Structural Impact of Lean Manufacturing Practice Bundles on Corporate Sustainability in Malaysia

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ABSTRACT

In Malaysia, as organisations in the public and private sectors intensify their efforts to extend their goals related to sustainability, the issue has turned into a strategic one. Sustainability data, particularly ESG data, has the potential to significantly enhance Malaysia's sustainability environment. Nevertheless, such data remains difficult to access, particularly for the manufacturing sector in Malaysia. Hence, this study investigates the influence of lean practices on the Triple Bottom Line (TBL) reporting in Malaysian manufacturing organisations, given the critical role that private sector participation plays in enabling the accomplishment of Malaysian sustainability. The purpose of this research is to better understand how stakeholders monitor and manage sustainability, as well as the potential influence of lean practices on sustainability in the private sector, particularly in Malaysian manufacturing. This research adopts a quantitative research design, data was collected from 115 manufacturing firms through structured survey distributed to middle and upper management. The structural model analysis reveals that lean manufacturing practices, when implemented as an integrated bundle, explain a substantial percentage of the variance across all three sustainability pillars: 63.7% for Economic, 62.2% for Environmental, and 58.7% for Social sustainability. At a granular level, the findings uncover the absolute path dominance of Gemba Walks (Floor Leadership Engagement) as the most robust and statistically significant driver of sustainability performance across the TBL. Conversely, traditional structural tools such as 5S, TPM, and Kaizen demonstrated weak and non-significant direct path relationships in this specific sample, suggesting they function as secondary stabilizing platforms rather than immediate performance drivers. This research provides empirical validation emphasizing that Malaysian manufacturers should adopt lean practices as a holistic, unified system driven by active leadership on the shop floor to effectively meet reporting demands and enhance corporate responsibility.

Keywords: Lean Manufacturing Practices, Sustainability Performance, Triple Bottom Line (TBL), Malaysian Manufacturing

INTRODUCTION

Selecting the right lean management tools can save time and increase productivity by improving performance metrics and reducing or eliminating waste. This holistic approach focuses on the interactions among organisational processes while also considering external influences within the broader value creation network. It underscores the significance of clearly defined visions, missions, and objectives for enterprises.

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Standardisation involves defining consistent best practices for repetitive tasks to maintain stability and enhance efficiency. The Zero Defects principle stresses preventing mistakes at the source by applying quality assurance tools, promoting a quality-oriented mindset, and maintaining high standards. Meanwhile, the Flow principle focuses on designing processes that allow a smooth movement of materials and information, thereby reducing delays and improving efficiency. The Pull principle requires production to occur only in response to customer demand, which helps lower inventory levels and prevent overproduction.

Since sustainability has become a major concern for businesses all over the world, reliable reporting systems are required to monitor economic, social, and environmental performance. Reporting on sustainability has grown in importance in non-financial reporting. This is demonstrated by the increasing global trend of sustainability reporting adherents (Wijesinghe et al., 2023). A sustainability report is a document published by a business or organisation detailing the social, environmental, and economic effects of its regular operations. The organisation's principles, governance structure, and the connection between its strategy and dedication to a sustainable global economy are all presented in the sustainability report (Eranga & Wijesinghe, 2021). However, Malaysian manufacturing companies display a significant lack of complete sustainability information. These organisations are unable to effectively monitor and assess their sustainability initiatives due to the lack of data. Moreover, even though lean practises are widely acknowledged to enhance efficiency, reduce waste, and promote continuous improvement, their incorporation into sustainability reporting is still a relatively unexplored area in Malaysia's industrial environment.

Although lean concepts are well known for their capacity to avoid waste and improve operational efficiency, there is still much to be discovered about how well they work with sustainability reporting procedures in the Malaysian manufacturing sector. In this context, the possible advantages of using lean approaches to enhance sustainability measures demand further examination, such as lowering environmental impact, boosting social responsibility, and guaranteeing economic viability. Lean is one of the projects that seems to be related to sustainability (Durojaye Moshood et al., 2020).

Inadequate sustainability reporting influences the sector as a whole in addition to specific companies. For instance, inadequate reporting systems impede the advancement of sustainable development objectives as a whole. Furthermore, it might be difficult for companies to comply with regulations, win over stakeholders, and improve Malaysia's standing in global marketplaces where sustainability credentials are crucial. In fact, to stay competitive in the face of fierce competition, Malaysian manufacturing enterprises need to continuously enhance their social stability, environmental impact, and operational efficiency (Abidin et al., 2022).

Figure 1. Sustainability Report Findings

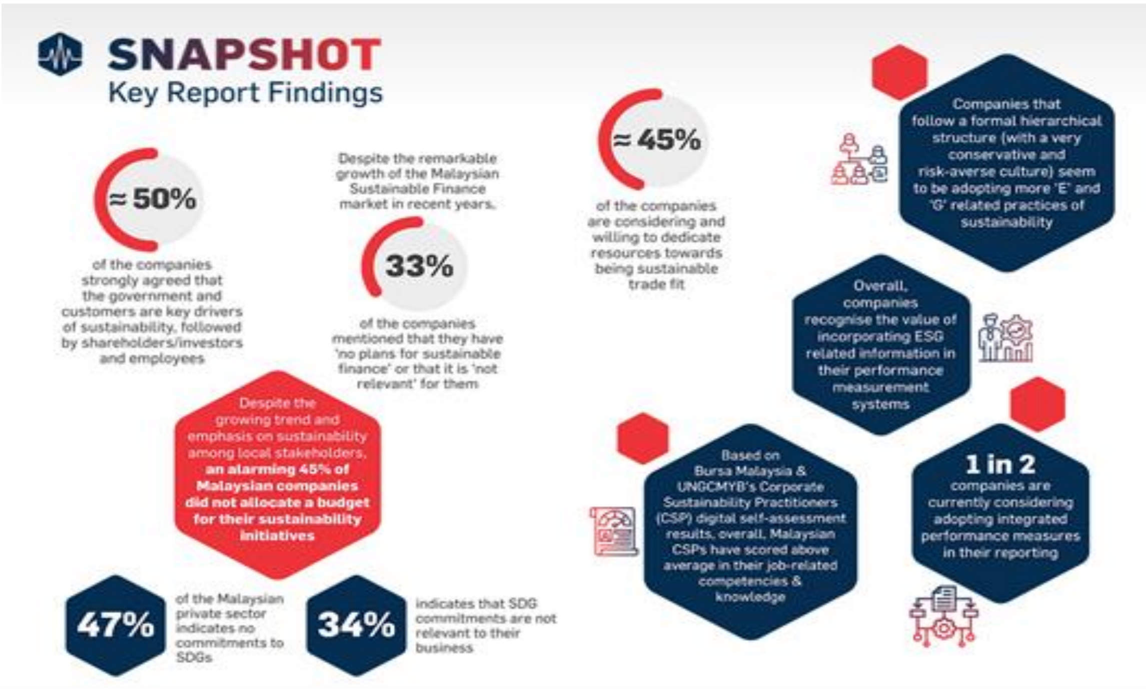


Figure 1 presents the results of a sustainability report for Malaysia in 2022. A significant barrier to accomplishing sustainable development goals is the existing lack of thorough sustainability data in Malaysian industrial organisations. The use of lean concepts to sustainability reporting is a new area of research with unrealised potential to improve social, economic, and environmental outcomes. To tackle this issue, a deliberate endeavour is required to close the data gap, implement lean approaches, and employ comprehensive reporting procedures. By doing so, Malaysian manufacturing companies can help advance more knowledgeable, effective, and sustainable business practises, which will benefit regional growth as well as international sustainability initiatives.

