The Impact of Lean Manufacturing Practices (LMP) on Sustainable Operational Performance in the Electrical and Electronics (E&E) Manufacturing Sector in Southern Malaysia

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ABSTRACT

The electrical and electronics (E&E) manufacturing sector plays a crucial role in Malaysia's economy, accounting for 5.8% of GDP and 40% of export revenue. Despite its economic significance, the sector faces sustainability challenges particularly in managing electronic waste (e-waste) which exceeds 365 000 tonnes annually and is projected to reach 24.5 million units by 2025. This study examines the role of lean manufacturing practices (LMP) specifically just-in-time (JIT), statistical process control (SPC) and pull system (PS) in enhancing sustainable operational performance in Southern Malaysia E&E manufacturing sector. A sample of 70 firms was selected using simple random sampling. Data were collected through structured questionnaires and analyzed using SPSS. The findings indicate that JIT has the most significant impact followed by PS and SPC in optimizing production processes, minimizing waste and mitigating e-waste generation. These findings highlight the importance of integrating multiple LMP to improve sustainability and aligning with Sustainable Development Goals (SDG) 9 and 12. Practitioners can use these insights to enhance resource efficiency and competitiveness. Policymakers can design incentives, regulations and training programs to drive sustainable industrial practices. Future research should explore additional LMP and their application in other industries to support sustainable operational performance.

Keywords
Electrical and Electronics, Manufacturing, Lean Manufacturing Practices, Southern Malaysia, Sustainable Operational Performance

Introduction

The electrical and electronics (E&E) manufacturing sector is a crucial contributor to Malaysia's economy. The total value of E&E exports for 2023 amounted to RM575.46 billion contributing 47.3% of Malaysia's total manufactured exports. These markets collectively accounted for 67.1% of Malaysia's total E&E exports (MITI, 2023). However, this sector faces significant environmental and operational challenges particularly in managing electronic waste (e-waste). According to research by the Department of Environment (2022), Malaysia produces over 365,000 tonnes of e-waste annually with projections indicating a sharp increase in the coming years. Inefficient e-waste management directly impacts the sustainable operational performance of E&E manufacturers by increasing costs, risking regulatory non-compliance and causing environmental degradation.

These challenges undermine the sector's ability to achieve economic efficiency, environmental sustainability and social responsibility which are key pillars of sustainable operational performance. The southern region of Malaysia identified by MITI (2023) as a hub for the rapidly expanding E&E manufacturing sector as shown in figure 1 faces substantial sustainability challenges due to its concentration of E&E manufacturers.

The integration of lean manufacturing practices (LMP) in the electrical and electronics (E&E) manufacturing sector has the potential to address e-waste issues while enhancing sustainable operational performance across economic, environmental and social dimensions. This alignment not only supports organizational efficiencies but also contributes to broader sustainability objectives including those outlined in the United Nations Sustainable Development Goals

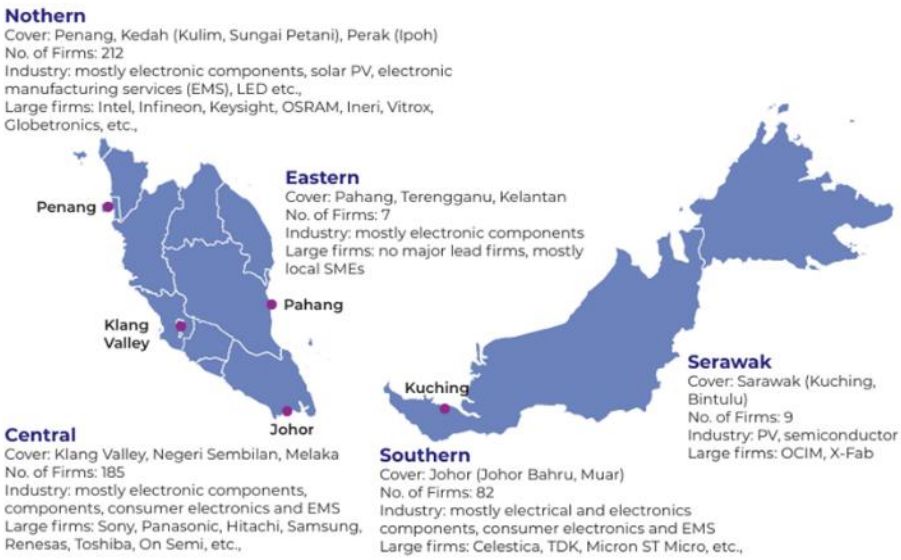

Figure 1. Geographic Distribution of E&E Industry in Malaysia

(SDGs). This study aims (i) to analyze the impact of just-in-time (JIT) practices on sustainable operational performance in the E&E manufacturing sector, (ii) to investigate the impact of statistical process control (SPC) practices on sustainable operational performance and (iii) to examine the impact of pull system (PS) practices on sustainable operational performance in the sector.

