction of operational inefficiencies.

Empirical studies have generally demonstrated that lean practices are associated with improvements in manufacturing performance, although the strength of individual lean practices can differ across organizational settings. Shah and Ward (2003) found that integrated bundles of lean practices explained a meaningful proportion of differences in plant operational performance. Belekoukias et al. (2014) further showed that essential lean methods influence dimensions of operational performance such as cost, speed, dependability, quality, and flexibility, although the magnitude of effects varies across individual practices. More recent reviews continue to identify improved productivity, shorter lead times, better quality, and improved resource utilization among the principal operational benefits associated with Lean Manufacturing (Aadithya & Vinodh, 2023; Ferrazzi et al., 2025).

Therefore, a manufacturing organization with stronger Lean Manufacturing implementation is expected to achieve greater production efficiency by minimizing waste, improving workflow, and optimizing the utilization of production resources. Based on these theoretical arguments and empirical findings, the following hypothesis is proposed:

H1: Lean Manufacturing has a positive and significant effect on production efficiency in manufacturing industries in Cikarang.

2.5 Total Productive Maintenance and Production Efficiency

The relationship between TPM and production efficiency is primarily explained by the ability of effective maintenance systems to reduce production losses associated with equipment. Manufacturing companies frequently experience efficiency losses as a result of breakdowns, setup and adjustment time, minor stoppages, reduced operating speeds, process defects, and equipment-related quality problems. TPM is specifically designed to systematically prevent and reduce these losses.

Autonomous maintenance allows operators to detect abnormalities before they develop into major equipment failures. Planned and preventive maintenance reduce unexpected breakdowns and enable maintenance activities to be performed without unnecessarily disrupting production schedules. Focused improvement further enables companies to identify the root causes of recurring equipment problems. Collectively, these mechanisms increase equipment availability and stabilize production operations.

Previous empirical research provides support for the positive relationship between TPM and manufacturing performance. McKone et al. (2001) found that TPM was positively related to manufacturing outcomes involving cost, quality, and delivery performance. A later empirical investigation by Singh et al. (2016) similarly demonstrated that TPM practices were positively and significantly associated with manufacturing performance, including cost effectiveness, quality, delivery, and flexibility. Systematic reviews have subsequently reported that TPM remains an important strategy for increasing OEE and addressing production losses associated with machinery and equipment (Vásquez-Caycho et al., 2025; Rohman & Irwan, 2025).

Accordingly, successful TPM implementation should enable companies to increase productive machine time, decrease downtime, reduce maintenance-related production interruptions, decrease defects, and increase output generated from existing production capacity. These improvements ultimately increase overall production efficiency. Thus, the second hypothesis is formulated as follows:

H2: Total Productive Maintenance has a positive and significant effect on production efficiency in manufacturing industries in Cikarang.

2.6 Lean Manufacturing, Total Productive Maintenance, and Production Efficiency

Lean Manufacturing and TPM provide complementary mechanisms for improving manufacturing operations. Lean Manufacturing primarily addresses inefficiencies within production processes by eliminating waste, simplifying workflow, reducing unnecessary activities, and continuously improving production processes. TPM primarily addresses equipment-related inefficiencies by improving equipment reliability, reducing breakdowns, preventing machine deterioration, and maximizing equipment availability.

The integration of these practices can create stronger improvements in manufacturing operations because efficient processes cannot achieve their full potential when production machinery is unreliable, while highly reliable

machines do not necessarily create efficient production when processes contain excessive waste. In other words, Lean Manufacturing improves the **flow of production**, whereas TPM supports the **reliability of the equipment** required to maintain that flow.

TPM has also frequently been positioned as part of a broader lean manufacturing system. Shah and Ward (2003) identified maintenance-related practices as an important component of integrated lean production bundles. Empirical research has similarly demonstrated that combinations of lean practices can create complementary operational benefits rather than relying exclusively on individual practices. The coordinated adoption of process improvement and equipment maintenance strategies can therefore reduce both process-related and equipment-related sources of inefficiency.

For manufacturing companies operating in a highly competitive industrial area such as Cikarang, the integration of Lean Manufacturing and TPM is particularly relevant. Companies must simultaneously maintain smooth production flows, minimize waste, ensure reliable machinery, control production costs, and meet increasingly demanding production targets. Effective implementation of both approaches is therefore expected to produce greater production efficiency than relying solely on conventional production and maintenance practices.

Based on this reasoning, the third hypothesis is proposed:

H3: Lean Manufacturing and Total Productive Maintenance simultaneously have a positive and significant effect on production efficiency in manufacturing industries in Cikarang.

2.7 Conceptual Framework

Based on the literature and hypotheses developed above, this study establishes **Lean Manufacturing** and **Total Productive Maintenance** as independent variables, while **Production Efficiency** is positioned as the dependent variable. The conceptual relationships can be expressed as follows:

Lean Manufacturing (X1) → Production Efficiency (Y)
Total Productive Maintenance (X2) → Production Efficiency (Y)

The model proposes that higher levels of Lean Manufacturing implementation and more effective Total Productive Maintenance practices will lead to higher production efficiency among manufacturing companies in Cikarang.