In manufacturing businesses, lean management principles have been widely used to improve productivity, reduce waste, and streamline procedures. Although lean techniques have been shown to be successful in enhancing operational performance, they might not naturally address the dynamic and frequently unpredictable nature of contemporary manufacturing operations (Samadhiya, Agrawal & Garza-Reyes, 2023). Sustainability has become a key component in assuring operational continuity and adaptation. While the synergy between lean manufacturing and sustainability is well-documented, a critical gap exists in the literature regarding the prioritisation of performance metrics for the Malaysian context. There is a lack of empirical research that statistically ranks these metrics based on the unique constraints of the Malaysian manufacturing sector, such as labour laws and supply chain maturity. This study fills that specific gap by moving beyond simple identification.

LITERATURE REVIEW

Sustainability

A firm's practices and operations that incorporate environmental, social, and economic factors frequently provide a reservoir of moral capital. This idea captures the immeasurable but enormous value that a corporation gains through exhibiting a commitment to moral, environmentally friendly, and socially conscious corporate operations. Organisations can generate favourable attitudes, establish stakeholder relationships, and improve their overall reputation by adhering to sustainability principles, resulting in a variety of beneficial effects (Abdul Razak, Ibrahim, & Ng, 2023). In today’s competitive global corporate world, adopting sustainable practices is frequently necessary to gain an advantage. Hence, many businesses are beginning to use more environmentally friendly techniques (Lee et al., 2021; Yadlapalli et al., 2018). Economic, environmental, and social sustainability are the three components of the Triple Bottom Line (TBL).

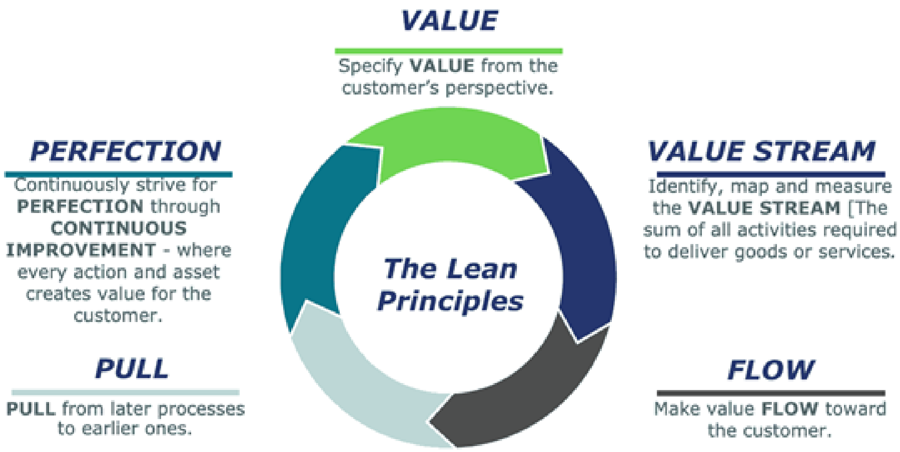
In the sustainability environment, companies and organisations that employ a lean management strategy, which consists of a set of rules and procedures designed to detect and remove waste, restructure processes, and enhance efficiency, have a substantial advantage. Utilising sustainability to its fullest potential can be aided by lean (Klein, De Guimaraes, Severo, Dorion & Feltrin, 2023). Besides, lean management has been playing a significant role in helping to improve companies' performance in the modern world as a result of the increased issues facing the industrial scene due to increased global competitiveness (Singh & Singh, 2020).

Lean Manufacturing Practices

Lean Manufacturing (LM) started in the early 1970s when Taiichi Ohno worked on a waste-free production system at Toyota (Ammon et al., 2013; Cil et al., 2013). Since then, the idea has been used in many areas, such as business processes, production, and logistics (Bertolini et al., 2022). It is now the standard for a modern customer-focused company (Bertolini et al., 2022). LM also marks a big change in how companies think, as it follows its principles and aims to remove waste, which reduces every non-value-adding process from the customer’s perspective (Ohno et al., 1988). Management should put efforts into addressing key types of waste. The lean concepts, which include the removal of waste through defining the value, identifying the value stream, flow, pull, and perfection, however, continue to apply (Womack & Jones, 1996).

According to Schonberger (2007), as well as Hallgren and Olhager (2009), the principles and practices associated with lean are the same as those of JIT, which came before it. The five key lean principles, as determined by Womack and Jones (1996), are as follows:

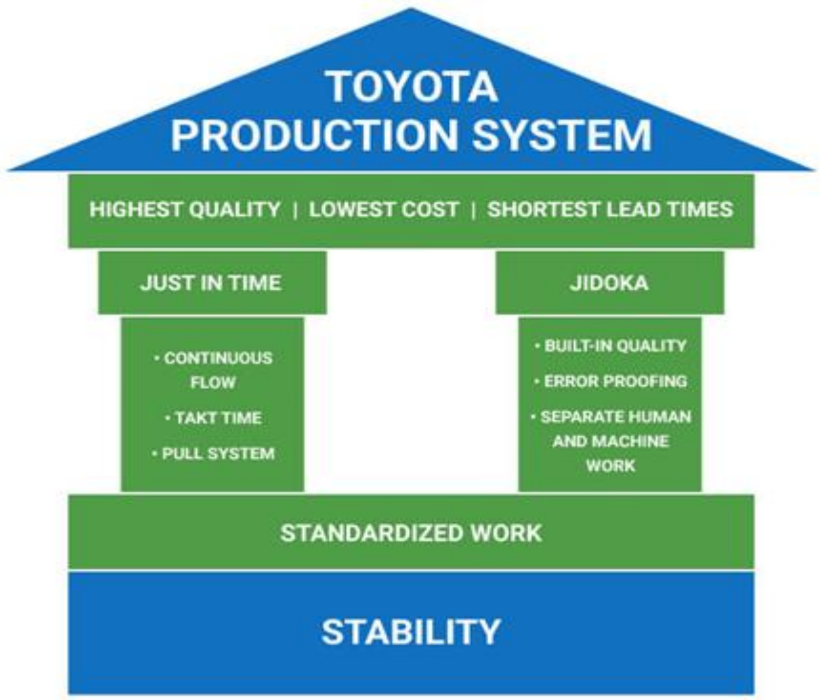
Figure 2. Lean Principles



i. Recognise the things that provide value to the customer and those that do not.
ii. Draw attention to waste that does not create value at any point in the value stream process.
iii. Allow value-adding actions to continue uninterrupted.
iv. Perform services that are solely requested by the client.
v. Aim for perfection by eliminating the waste in layers as they are uncovered.

These guidelines have been used as a reference for waste disposal. Using these concepts as a foundation, lean practices have access to a number of tools. JIT and Jidoka are the two major pillars on which lean is implemented. While Jidoka, the Japanese term for autonomy, can be loosely translated to signify quality at the source, JIT is a strategy for delivering the right amount at the right time and place. Human intervention is necessary in an automated process to avoid the creation of subpar products. The Jidoka production attitude can be extended to the maintenance position if the idea of quality at source has infiltrated the workforce's culture (Aikens, 2011). LM techniques are then put into effect, which improves performance. Figure 3 shows the Toyota Production System (TPS) as the pillar of lean management. Efficiency and quality are redefined in the manufacturing industry by the revolutionary Toyota Production System (TPS). It is a system designed by Toyota with the goals of cutting waste, raising output, and upholding strict quality controls. This book dives deep into TPS, covering everything from its core ideas and philosophy to the instruments and methods that propel its application. It has been used as a guide for implementing LM.