Literature Review

LMP aim to minimize waste while maintaining productivity by eliminating non-value-added activities and emphasizing value-adding processes (Nawanir et al., 2016). This study focuses on three dimensions of LMP which are JIT, SPC and PS practices. JIT improves efficiency by producing and delivering goods only when needed, reducing inventory costs and aligning production with demand (Ohno, 1988). SPC uses statistical tools to ensure process consistency, reduce defects and enhance quality (Yadav et al., 2019). PS drives production based on actual demand, minimizing overproduction and inventory while improving responsiveness to customer needs (Womack & Jones, 1997).

Lean Manufacturing Practices (LMP)

Table 1 Summary of Lean Manufacturing Practices Studied by Previous Researchers

LMP Author	JIT	SPC	PS
Lizarelli et al. (2023)			X
Naufal Adnan et al. (2023)	X	X	
Ooi et al. (2023)	X	X	X
Bandi et al. (2022)	X		X
Manzoor et al. (2022)	X	X	X
Kovilage (2021)			X
Terdpaopong et al. (2021)	X		X
Nawanir et al. (2020)			X
Al Bashar et al. (2019)	X		
Yadav et al. (2019)		X	X
Total	6	4	9

The analysis of previous studies on LMP indicates that PS are the most extensively studied practices featured in 9 out of 10 studies as shown in table 1. While JIT is the second most frequently studied appearing in 6 out of 10 studies. In contrast, SPC is less frequently studied appearing in only 4 studies. Notably, two study comprehensively examined all three practices highlighting the complementary nature of these methods. Thus, these LMP practices were chosen for study because they address critical aspects of manufacturing efficiency and productivity.

Sustainable Operational Performance

Sustainable operational performance refers to an organisation's ability to balance operational efficiency with the triple bottom line of sustainability economic, environmental and social dimensions (Elkington, 1997). In the context of the electrical and electronics (E&E) manufacturing organisation, this study focuses on how manufacturing organisations can achieve high operational efficiency while addressing the sector's significant environmental impacts such as e-waste and improving social and economic outcomes.

Table 2 Summary of Sustainable Operational Performance Studied by Previous Researchers

Sustainable Operational Performance Author	Economic	Environment	Social
Lizarelli et al. (2023)	X	X	X
Naufal Adnan et al. (2023)	X	X	X
Ooi et al. (2023)	X	X	X
Ilangakoon et al. (2022)	X	X	X
Rathi et al. (2022)	X	X	X
Kovilage (2021)	X	X	X
Terdpaopong et al. (2021)	X	X	X
Nawanir et al. (2020)	X		
Hussain et al. (2019)	X	X	X
Yadav et al. (2019)	X	X	
Total	10	9	8

The analysis of previous studies on sustainable operational performance reveals that the economic dimension is addressed in all 10 studies. The environmental dimension is covered in 9 studies while the social dimension is addressed in 8 studies as shown in table 2. Notably, studies after 2021 focus on all three aspects economic, environmental and social indicating a shift toward a more holistic approach to sustainability. Earlier studies often emphasized the economic dimension alone. Thus, all three dimensions was selected to align with the emerging trend and to contribute to a more comprehensive understanding of sustainable operational performance.

Conceptual Research Framework

An impact analysis was conducted to examine the impact of the independent variables on the dependent variables. The proposed conceptual research framework presented in figure 2 illustrates the framework guiding this study.