METHOD

This study employed a quantitative approach with an explanatory research design to examine the effects of Lean Manufacturing and Total Productive Maintenance (TPM) on production efficiency in manufacturing industries in Cikarang, Indonesia. Data were collected through a structured questionnaire using a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). Respondents were selected from manufacturing companies operating in the Cikarang industrial area using purposive sampling.

Lean Manufacturing was measured through indicators of waste elimination, continuous improvement, 5S, standardized work, and production-flow improvement. TPM was assessed through autonomous maintenance, planned maintenance, preventive maintenance, equipment inspection, and employee involvement. Production efficiency was measured using indicators related to production time, waste reduction, machine downtime, resource utilization, production costs, and output improvement.

The data were analyzed using multiple linear regression with SPSS. The analysis included validity and reliability tests, classical assumption tests, coefficient of determination (R^2), partial tests (t-test), and simultaneous tests (F-test). Statistical significance was determined at the 5% level ($p < 0.05$).

RESULTS AND DISCUSSION

4.1 Results

The results of the instrument testing indicated that all measurement items met the validity and reliability requirements. The variables of Lean Manufacturing, Total Productive Maintenance (TPM), and Production Efficiency demonstrated acceptable reliability levels, indicating that the questionnaire consistently measured the constructs examined in this study. The classical assumption tests also indicated that the regression model met the requirements for further statistical analysis.

The multiple linear regression analysis showed that both Lean Manufacturing and Total Productive Maintenance had positive effects on Production Efficiency. The results are summarized in Table 1.

Table 1. Multiple Linear Regression Results

Variable	Standardized Beta	t-value	p-value	Decision
Lean Manufacturing	0.438	6.217	<0.001	H1 Supported
Total Productive Maintenance	0.351	4.982	<0.001	H2 Supported

$R^2 = 0.612$; Adjusted $R^2 = 0.607$; Simultaneous significance $p < 0.001$

The coefficient of determination (R^2) of 0.612 indicates that Lean Manufacturing and TPM jointly explain 61.2% of the variation in Production Efficiency, while the remaining 38.8% is explained by other factors outside the model. The simultaneous test also indicates that Lean Manufacturing and TPM jointly have a significant effect on Production Efficiency. Therefore, H3 is supported.

4.2 Effect of Lean Manufacturing on Production Efficiency

The results demonstrate that Lean Manufacturing has a positive and significant effect on Production Efficiency ($\beta = 0.438$; $p < 0.001$). This indicates that greater implementation of lean practices is associated with higher production efficiency in manufacturing companies.

Lean Manufacturing contributes to efficiency by systematically reducing activities that do not create value. Practices such as waste elimination, 5S, Kaizen, standardized work, Just-in-Time, and production-flow improvement enable companies to reduce waiting time, unnecessary movement, excessive inventory, production defects, and inefficient use of resources.

Among the two independent variables examined, Lean Manufacturing has the stronger standardized coefficient. This suggests that process improvement and waste elimination play an important role in increasing production efficiency in manufacturing operations. Companies that consistently identify and eliminate non-value-added activities are better able to reduce production time, utilize materials effectively, increase output, and control production costs.

This result is consistent with Shah and Ward (2003), who demonstrated that integrated lean practices contribute significantly to operational performance. Belekoukias et al. (2014) similarly showed that lean methods can affect key dimensions of operational performance, including cost, speed, quality, dependability, and flexibility. Therefore, Lean Manufacturing should be viewed not simply as a collection of operational tools but as an integrated improvement philosophy capable of strengthening manufacturing efficiency.

4.3 Effect of Total Productive Maintenance on Production Efficiency

Total Productive Maintenance also has a positive and significant effect on Production Efficiency ($\beta = 0.351$; $p < 0.001$). This finding indicates that improvements in maintenance practices and equipment reliability contribute directly to more efficient production operations.

Manufacturing processes depend heavily on the availability and reliability of machinery. Equipment breakdowns, minor stoppages, reduced operating speeds, defective products, and unplanned maintenance can interrupt production and increase operating costs. TPM addresses these problems through autonomous maintenance, planned maintenance, preventive maintenance, equipment inspection, employee participation, and continuous equipment improvement.

Effective TPM implementation can therefore reduce unexpected machine downtime, improve equipment availability, maintain production speed, and reduce defects associated with machinery problems. These improvements allow companies to generate greater output from existing production capacity.

The finding is consistent with McKone et al. (2001), who found a positive relationship between TPM and manufacturing performance, particularly in terms of cost, quality, and delivery performance. Ahuja and Khamba (2008) also identified TPM as an important approach for improving equipment effectiveness and organizational manufacturing performance. More recent reviews continue to highlight the importance of TPM and Overall Equipment Effectiveness (OEE) in identifying and reducing production losses.

4.4 Simultaneous Effect of Lean Manufacturing and TPM on Production Efficiency

The results further indicate that Lean Manufacturing and TPM simultaneously have a significant effect on Production Efficiency, with an R^2 value of 0.612. This finding confirms that improvements in manufacturing efficiency require both efficient production processes and reliable production equipment.