Figure 3. Toyota Production System (TPS)



According to this point of view, six factors are used to measure LM as procedures have been established and are being widely utilised. The six components of lean practices are 5s, Total Productive Maintenance, Kaizen, Just-in-Time (JIT), Gemba, and Overall Equipment Effectiveness (OEE).

In light of this, establishments in the manufacturing sector must ascertain, evaluate, and enhance their manufacturing performance, which is mostly correlated with their operational and production performance (Tan & Wong, 2015). However, owing to its varied and multi-dimensional manufacturing qualities, manufacturing performance measurement continues to be a controversial topic (Hon, 2005). However, for businesses to survive the unprecedented levels of global competition that exist today, they must develop and provide better products and services, as well as enhance their production processes (Taj & Morosan, 2011).

A significant barrier to accomplishing sustainable development goals is the existing lack of thorough sustainability data in Malaysian industrial organisations. The use of lean concepts to sustainability reporting is a new area of research with unrealised potential to improve social, economic, and environmental outcomes. To tackle this issue, a deliberate endeavour is required to close the data gap, implementing lean approaches and comprehensive reporting procedures. Therefore, Malaysian manufacturing companies can help advance more knowledgeable, effective, and sustainable business practises, which will benefit regional growth as well as international sustainability initiatives.

5S

The 5S methodology is a strategic business practice centered on standardising workflows and maintaining workplace cleanliness to minimise production time and resource consumption (Díaz-Reza et al., 2024). By establishing strict operational norms, the framework facilitates organisations of the workspace and the elimination of waste, thereby preventing accidents and ensuring safety (Palange et al., 2021). Specifically, 5S has been proven effective in mitigating various forms of inefficiency, including those associated with transportation, inventory, motion, waiting, overproduction, and overprocessing (Kumar et al., 2022). Ultimately, the adoption of 5S optimises the usage of time, energy, and space, resulting in enhanced product quality, improved employee morale, and a safer working environment (Shahriar et al., 2022).

The primary objective of 5S in industrial practice is to optimise worker behaviours and environmental conditions. Veres et al. (2018) posited that when essential tools are consistently categorised, arranged, and maintained in a state of readiness, the methodology evolves from a mere task into an ingrained standard. Consequently, this habituation confers significant operational and production advantages upon the organisation. Regarding the evaluation of this framework, García-Alcaraz et al. (2021) identified five critical components that constitute the 5S implementation level assessment: the execution of cleaning procedures, the standardisation of tool usage, the performance of adherence audits, the documentation of processes, and the recognition of employee achievements.

Total Productive Maintenance

Total Productive Maintenance (TPM), a key element of lean principles for production optimisation, serves as an effective tool for enhancing maintenance quality. By improving maintenance practices, TPM extends the lifespan of production equipment while increasing its reliability and efficiency (Slavina and Štefanić, 2024). Workplace organisation, procedures, and maintenance schedules can also be greatly improved (Ng et al., 2012). The implementation of TPM aims to achieve an ideal manufacturing state. This vision includes zero breakdowns, zero defects, zero abnormalities, and zero accidents (Suryaprakash et al., 2021).

A successfully implemented TPM enhances the availability, efficiency, and reliability of production equipment. These three factors represent the primary indicators of equipment performance. Availability refers to the proportion of time equipment is ready for its intended use. Reliability indicates how consistently equipment performs its function without failure. Efficiency is measured as the ratio of actual output products meeting quality standards to the rated output during operational time (Andras et al., 2006). The objective is to enhance these performance indicators without adding to the workload, primarily by organising tasks more efficiently. In the context of modern production demands, where minimising waste and addressing increasing competition are essential, manufacturers must rely on high-quality and dependable equipment. Implementing lean principles may take up to two years, since TPM is one of the more complex lean tools, requiring a carefully planned and structured approach (Slavina and Štefanić, 2024).

The successful adoption and effective use of lean practices and TPM tools in a production plant require specialised expertise and a structured methodology (Slavina and Štefanić, 2024). Nakajima (1988) observed that although many industries have attempted to implement TPM, only a few have achieved utilisation or output rates as high as 60–90%.

Kaizen

Kaizen plays a critical role in organisational growth by enabling firms to meet customer requirements and strengthen market competitiveness. To achieve a comprehensive assessment of kaizen, however, sustainability considerations, particularly social and economic dimensions, must be incorporated (Yousefloo et al., 2023). In addition, kaizen initiatives should prioritise improvements in production and operational efficiency to sustain competitive advantage. Through systematic process analysis and continuous refinement, organisations can identify and eliminate inefficiencies, thereby reducing waste while enhancing product quality and customer satisfaction (Imran et al., 2023).

Kaizen is widely recognised as a management philosophy centred on continuous improvement through incremental and systematic changes in organisational processes (Berhe, 2022). It represents an overarching approach that encompasses a range of methods aimed at enhancing productivity, quality, and efficiency across diverse industrial contexts. Empirical evidence suggests that kaizen contributes to improvements in production performance, time efficiency, profitability, and quality outcomes (Queiroz et al., 2022). Moreover, kaizen supports the reduction of raw material usage and energy consumption by facilitating the identification and mitigation of root causes of operational inefficiencies, thereby enabling sustained continuous improvement within organisations (Díaz-Reza et al., 2024).

Just-in-Time (JIT)

Just-in-Time (JIT) production emphasises the continuous and systematic enhancement of operational efficiency by eliminating time- and resource-related waste across the production system. Through accelerated production processes and reduced flow time, JIT simultaneously improves quality, cost efficiency, and delivery performance. Central to this approach is the reduction of non-value-added activities, excess inventory, and equipment downtime. To increase the availability of finished goods for shipment and minimise work-in-process (WIP) inventory, JIT promotes the maintenance of minimal inventory levels. As a result, JIT implementation leads to substantial improvements in raw material storage, finished goods warehousing, and overall production operations. Furthermore, JIT contributes to shorter lead times, reduced raw material inventory, increased production speed, optimised utilisation of machinery and labour, and lower WIP levels (Kilic & Erkayman, 2021).

JIT is interpreted in the literature as a management philosophy and as a set of operational techniques, reflecting its diverse applications across industries. Its primary objective is to produce only what is required, when it is required, while minimising production quantities. Empirical studies indicate that JIT supports effective inventory control, improves delivery reliability, reduces labour and material handling costs, and enhances employee involvement in production activities (Dieste et al., 2019).

Gemba

Gemba (GEM) refers to the practice of walking through production areas to identify opportunities for on-site improvement and gather first-hand insights by engaging directly with employees (Romero et al., 2020). Furthermore, GEM entails visiting the workplace to observe and comprehend production processes, offering a framework to identify and eliminate waste and inefficiencies to enhance sustainability.

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This practice requires organisational leaders to visit the workplace or shop floor to observe processes, identify waste, and collaborate with employees to resolve inefficiencies. Such engagement enhances understanding of the work environment and fosters a culture of continuous improvement (Elemure *et al.*, 2023).

It enables real-time monitoring, integrates employees into decision-making, and facilitates rapid problem-solving, thereby supporting sustainable practices (Cherrafi et al., 2019). Moreover, GEM provides an opportunity to capture employees' perspectives on the impacts of Lean Manufacturing Tools (LMTs) applied on the production line (Díaz-Reza *et al.*, 2024).

Overall Equipment Effectiveness (OEE)

Overall Equipment Effectiveness (OEE) is calculated as the product of the availability, throughput, and quality rates. The availability rate reflects the proportion of time that equipment is operational relative to the total time it is scheduled to operate. The throughput rate represents the actual output achieved during operating time compared with the theoretical output at the equipment's designed speed. The quality rate is defined as the ratio of conforming or good products to the total number of products produced (Suryaprakash et al., 2021).