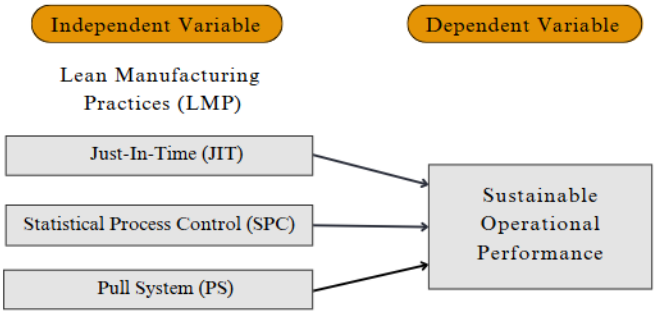

Figure 2. Conceptual Research Framework

Hypothesis Development

The JIT practices aimed at improving efficiency by minimizing waste particularly in inventory management. Studies show that JIT enhances operational efficiency by reducing inventory costs, cycle times and unnecessary maintenance waste contributing to better resource utilization (Bandi et al., 2022; Maware & Adetunji, 2019). Its application in the E&E sector has been linked to increased productivity, reduced production costs and greater adaptability to market changes ultimately improving sustainable operational performance metrics such as economic efficiency and environmental sustainability (Ooi et al., 2023). Therefore, the following hypothesis is formulated:
H1: The implementation of JIT practices significantly impacts the sustainable operational performance of the E&E manufacturing sector.

The SPC practices aims to improve sustainable operational performance by enhancing process stability, reducing defects and minimizing resource waste. Studies reveal that SPC utilizes statistical tools to monitor and control production processes, 5 enabling early detection of variations and fostering consistent quality (Ooi et al., 2023). Although limited application in the E&E sector, SPC demonstrates significant potential for aligning with sustainability goals such as waste reduction and efficient resource usage (Yadav et al., 2019) SPC emerges as a valuable tool for sustainability initiatives by supporting long-term environmental and economic benefits (Manzoor et al. (2022). Therefore, the following hypothesis is formulated:
H2: The implementation of SPC practices significantly impacts the sustainable operational performance of the E&E manufacturing sector.

The PS practices emphasize producing only when demand exists, reducing overproduction and inventory costs. It organizes production processes efficiently often through cellular manufacturing to align resources with specific product needs (Nawanir et al., 2020). The primary advantage of PS is inventory reduction which not only cuts costs but also improves responsiveness to customer needs and contributes to sustainable operational performance through resource optimization and waste minimization (Kovilage, 2021; Ooi et al., 2023). Therefore, the following hypothesis is formulated:
H3: The implementation of PS practices significantly impacts the sustainable operational performance of the E&E manufacturing sector.

Methods

Research Design

This study adopts a well-structured research design guided by Saunders' Research Onion (Saunders et al., 2020) to ensure methodological validity. The research follows a positivist paradigm and adopting a deductive approach to test hypotheses based on existing theories. A survey strategy is implemented to collect quantitative data using a cross-sectional time horizon. Data was obtained by distributing structured questionnaires within the E&E manufacturing sector in Southern Malaysia. The responses were analyzed using SPSS to determine the impact of JIT, SPC and PS practices on sustainable operational performance. This structured approach ensures a robust methodology for obtaining reliable and valid results as illustrated in figure 3.

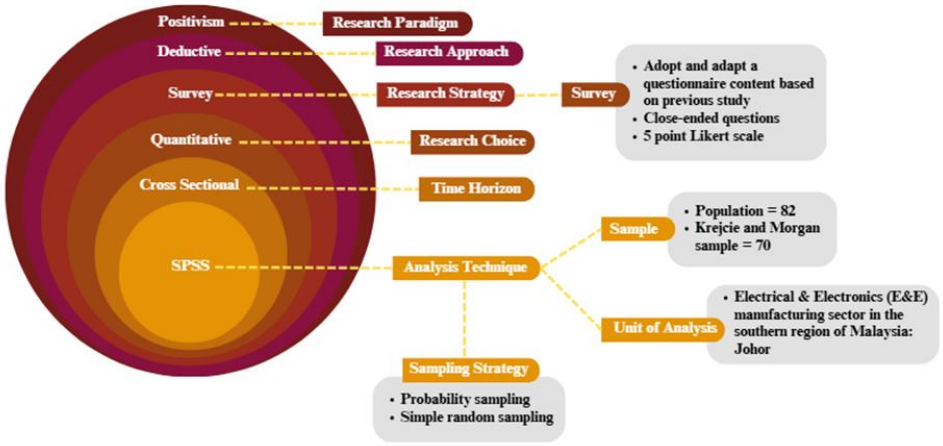

Figure 3. Saunder's Research Onion

Population, sample and analysis technique

This research focuses on organizations within the E&E manufacturing sector as the unit of analysis. This research focuses on organizations as whole entities including key roles such as the CEO, assistant manager and supervisor rather than on individual employees. According to data from the Ministry of International Trade and Industry (MITI), there are 82 E&E manufacturing sectors in Southern Malaysia. The Krejcie and Morgan sample size table indicates that 70 respondents are required. Simple random sampling was employed to ensure an unbiased selection process. A simple random sampling calculator was employed to select 70 organizations, ensuring that each had an equal probability of being included in the study.