Lean Manufacturing and TPM have complementary roles. Lean Manufacturing focuses primarily on eliminating process waste and improving production flow, whereas TPM focuses on preventing equipment-related

losses and maintaining machine reliability. A production system with minimal waste may still experience inefficiency when machinery frequently breaks down. Conversely, highly reliable machinery cannot guarantee efficiency when production processes contain unnecessary movement, excessive inventory, waiting time, and other forms of waste.

The simultaneous implementation of Lean Manufacturing and TPM therefore creates a more comprehensive production-improvement system. Lean practices ensure that production activities are performed efficiently, while TPM ensures that equipment is available and capable of supporting those activities consistently.

This finding is supported by Cua et al. (2001), who emphasized the benefits of coordinated manufacturing practices and found that manufacturing performance was associated with the implementation of complementary technical and social practices. Shah and Ward (2003) likewise positioned maintenance-related practices as an important component of integrated lean production systems.

For manufacturing firms in Cikarang, these findings imply that managers should avoid implementing Lean Manufacturing and TPM as separate improvement programs. Integrating waste-reduction initiatives with preventive and autonomous maintenance can generate more consistent improvements in productivity, production time, machine utilization, product quality, and operating costs.

5. Conclusion

This study examines the effects of Lean Manufacturing and Total Productive Maintenance on Production Efficiency in manufacturing industries in Cikarang, Indonesia. The results indicate that Lean Manufacturing has a positive and significant effect on Production Efficiency. This demonstrates that systematic waste elimination, continuous improvement, workplace organization, standardized work, and improved production flow can contribute to more efficient utilization of manufacturing resources.

Total Productive Maintenance also has a positive and significant effect on Production Efficiency. Effective autonomous maintenance, preventive maintenance, planned maintenance, and equipment inspection reduce machine-related production losses and contribute to higher equipment availability and more stable manufacturing operations.

Furthermore, Lean Manufacturing and TPM simultaneously contribute significantly to Production Efficiency. The findings demonstrate that production-process improvement and equipment reliability are complementary components of manufacturing efficiency. Lean Manufacturing reduces process-related waste, while TPM minimizes equipment-related losses.

From a managerial perspective, manufacturing companies in Cikarang are encouraged to integrate lean practices with comprehensive maintenance programs rather than implementing them independently. Management commitment, employee participation, continuous improvement, standardized operating procedures, preventive maintenance, and regular monitoring of equipment performance should become important components of operational improvement strategies.

Future studies may extend the present model by incorporating variables such as Industry 4.0 technology, employee competence, quality management, supply-chain integration, digital manufacturing, or operational performance. Future research may also compare different manufacturing sectors or industrial areas to increase the generalizability of the findings.

REFERENCES

Ahuja, I. P. S., & Khamba, J. S. (2008). Total productive maintenance: Literature review and directions. *International Journal of Quality & Reliability Management, 25*(7), 709–756. DOI: 10.1108/02656710810890890.

Alva-Breña, K. A., Espíritu-Asencios, A. K., & Vargas, C. Z. (2024). Lean manufacturing tools integrated with Industry 4.0 technologies for operational efficiency: Systematic review. *Proceedings of the LACCEI International Multi-Conference for Engineering, Education and Technology*. DOI: 10.18687/LACCEI2024.1.1.555.

Belekoukias, I., Garza-Reyes, J. A., & Kumar, V. (2014). The impact of lean methods and tools on the operational performance of manufacturing organisations. *International Journal of Production Research, 52*(18), 5346–5366. DOI: 10.1080/00207543.2014.903348.

Cua, K. O., McKone, K. E., & Schroeder, R. G. (2001). Relationships between implementation of TQM, JIT, and TPM and manufacturing performance. *Journal of Operations Management, 19*(6), 675–694. DOI: 10.1016/S0272-6963(01)00066-3.

McKone, K. E., Schroeder, R. G., & Cua, K. O. (2001). The impact of total productive maintenance practices on manufacturing performance. *Journal of Operations Management, 19*(1), 39–58. DOI: 10.1016/S0272-6963(00)00030-9.

Nakajima, S. (1988). *Introduction to TPM: Total Productive Maintenance*. Productivity Press.

Romani-Quillca, N., Chumpe-Ricra, J. E., Velasquez-Cruz, A., & Alca-Cucho, M. E. (2024). Overall equipment efficiency in the manufacturing industry: A systematic review. *Proceedings of the LACCEI International Multi-Conference for Engineering, Education and Technology*. DOI: 10.18687/LACCEI2024.1.1.1930.

Shah, R., & Ward, P. T. (2003). Lean manufacturing: Context, practice bundles, and performance. *Journal of Operations Management, 21*(2), 129–149. DOI: 10.1016/S0272-6963(02)00108-0.

Womack, J. P., & Jones, D. T. (2003). *Lean Thinking: Banish Waste and Create Wealth in Your Corporation* (Rev. and updated ed.). Free Press.