Numerous industrial studies have documented the application of OEE as a means of evaluating the robustness of production systems. Empirical evidence indicates that OEE contributes to improved organisational performance across multiple dimensions. For instance, Costa and Lopes (2021) reported that OEE enhances productivity, reduces operational costs, and improves sales and financial performance in the automotive industry. Similarly, Purwanto and Jaqin (2021) linked OEE implementation to productivity improvements in the tyre manufacturing sector. In addition, Cercós et al. (2019) demonstrated an association between OEE and the environmental impacts of production processes.

Theoretical Framework

Figure 4. Theoretical Framework

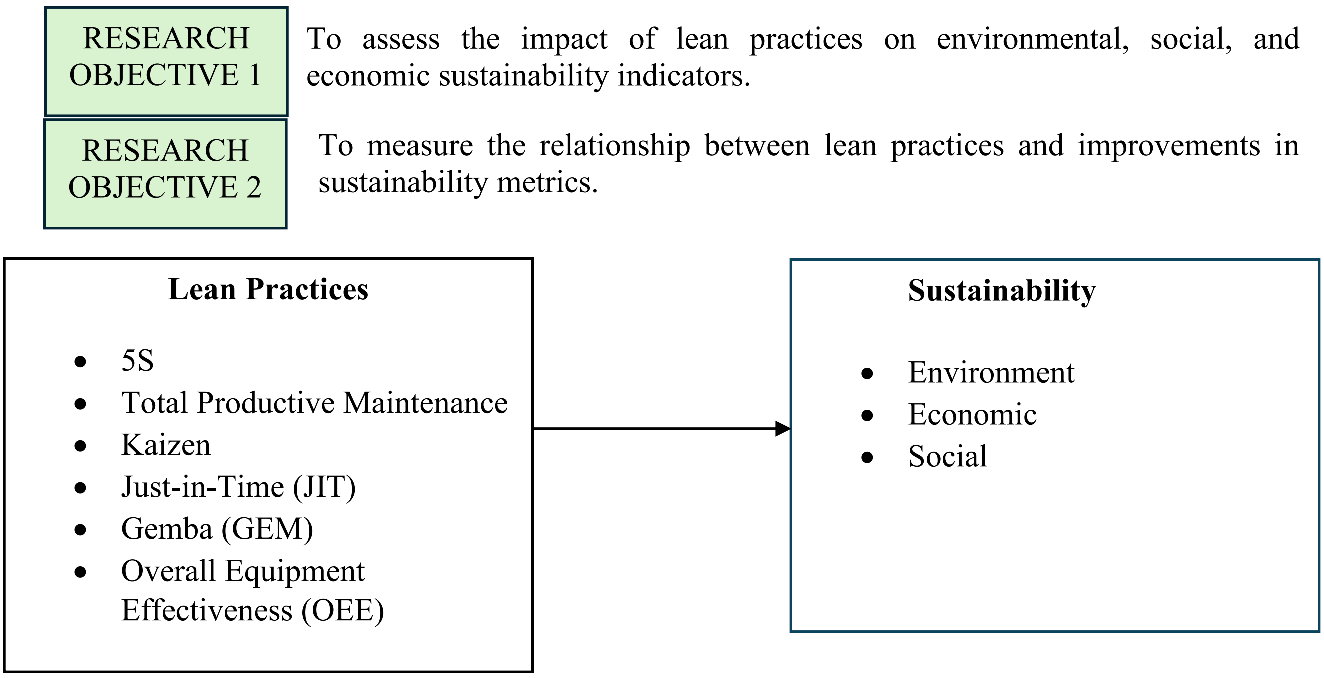

Figure 4 illustrates the theoretical framework presented in this study. This study empirically explores the impact and relationships between lean manufacturing practices and sustainability. Moreover, it formulates lean performance metrics for holistic sustainability reporting in Malaysian manufacturing organisations.

METHODOLOGY

This study utilises a quantitative approaches. This strategy allows for a comprehensive investigation, leveraging the strengths of quantitative data to identify trends.This study focuses on 3,300 manufacturing companies listed in the Malaysia Federation of Manufacturing (FMM) directory. Using the Krejcie and Morgan (1970) table, a sample of 346 respondents was randomly selected to ensure statistical validity. The organisation serves as the primary unit of analysis. Data were collected from middle and upper management (directors, department heads, and managers) as they possess the requisite knowledge regarding manufacturing operations and sustainability outputs.

A 5-point Likert scale questionnaire was used to collect data on lean practices and sustainability metrics. This scale was chosen for its ability to capture nuanced responses, which enhances the reliability and interpretability of the data. SPSS was used for descriptive statistics. SmartPLS was employed for inferential statistics, including correlation analysis and regression analysis, to evaluate the relationships between lean practices and sustainability indicators. Hypotheses were tested using a bootstrapping procedure with 5,000 resamples to determine statistical significance.

RESULTS

Data Integrity and Response Rate

Preliminary data examination was conducted using SPSS, while SmartPLS was utilised for measurement and structural model assessments. Out of 346 eligible respondents, a final response rate of 33.24% (115 completed surveys) was achieved, which is statistically acceptable for this field. Descriptive statistics indicate that Lean Manufacturing Practices (LMPs) received the highest agreement from respondents (Mean = 4.15), followed by a high emphasis on Sustainability (SUS) (Mean = 3.91).

Table 1. Descriptive Statistics of Each Construct

Constructs	Mean	Std. Dev
5S (FIVEs)	4.3145	0.59073
Total Productive Maintenance (TPM)	4.2509	0.57242
KAIZEN (KAI)	4.0782	0.63425
Just in Time (JIT)	4.0691	0.66935
Gemba (GEM)	4.1309	0.63097
Overall Equipment Effectiveness (OEE)	4.1055	0.62996
Economic Performance (ECP)	3.8873	0.70829
Social Performance (SOP)	3.9582	0.68915
Environmental Performance (ENP)	3.8945	0.69373
Lean Manufacturing Practices (LMP)	4.1582	0.53124
Sustainability (SUS)	3.9133	0.64202

Measurement Model

To ensure the robustness of the measurement model, indicator reliability, internal consistency reliability, and convergent validity were systematically assessed. Indicator reliability was evaluated through outer loadings, with values exceeding the recommended threshold of 0.708 considered acceptable (Hair Jr et al., 2014). Internal consistency reliability was examined using Cronbach's alpha (α) and composite reliability (pc), where coefficients above 0.70 indicated satisfactory reliability (Hair et al., 2017). Convergent validity was

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subsequently assessed using the Average Variance Extracted (AVE). An AVE value of 0.50 or higher was adopted as the benchmark, indicating that the indicators adequately captured the variance of their respective constructs (Cheung, 2024). Table 2 summarises the results of these assessments and demonstrates that all indicators and constructs satisfied the established reliability and validity requirements.