Research Instrument

This research employed a quantitative method to collect primary data utilizing a questionnaire as the measurement instrument to ensure the validity and reliability of the data. The questionnaire was distributed via google forms to respondents within the E&E manufacturing sector located in southern Malaysia. The questionnaire was divided into three main sections. The first section covered demographic information, while the second section evaluated the level of LMP implementation. The final section assessed the influence of these practices on sustainable operational performance. Responses were measured using a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). A close-ended questionnaire format was employed to ensure clarity and structure in the data collected.

Data Analysis

The data gathered was analyzed with the Statistical Package for the Social Sciences (SPSS) software to examine the effect of LMP on sustainable operational performance. Descriptive statistical techniques were applied to summarize the data. The reliability analysis was conducted using Cronbach's alpha to ensure the internal consistency of the questionnaire items and verifying the reliability of the measurement scales. Additionally, regression analysis applied to identify and quantify the impact of the variables. These analytical methods were selected to address the research objectives and provide evidence-based conclusions.

Results

Respond Rate and Result of Reliability Test

The questionnaire was distributed to 70 electrical and electronics (E&E) manufacturing organizations in southern Malaysia with all 70 organizations responding. Therefore, the response rate for this research is 100%.

Table 3 Cronbach's Alpha Reliability

Variables	No. of Items	Pilot test (n=30)	Actual Study Result (n=70)
		Cronbach's Alpha	Cronbach's Alpha
JIT	5	0.93	0.93
SPC	5	0.85	0.87
PS	5	0.91	0.90
Sustainable Operational Performance	15	0.78	0.82

Table 3 presents the Cronbach's Alpha reliability values for both the pilot test and the actual study. The same questionnaire was used in both phases. The pilot test involved 30 participants while the actual study involved 70 participants. The results indicate that both JIT and PS achieved Cronbach's Alpha values above 0.90 which is categorized as very good. Meanwhile, SPC and Sustainable Operational Performance scored above 0.80 which is categorized as good. These findings demonstrate that all the variables used in this study are reliable and consistent.

Result of Descriptive Analysis

Descriptive analysis provides a summary of the collected data that offering insights into the characteristics of the sample. This analysis includes measures such as frequencies, percentages, means and standard deviations to describe and summarize the key features of the data in a clear and concise manner. This analysis supports research objectives 1 to 3 by highlighting the implementation levels of JIT, SPC and PS in the E&E manufacturing sector.

Table 4 Descriptive Analysis

Variables	N	Minimum	Maximum	Mean	Std. Deviation
JIT	70	1.80	5.00	4.224	.750
SPC	70	3.00	5.00	4.620	.460
PS	70	2.20	5.00	4.086	.734
Sustainable Operational Performance	70	3.33	5.00	4.182	.430

The descriptive statistics as shown in table 4 depicted that SPC is the best rated independent variable with the highest mean score of 4.620 and the lowest variability with a standard deviation of 0.460 indicating that participants rated it most consistently and favourably. It is followed by JIT which has a mean of 4.224 and a higher standard deviation of 0.750 suggesting positive ratings but with more variability in responses. PS had the lowest mean score of 4.086 with a standard deviation of 0.734 reflecting positive but more variable ratings. As for the dependent variable, sustainable operational performance had a mean score of 4.182 and a low standard deviation of 0.430 showing high and consistent ratings across participants.

Result of Regression Analysis

Regression analysis is a statistical approach used to determine the relationship between independent and dependent variables. It quantifies the extent to which changes in one variable affect another. In this study, simple regression analysis was conducted to evaluate the individual impact of each LMP on sustainable operational performance. Simple regression was chosen instead of multiple regression to allow a focused examination of how each specific LMP independently contributes to sustainable operational performance within the Southern Malaysia E&E manufacturing sector.

Table 5 Just-In-Time (JIT) Practices

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.731[a]	.534	.527	.29556

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6.806	1	6.806	77.907	<.001[b]
	Residual	5.940	68	.087		
	Total	12.746	69			

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.412	.204		11.852	<.001
	JIT	.419	.047	.731	8.826	<.001

The regression analysis as shown in table 5 reveals that JIT has a significant positive impact on sustainable operational performance. The R-square value is 0.534 indicating that 53.4% of the variance in sustainable operational performance is explained by JIT practices. The ANOVA table confirms that the model is statistically significant with an F-value of 77.907 and a p-value less than 0.001. The standardized coefficient (Beta) for JIT is 0.731 and its corresponding t-value is 8.826 ($p < 0.001$) highlighting the strength and relevance of the relationship. The unstandardized coefficient (B=0.419) suggests that a one-unit increase in JIT practice contributes to a 0.419-unit increase in sustainable operational performance.