Table 2. Internal Consistency Reliability and Convergent Validity Results

Construct		Item	Loading	α	pc	AVE
1st Order (LOC)	**2nd Order (HOC)**					
5S		5S1	0.849	0.921	0.941	0.760
		5S2	0.899			
		5S3	0.876			
		5S4	0.880			
		5S5	0.854			
Total Productive Maintenance (TPM)		TPM1	0.846	0.913	0.935	0.743
		TPM2	0.848			
		TPM3	0.847			
		TPM4	0.894			
		TPM5	0.876			
KAIZEN (KAI)		KAI1	0.885	0.912	0.934	0.740
		KAI2	0.822			
		KAI3	0.896			
		KAI4	0.895			
		KAI5	0.799			
Just in Time (JIT)		JIT1	0.859	0.911	0.934	0.740
		JIT2	0.842			
		JIT3	0.837			
		JIT4	0.874			
		JIT5	0.885			
Gemba (GEM)		GEM1	0.814	0.919	0.940	0.757
		GEM2	0.910			
		GEM3	0.876			
		GEM4	0.888			
		GEM5	0.860			
Overall Equipment Effectiveness (OEE)		OEE1	0.891	0.913	0.935	0.742
		OEE2	0.852			
		OEE3	0.883			
		OEE4	0.885			
		OEE5	0.793			
	Lean Manufacturing Practices (LMP)	5S	0.713	0.971	0.973	0.549
		TPM	0.793			
		KAI	0.840			
		JIT	0.847			

		GEMBA	0.936			
		OEE	0.853			
Economic Performance (ECP)		ECP1	0.923	0.940	0.954	0.807
		ECP2	0.919			
		ECP3	0.896			
		ECP4	0.901			
		ECP5	0.883			
Social Performance (SOP)		SOP1	0.872	0.916	0.937	0.749
		SOP2	0.898			
		SOP3	0.788			
		SOP4	0.915			
		SOP5	0.848			
Environmental Performance (ENP)		ENP1	0.893	0.933	0.950	0.790
		ENP2	0.908			
		ENP3	0.917			
		ENP4	0.917			
		ENP5	0.804			
	Sustainability Performance (SP)	ECP	0.930	0.964	0.967	0.664
		SOP	0.940			
		ENP	0.893			

Note: α and pc >0.70, AVE > 0.50 (Hair et al., 2017)

The results presented in Table 2 indicate that indicator reliability was successfully established, as all measurement items achieved outer loading values exceeding the recommended threshold of 0.708. Furthermore, all constructs demonstrated satisfactory internal consistency reliability, with Cronbach's alpha (α) and composite reliability (CR) values surpassing the acceptable benchmark. Convergent validity was also confirmed, as the Average Variance Extracted (AVE) for each construct exceeded the minimum criterion of 0.50. These findings suggest that the measurement model possesses adequate reliability and validity. By satisfying the established evaluation criteria, the model demonstrates a high level of measurement quality and stability. Consequently, the validated measurement model provides a sound foundation for subsequent structural model assessment and hypothesis testing.

Discriminant Validity Assessment

After establishing convergent validity, the measurement model was further evaluated to determine discriminant validity. Three complementary assessment techniques were employed: the Fornell-Larcker criterion, cross-loading analysis, and the Heterotrait-Monotrait (HTMT) ratio of correlations. According to the Fornell-Larcker criterion (Fornell & Larcker, 1981), discriminant validity is established when the square root of the Average Variance Extracted (AVE) for a construct exceeds its correlations with all other constructs in the model. This requirement indicates that a construct shares more variance with its own indicators than with those of other constructs, thereby confirming adequate construct distinctiveness.

Table 3. Results of Fornell & Larcker (1981) criterion

Constructs	**LMP**	**SP**
LMP	0.855	
SP	0.826	0.921

Table 3 presents the results of the Fornell-Larcker discriminant validity assessment. The bold values located on the principal diagonal represent the square root of the Average Variance Extracted (AVE) for each latent construct. According to the Fornell-Larcker criterion (Fornell & Larcker, 1981), discriminant validity is established when these diagonal values exceed the corresponding inter-construct correlations in both the respective rows and columns. An examination of the correlation matrix indicates that the square root of the AVE for each construct is consistently greater than its correlations with other constructs. These findings provide strong evidence that the constructs are empirically distinct from one another. Therefore, the measurement model demonstrates satisfactory discriminant validity.

Furthermore, the cross-loading analysis presented in Table 4 indicates that the outer loading of each indicator exceeded its corresponding cross-loadings on all other constructs. This result demonstrates that each measurement item is more strongly associated with its designated construct than with any alternative construct. Therefore, the findings provide additional evidence supporting the discriminant validity of the measurement model.

Table Error! No text of specified style in document.**. Results of Cross-loadings**

	5S	TPM	KAI	JIT	GEM	OEE	ECP	SOP	ENP
5S1	**0.849**	0.621	0.517	0.457	0.478	0.509	0.361	0.402	0.499
5S2	**0.899**	0.696	0.594	0.512	0.537	0.59	0.440	0.441	0.592
5S3	**0.876**	0.625	0.574	0.481	0.52	0.551	0.518	0.511	0.592
5S4	**0.880**	0.721	0.586	0.476	0.554	0.595	0.472	0.442	0.549
5S5	**0.854**	0.682	0.605	0.553	0.508	0.557	0.477	0.413	0.569
TPM1	0.692	**0.846**	0.613	0.519	0.559	0.626	0.476	0.534	0.596
TPM2	0.665	**0.848**	0.634	0.534	0.511	0.649	0.442	0.49	0.592
TPM3	0.587	**0.847**	0.582	0.511	0.562	0.601	0.479	0.588	0.553
TPM4	0.704	**0.894**	0.670	0.507	0.589	0.617	0.521	0.525	0.548
TPM5	0.660	**0.876**	0.626	0.500	0.616	0.639	0.517	0.546	0.591
KAI1	0.586	0.603	**0.885**	0.651	0.650	0.616	0.653	0.607	0.577
KAI2	0.606	0.643	**0.822**	0.510	0.564	0.598	0.513	0.502	0.514
KAI3	0.595	0.681	**0.896**	0.665	0.678	0.623	0.588	0.524	0.596
KAI4	0.540	0.631	**0.895**	0.598	0.586	0.612	0.571	0.565	0.572
KAI5	0.521	0.563	**0.799**	0.604	0.588	0.540	0.594	0.520	0.539
JIT1	0.511	0.580	0.615	**0.859**	0.646	0.624	0.595	0.580	0.529
JIT2	0.534	0.591	0.627	**0.842**	0.692	0.673	0.590	0.537	0.554
JIT3	0.398	0.393	0.512	**0.837**	0.520	0.569	0.548	0.533	0.592
JIT4	0.528	0.524	0.655	**0.874**	0.628	0.602	0.6	0.578	0.611
JIT5	0.472	0.472	0.623	**0.885**	0.622	0.546	0.573	0.557	0.534
GEM1	0.421	0.484	0.549	0.643	**0.814**	0.574	0.64	0.565	0.544
GEM2	0.536	0.615	0.621	0.644	**0.910**	0.672	0.701	0.700	0.668
GEM3	0.499	0.582	0.623	0.553	**0.876**	0.562	0.609	0.61	0.608
GEM4	0.585	0.613	0.712	0.699	**0.888**	0.711	0.698	0.657	0.618