Table 6 Statistical Process Control (SPC) Practices

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.631[a]	.398	.389	.33589

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.074	1	5.074	44.972	<.001[b]
	Residual	7.672	68	.113		
	Total	12.746	69			

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.456	.408		3.564	<.001
	SPC	.590	.088	.631	6.706	<.001

The results for SPC as shown in table 6 also indicate a statistically significant positive relationship with sustainable operational performance. The R-square value is 0.398 meaning SPC accounts for 39.8% of the variance in the dependent variable. The F-value is 44.972 with a p-value below 0.001 confirming the model's significance. The standardized coefficient (Beta) for SPC is 0.631 while the t-value is 6.706 ($p < 0.001$). The unstandardized coefficient ($B = 0.590$) shows that for every unit increase in SPC sustainable operational performance improves by 0.590 units. Although significant SPC's impact is less pronounced compared to JIT.

Table 7 Pull System (PS) Practices

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.684[a]	.468	.460	.31592

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.959	1	5.959	59.705	<.001[b]
	Residual	6.787	68	.100		
	Total	12.746	69			

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.546	.215		11.838	<.001
	PS	.400	.052	.684	7.727	<.001

The PS practices as shown in table 7 also has a significant positive effect on sustainable operational performance. The R-square value is 0.468 indicating that 46.8% of the variance in the dependent variable is explained by the pull system. The F-value of 59.705 and p-value of less than 0.001 confirm the model's statistical significance. The standardized coefficient (Beta) is 0.684 with a t-value of 7.727 ($p < 0.001$). The unstandardized coefficient ($B = 0.400$) indicates that a one-unit increase in the pull system improves sustainable operational performance by 0.400 units. The impact of the pull system lies between JIT and SPC in terms of strength.

Hypothesis Validity

According to the research findings, all the LMP have a statistically significant and positive impact on sustainable operational performance. Each practice JIT, SPC and PS is strongly associated with sustainable operational performance. Among these, JIT is the most influential (Beta = 0.731). The PS follows with a moderate impact (Beta = 0.684). SPC has the lowest though still significant impact (Beta = 0.631). This ranking reflects the relative influence of the practices. The results support the hypotheses and confirm the strong relationship between LMP and sustainable operational performance as summarized in table 8.

Table 8 Summary of Hypothesis Validity

Hypothesis	Result	Rank
H1: The implementation of JIT practices significantly impacts the sustainable operational performance of the E&E manufacturing sector.	Supported	1
H2: The implementation of SPC practices significantly impacts the sustainable operational performance of the E&E manufacturing sector.	Supported	3
H3: The implementation of PS practices significantly impacts the sustainable operational performance of the E&E manufacturing sector.	Supported	2

Discussions

The first research objective which aims to analyze the impact of JIT practices on the sustainable operational performance of the E&E manufacturing sector has been successfully achieved. The findings from the reliability analysis indicate that the Cronbach's alpha value for JIT is 0.93 demonstrating a very high level of reliability and internal consistency for this variable. In terms of descriptive statistics, JIT practices achieved a mean score of 4.224 with a standard deviation of 0.750 reflecting a generally positive perception among respondents albeit with some variability in their ratings. Regression analysis further confirms a strong and significant positive relationship between JIT practices and sustainable operational performance. These results are consistent with previous studies which highlight that JIT enhances operational efficiency by reducing inventory costs, cycle times, unnecessary waste and improving resource utilization (Bandi et al., 2022; Maware & Adetunji, 2019). In the E&E sector, JIT has also been linked to increased productivity, cost reduction and better adaptability contributing to improved sustainability outcomes (Ooi et al., 2023). These findings underscore that JIT practices are among the most impactful strategies for enhancing sustainable operational performance. It is recommended that the E&E manufacturing sector implement JIT practices to not only improve operational efficiency but also reduce e-waste by minimizing excess inventory, streamlining production processes and optimizing resource utilization. This approach would contribute significantly to achieving sustainability goals while addressing the growing concerns over environmental impacts.