GEM5	0.546	0.567	0.599	0.608	**0.860**	0.65	0.644	0.605	0.645
OEE1	0.626	0.656	0.628	0.716	0.683	**0.891**	0.630	0.584	0.664
OEE2	0.582	0.67	0.623	0.618	0.605	**0.852**	0.58	0.618	0.589
OEE3	0.502	0.613	0.576	0.592	0.662	**0.883**	0.578	0.546	0.609
OEE4	0.596	0.64	0.62	0.604	0.642	**0.885**	0.583	0.492	0.619
OEE5	0.453	0.541	0.54	0.472	0.547	**0.793**	0.516	0.508	0.498
ECP1	0.445	0.516	0.604	0.601	0.72	0.584	**0.899**	0.766	0.62
ECP2	0.442	0.464	0.602	0.580	0.669	0.570	**0.918**	0.775	0.637
ECP3	0.543	0.570	0.669	0.622	0.704	0.638	**0.899**	0.778	0.667
ECP4	0.427	0.469	0.571	0.628	0.627	0.621	**0.898**	0.764	0.629
ECP5	0.493	0.513	0.608	0.607	0.678	0.604	**0.876**	0.737	0.683
SOP1	0.426	0.476	0.491	0.565	0.625	0.52	0.771	**0.851**	0.644
SOP2	0.451	0.544	0.59	0.597	0.639	0.579	0.785	**0.896**	0.685
SOP3	0.469	0.562	0.519	0.451	0.576	0.465	0.618	**0.805**	0.582
SOP4	0.479	0.587	0.585	0.59	0.674	0.63	0.767	**0.916**	0.682
SOP5	0.416	0.530	0.553	0.596	0.613	0.562	0.736	**0.856**	0.661
ENP1	0.475	0.507	0.547	0.606	0.563	0.573	0.609	0.611	**0.885**
ENP2	0.547	0.59	0.534	0.555	0.582	0.596	0.618	0.685	**0.902**
ENP3	0.555	0.587	0.578	0.590	0.659	0.683	0.668	0.705	**0.912**
ENP4	0.611	0.642	0.598	0.617	0.684	0.668	0.688	0.723	**0.921**
ENP5	0.663	0.631	0.631	0.551	0.652	0.556	0.611	0.614	**0.821**

Finally, in response to methodological concerns that traditional approaches may be insufficient for detecting discriminant validity issues in certain contexts, the Heterotrait–Monotrait (HTMT) ratio was employed as a more stringent evaluation criterion. As reported in Table 5, the HTMT results provide additional confirmation of the distinctiveness among the latent constructs. This further reinforces the robustness of discriminant validity within the measurement model.

Table 5. Results of HTMT ratio

Constructs	**LMP**	**SP**
LMP		
SP	0.848	

The Heterotrait–Monotrait (HTMT) results presented in Table 5 indicate that all values fall within the acceptable threshold of 0.90, while the EI–LMP relationship specifically satisfies the more conservative criterion of 0.85. According to Franke and Sarstedt (2019), HTMT values should remain below the range of 0.85 to 0.90 to ensure adequate discriminant validity. In this study, all constructs meet these recommended thresholds, thereby confirming their empirical distinctiveness. With both reliability and validity of the measurement model firmly established, the analysis proceeds to the evaluation of the structural model and subsequent hypothesis testing.

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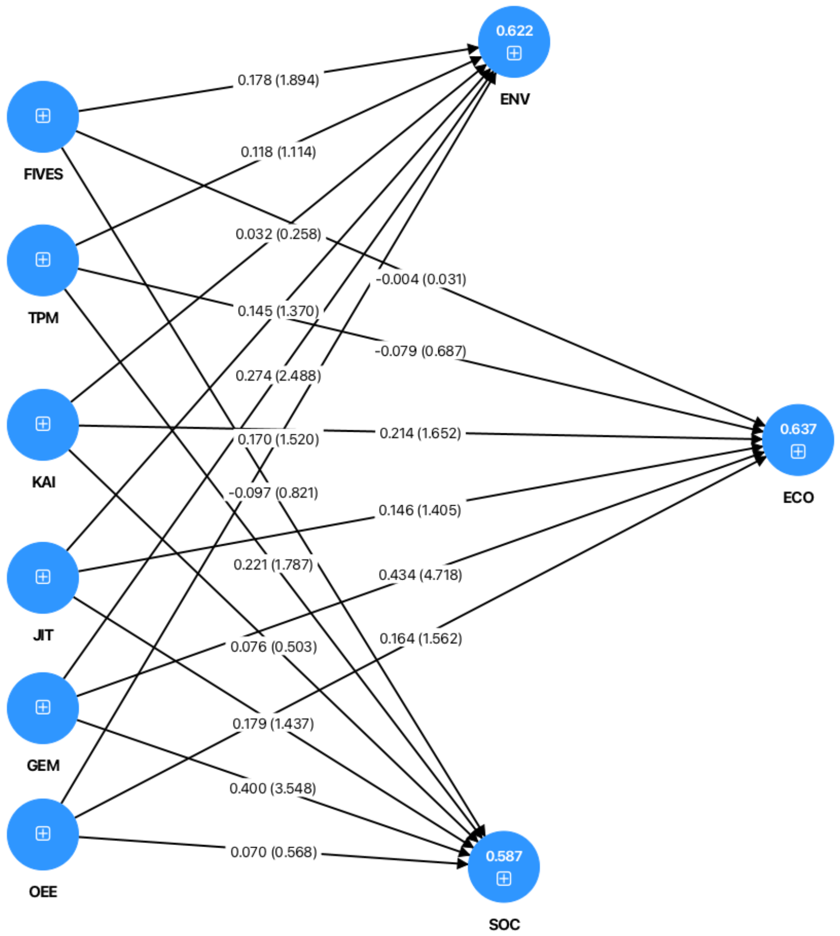
Structural Model

Following the measurement model validation, a structural model analysis was conducted to address the primary research objectives. To evaluate the significance of the hypothesised relationships, a bootstrapping procedure was performed with 5000 resamples, using a two-tailed significant test at the 0.05 level as well as using SmartPLS 4 software, consistent with the recommendations of Hair et al. (2017). This technique facilitated the derivation of empirical t-statistics (t-values), which serve as the basis for determining the statistical significance of the paths. The structural model evaluated in this study is illustrated in Figure 5.

Figure 5. Structural Model



The structural model for this study is depicted in Figure 5, illustrating the hypothesised relationships between the latent variables: Lean manufacturing practices (LMPs), including 5S, TPM, KAI, JIT, GEM, OEE, and Sustainability. Within this framework, SUS served as the endogenous (dependent) construct, while LMPs acted as the exogenous variables (predictors). Furthermore, the directional arrows denote these pathways, labelled with their respective path coefficients (β) and empirical t-statistics (indicated in brackets).

Impact of Lean on the Triple Bottom Line (RO1)

H1a states that LMPs have a significant impact on environmental sustainability indicators. The structural model revealed an R^2 value of 0.622. Bootstrapping confirmed this overall impact as highly significant ($p<0.05$). Therefore, H1a is supported.

H1b evaluates the impact of lean practices on economic sustainability indicators. The model accounted for 63.7% of the variance in economic metrics ($R^2=0.637$, $p<0.05$). Consequently, H1b is supported.

H1c measures the impact on social sustainability indicators. The independent variables explained 58.7% of social sustainability variance ($R^2=0.587$, $p<0.05$). Thus, H1c is supported.