The second research objective which focuses on investigating the impact of SPC practices on sustainable operational performance has also been successfully addressed. The reliability analysis reveals a Cronbach's alpha value of 0.87 for SPC indicating a good level of reliability and internal consistency. Descriptive analysis shows that SPC practices achieved the highest mean score among the three LMP variables with a mean value of 4.620 and a standard deviation of 0.460. These findings reflect highly consistent and favourable perceptions of SPC practices among respondents. The regression results further confirm the significant positive relationship between SPC practices and sustainable operational performance. These findings are in line with previous studies that highlight SPC's role in improving process stability, reducing defects and minimizing resource waste (Ooi et al., 2023; Yadav et al., 2019). SPC uses statistical tools to monitor and control production processes enabling early detection of variations and ensuring consistent quality. Although its application in the E&E sector has been limited, SPC shows strong potential to support sustainability goals such as waste reduction and efficient resource use, offering long-term environmental and economic benefits (Manzoor et al., 2022). Although SPC practices have a slightly lower impact than JIT and PS practices, they remain a vital contributor to sustainable operational performance. It is highly recommended that the E&E manufacturing sector adopt SPC practices as part of their sustainability strategies. SPC practices can help minimize defects, reduce e-waste and ensure more efficient use of resources by focusing on rigorous quality control and process optimization. Implementing SPC practices will not only enhance operational performance but also support the sector in achieving its sustainability goals and addressing environmental challenges.

The third research objective which aims to examine the impact of PS practices on sustainable operational performance has also been successfully achieved. The reliability analysis indicates that PS practices have a Cronbach's alpha value of 0.90 signifying very high reliability and internal consistency. From the descriptive analysis, PS practices achieved a mean score of 4.086 with a standard deviation of 0.734. Regression analysis further confirms that PS practices have a significant and positive impact on sustainable operational performance. These results align with previous studies which emphasize that PS practices focus on producing only when demand exists, thereby reducing overproduction and inventory costs (Nawanir et al., 2020). PS typically organizes production through efficient systems such as cellular manufacturing and aligning resources to specific product needs for better efficiency. The main advantage of PS lies in inventory reduction which not only lowers costs but also enhances responsiveness to customer demand. It further promotes sustainability through resource optimization and waste minimization (Kovilage, 2021; Ooi et al., 2023). Among the three LMP analyzed, PS practices are the second most impactful in enhancing sustainable operational performance. It is highly recommended that the E&E manufacturing sector implement PS practices as part of their sustainability efforts. PS practices can help minimize overproduction, reduce e-waste, and optimize resource utilization by aligning production with actual demand. Adopting PS practices will not only improve operational efficiency but also contribute significantly to the sector's environmental sustainability goals.

Conclusion

The study on the impact of LMP on sustainable operational performance in the E&E manufacturing sector in southern Malaysia has been successfully completed with all research objectives fully achieved. The findings confirm that all three LMP elements have a significant and positive impact on sustainable operational performance. Among them, JIT emerged as the most impactful followed by PS and SPC. This indicates that the implementation of LMP plays a vital role in driving both operational efficiency and sustainability. The results provide valuable insights for manufacturers seeking to reduce waste align production with actual demand and enhance process control to improve performance while reducing environmental impact. By adopting these practices, manufacturers can optimize resource usage, minimize e-waste and strengthen their competitiveness in a sustainable way. For policymakers, the study offers a strong foundation for developing supportive incentives, regulatory frameworks and training programs to encourage broader adoption of LMP across the sector. These efforts can be aligned with national and global sustainability agendas particularly the SDGs to foster responsible and future-ready industrial growth. Overall, the research underscores that LMP is not only an effective approach for improving operational outcomes but also a strategic enabler of long-term environmental and economic sustainability in the E&E manufacturing industry.

Limitations and Future Studies

This study encountered difficulties in obtaining respondents from the manufacturing sector due to strict data disclosure policies and the demanding work schedules of industry professionals. These challenges led to delays in response rates requiring multiple follow-ups to secure sufficient participation. For future research, expanding the study to other industries such as automotive, pharmaceuticals or food manufacturing could provide comparative insights into the impact of LMP on sustainable operational performance. Additionally, exploring different geographical regions including rural and international settings may help identify variations influenced by economic or regulatory differences. Future studies could also benefit from adopting a longitudinal research design instead of a cross-sectional approach. This would allow researchers to track changes over time and gain deeper insights into the long-term effects of LMP on sustainable operational performance.

Conflict of Interest

The authors declare no conflicts of interest in connection with the publication of this paper.

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