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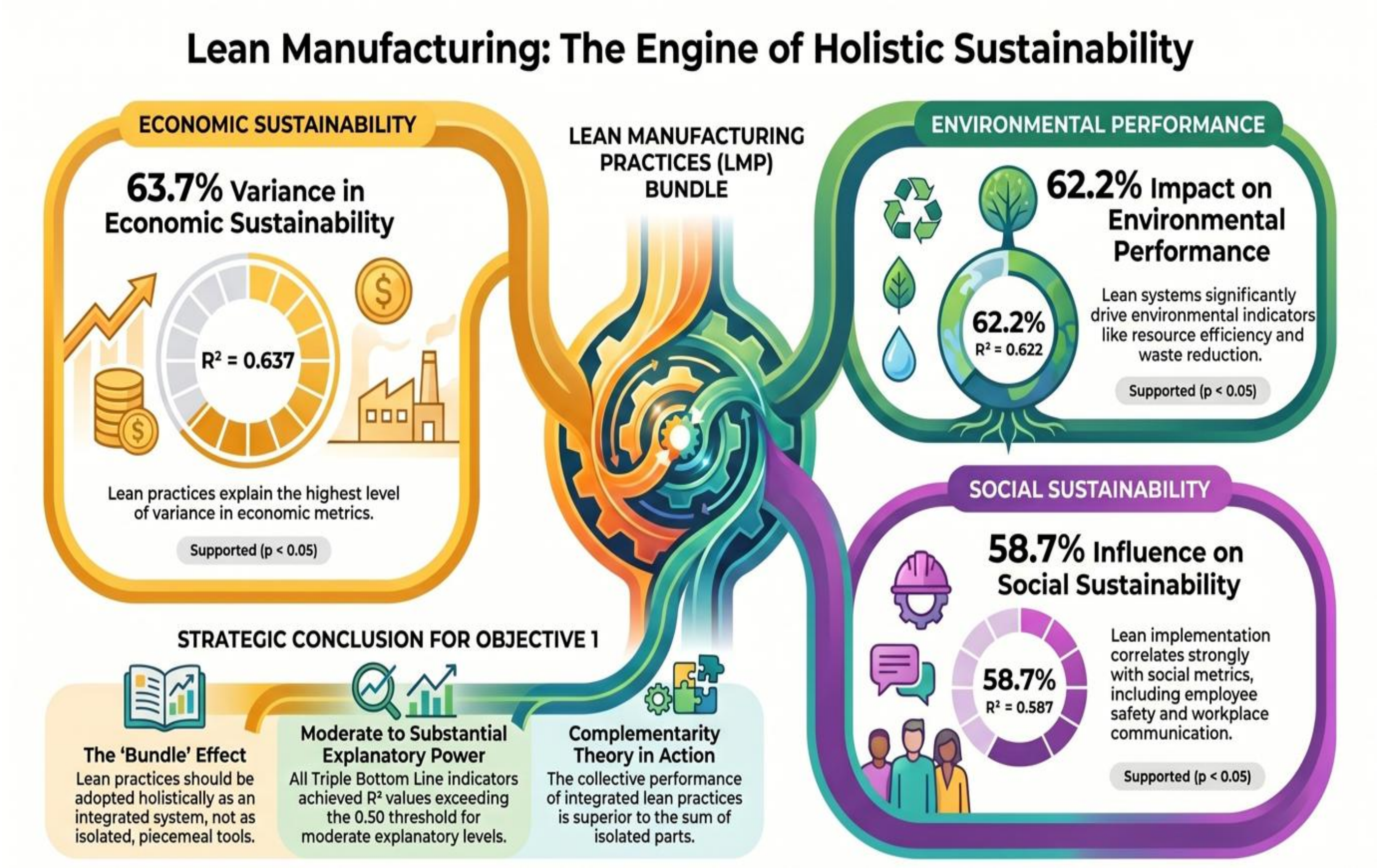
The results in Table 6 conclude that LMP were positively influenced by Sustainability, explaining 62.2% (R^2 = .622), 63.7% (R^2 = .637), and 58.7% (R^2 = .587) of the variance in Sustainability indicators.

Table 6Impact of Lean Practices on Environmental, Social, and Economic Sustainability Indicators.

	Path Coefficient (β)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	Decision
H1a: Lean -> ENV	0.622	0.643	0.060	10.344	0.000	Supported
H1b: Lean -> ECO	0.637	0.658	0.059	10.838	0.000	Supported
H1c: Lean -> SOC	0.587	0.615	0.075	7.842	0.000	Supported

Figure 6. Summarised Result of Research Objective 1



Relationships Between Lean Practices and Environmental, Social, and Economic Sustainability (RO2)

To evaluate H2a, bootstrapping was conducted to measure the statistical significance of these relationships between lean practices and improvement in sustainability metrics. The individual paths driving Environmental Sustainability were examined. The results indicate Gemba **(**β=0.274, T=2.488, $p<0.05$**)** as a statistically significant driver. Conversely, Kaizen (β=0.032, T=0.258, p is 0.796, which is more than 0.05) did not have a statistically significant relationship with environmental in this sample.

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Table 7. Results for the Relationships Between Lean Practices and Environmental Sustainability (H2a)

Path	Path Coefficient (β)	Standard deviation (STDEV)	T-statistics	P-value	Decision
H2a_1: FIVES -> ENV	**0.178**	**0.094**	**1.894**	**0.058**	**Not Supported**
H2a_2: TPM -> ENV	**0.118**	**0.106**	**1.114**	**0.265**	**Not Supported**
H2a_3: KAI -> ENV	**0.032**	**0.124**	**0.258**	**0.796**	**Not Supported**
H2a_4: JIT -> ENV	**0.145**	**0.106**	**1.370**	**0.171**	**Not Supported**
H2a_5: GEM -> ENV	**0.274**	**0.110**	**2.488**	**0.013**	**Supported**
H2a_6: OEE -> ENV	**0.170**	**0.112**	**1.520**	**0.129**	**Not Supported**

For H2b, the relationship between lean practices and economic sustainability was measured. Gemba was observed as the most dominant and significant predictor (β=0.434, T=4.718, p<0.05). Interestingly, traditional practices like 5S (β=-0.004, T=0.031, p>0.05) and TPM (β=-0.079, T=0.687, p>0.05) displayed weak and non-significant direct relationships with economic indicators.

Table 8. Results for the Relationships Between Lean Practices and Economic Sustainability (H2b)

Path	Path Coefficient (β)	Standard deviation (STDEV)	T-statistics	P-value	Decision
H2b_1: FIVES -> ECO	**-0.004**	**0.116**	**0.031**	**0.975**	**Not Supported**
H2b_2: TPM -> ECO	**-0.079**	**0.115**	**0.687**	**0.492**	**Not Supported**
H2b_3: KAI -> ECO	**0.214**	**0.129**	**1.652**	**0.099**	**Not Supported**
H2b_4: JIT -> ECO	**0.146**	**0.104**	**1.405**	**0.160**	**Not Supported**
H2b_5: GEM -> ECO	**0.434**	**0.092**	**4.718**	**0.000**	**Supported**
H2b_6: OEE -> ECO	**0.164**	**0.105**	**1.562**	**0.118**	**Not Supported**

Finally, H2c measures the relationship driving Social Sustainability. Gemba exerted the strongest, highly significant positive relationship on social metrics (β=0.400, T=3.548, p<0.05). In summary, while Research Objective 2 statistically measures significant lean relationships, it does not provide the exact operational metrics required for reporting. Therefore, Objective 3 used qualitative interview consensus via Kendall's analysis to formulate the precise performance metrics based on these proven drivers.

Table 9. Results for the Relationships Between Lean Practices and Social Sustainability (H2c)

Path	Path Coefficient (β)	Standard deviation (STDEV)	T-statistics	P-value	Decision
H2c_1: FIVES -> SOC	**-0.097**	**0.118**	**0.821**	**0.412**	**Not Supported**

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H2c_2: TPM -> SOC	**0.221**	**0.124**	**1.787**	**0.074**	**Not Supported**
H2c_3: KAI -> SOC	**0.076**	**0.152**	**0.503**	**0.615**	**Not Supported**
H2c_4: JIT -> SOC	**0.179**	**0.125**	**1.437**	**0.151**	**Not Supported**
H2c_5: GEM -> SOC	**0.400**	**0.113**	**3.548**	**0.000**	**Supported**
H2c_6: OEE -> SOC	**0.070**	**0.123**	**0.568**	**0.570**	**Not Supported**

Figure 7. Summarised Result of Research Objective 2

DISCUSSION

Research Objective 1: To assess the impact of lean practices on environmental, social, and economic sustainability indicators.

The empirical findings generated through the structural model evaluation successfully satisfied Research Objective 1 by demonstrating that lean manufacturing practices exerted a robust, statistically substantial overall impact across the entire Triple Bottom Line. The structural model demonstrated that the six lean practices collectively accounted for 63.7% of the variance in Economic Sustainability (R2= 0.637), 62.2% in Environmental Sustainability (R2= 0.622), and 58.7% in Social Sustainability (R2= 0.587).

According to Hair et al. (2017) guidelines, R^2 results of 0.75, 0.50, and 0.25 serve as indicators of substantial, moderate, and weak explanatory levels. These findings provide powerful empirical validation that lean systems act as massive structural conduits for corporate sustainability within the Malaysian context. This high level of explained variance suggests that when local manufacturers implement lean tools as a unified strategic 'bundle', they naturally build an operational ecosystem that fulfills external MyESG and regulatory reporting frameworks simultaneously. These high coefficients of determination provide powerful empirical evidence regarding the core systemic nature of lean frameworks. Crucially, the strong predictive power achieved across all three dimensions implies that lean practices should be adopted holistically as an integrated system, rather than putting any individual practice in isolation. This finding strongly confirmed previous operational studies conducted by Bortolotti et al. (2013), Nawanir et al. (2018), and Shah and Ward (2003), which uniformly agreed that lean tools should not be applied through a fragmented, piecemeal approach where organisations select certain popular practices while setting others aside.

In the context of Malaysian manufacturing, attempting to track or implement sustainability metrics in isolated silos is a primary cause of managerial initiative fatigue. The substantial values generated in this study mirror the foundational assertions of Sahoo and Yadav (2018), extending their logic from general business performance to comprehensive Triple Bottom Line metrics by proving that lean 'bundles' significantly maximise sustainability reporting capability compared to standalone, disconnected practices.

Research Objective 2: To measure the relationship between lean practices and improvements in sustainability metrics.

Research Objective 2 (RO2) aimed to measure the individual relationships between distinct lean manufacturing practices and improvements across environmental, economic, and social sustainability metrics. Rather than treating lean as a vague, uniform bundle, the path coefficient analysis and bootstrapping results exposed a highly specialised and skewed relational matrix. The most remarkable empirical revelation of this study was the absolute dominance of Gemba Walks (Floor Leadership Engagement) across all three dimensions of the Triple Bottom Line, contrasted by the non-significance of traditional structural tools of 5S, TPM, and Kaizen within this localised sample.

For Environmental Sustainability (H2a), Gemba emerged as a powerful, statistically significant driver. This quantitative finding is strongly aligned with the study conducted by Okoro (2024), which demonstrated that a primary benefit of implementing Gemba is the systematic mitigation of operational waste and inefficiencies. By empowering frontline personnel to detect and rectify disruptions in real time, organisations can optimise workflows, minimise operational downtime, and significantly enhance overall productivity. The institutionalisation of Gemba walks enables managers to accurately identify operational deficiencies and develop a deeper comprehension of departmental and organisational requirements. This practice facilitates the formulation of targeted strategies to eliminate systemic waste, thereby converting internal operational challenges into value-added quality services (Schultz & Klungseth, 2022).

For Economic Sustainability (H2b), Gemba similarly functioned as the most dominant and robust predictor. This study agrees with the study conducted by Zvidzayi (2021), showing that during a standardised Gemba walk, an executive manager observes a selected process where there is a live operational bottleneck, including a disruption in material flow, to actively help plant personnel see potential and high-priority areas for financial improvement. This relationship is robustly corroborated by contemporary lean literature conducted by García-Alcaraz et al. (2022), which posited that the deployment of Gemba walks across production lines directly yields substantial cost reductions. These financial and operational efficiencies manifest across new product development cycles, manufacturing processes, and resource consumption frameworks. Consequently, the systematic application of this methodology serves as a critical mechanism for minimising waste and optimising organisational expenditures.

Finally, Social Sustainability (H2c) was heavily driven by Gemba walks, which exerted an exceptionally strong, highly significant positive path coefficient. These direct, positive effects underscore the strategic value of conducting Gemba walks within manufacturing enterprises, aligning with the study conducted by Díaz-Reza et al. (2024). By facilitating the real-time identification of operational discrepancies and workplace inefficiencies, these walks establish a proactive environment where issues can be systematically addressed and resolved. Consequently, institutionalising this practice optimises operational workflows and fosters continuous workplace improvement. According to Zvidzayi (2021), when managers transition from rigid boardroom oversight to active floor engagement by frequently conducting structured Gemba walks and directly asking frontline operators about improvements achieved that week, employees quickly internalise which operational metrics are structurally important and align their daily priorities accordingly.

CONCLUSION

The empirical evidence demonstrated that lean manufacturing practices function as powerful structural conduits for corporate sustainability, explaining a substantial proportion of variance across the Triple Bottom Line: 63.7% for economic, 62.2% for environmental, and 58.7% for social sustainability. A critical takeaway is that lean tools must be adopted as a unified, interdependent strategic bundle rather than through a fragmented, pick-and-choose approach to successfully meet national regulatory demands. At the operational level, Gemba Walks (Floor Leadership Engagement) emerged as the absolute dominant engine for multi-dimensional improvement. While foundational tools like 5S and TPM provide vital secondary stabilising platforms, direct visual management through Gemba walks is what drives real-world outcomes by catching resource leaks, optimising throughput at bottlenecks, and elevating operator morale.

This research bridged the knowledge gap by producing actionable lean performance metrics that have immediate applications for manufacturing organisations. It assists the growth and competitiveness of the sector by offering workable ideas for enhancing production processes and sustainability practices. For instance, the findings can inform national strategies regarding innovation and sustainability, aligning with governmental efforts to promote ethical and resilient manufacturing practices. By emphasising sustainability reporting, this study fosters trust between manufacturing companies and society through promoted ethical governance and responsible production. The focus on resource efficiency and waste minimisation directly supports more environmentally friendly production practices, reducing adverse environmental impacts. For Malaysian managers, implementing lean as a unified strategic bundle builds an operational ecosystem that naturally fulfills external regulatory reporting frameworks, such as MyESG, thereby reducing managerial initiative fatigue.

The data is entirely localised to the Malaysian manufacturing sector. Consequently, the results may not be directly generalisable to Western countries or other developing economies with contrasting industrial structures or regulatory priorities. The sampling frame relied heavily on middle and upper production management. The empirical model currently lacks structured input from lower-tier, frontline shop-floor operators, whose perspectives are critical given the observed dominance of Gemba walks. A notable mathematical limitation was the statistical non-significance of foundational tools like 5S, TPM, and Kaizen regarding direct path relationships with sustainability metrics in this specific sample. This suggests a localised "initiative isolation" on the shop floor that limited the structural testing of individual path variations. To expand upon the structural paradigms established in this study, several paths for future research are proposed. Future studies should replicate this framework in other ASEAN or EU nations to determine if the dominance of Gemba walks is a global trend or specific to Malaysian corporate culture. In addition, since complex tools like TPM can take years to mature, future studies should track performance shifts over time rather than relying on cross-sectional data. Future sampling should also integrate shop-floor operators to balance the current management-heavy data and provide a more comprehensive view of social sustainability.

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