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Impact of Lean Manufacturing Practices on Firms' Sustainable Performance: Lean Culture as a Moderator

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Abstract: Nowadays, manufacturing firms are pressured by governments, non-governmental organizations and customers to operate in a sustainable manner. Although lean practices may provide environmental, social, and financial benefits to firms, their effect on sustainable performance is ambiguous. The aim of this study is to examine the effect of lean manufacturing practices on firms' environmental performance by considering lean culture as a moderator. Data were gathered through a survey of 187 manufacturing firms in Malaysia and were analyzed using the partial least squares technique. The results indicate that process and equipment, product design, supplier relationships, and customer relationships have a positive and significant effect on sustainable performance. It is also interesting to observe that lean culture positively moderated the effects of process and equipment and supplier relationships on sustainable performance. These results have important implications for enhancing the sustainable performance of manufacturing firms through lean manufacturing practices.

Keywords: lean practices; lean culture; sustainable performance; Malaysia

1. Introduction

Manufacturing industries account for a large amount of resource consumption and waste generation all over the world [1]. Stakeholders and regulatory agencies put pressure on manufacturing firms to be sustainable due to the warnings about global warming and social issues [2–4]. With increasing demand from stakeholders for firms to be environmentally and socially responsible, firms have become aware of the strategic role of sustainable performance for a competitive advantage [5,6]. A number of studies have proposed that the adoption of lean manufacturing can improve firms' environmental [7,8], social [9,10], and financial performance [11,12].

Lean manufacturing refers to "a methodology designed to lower the costs involved in production with a view to minimizing waste" [13]. Snee [14] defined lean manufacturing as "a business strategy and methodology that increases process performance resulting in enhanced customer satisfaction and improved bottom line results." Research has shown that lean manufacturing significantly improves the operational performance of firms [15]. Lean manufacturing is formed from different practices [16]. Researchers and practitioners have tried to find the best lean manufacturing practices. They have suggested various best lean practices for different industries, including the electronics industry [17],

the ceramic industry [18], the aerospace industry [19], and the automotive industry [20]. Panizzolo [21] categorized lean practices into six main areas, namely process and equipment, manufacturing planning and control, product design, human resources, customer relationships, and supplier relationships, and previous studies have shown that these six areas fit well in various industries [22].

Several studies have investigated the relationships between overall lean manufacturing and environmental performance [23,24] and financial performance [25,26]. These studies suffer from two limitations. First, the impact of lean manufacturing on the sustainable performance of firms, including environmental, social, and economic aspects of sustainability simultaneously, has received less attention in the literature. To compete in the current competitive market, manufacturing firms should balance their environmental, economic, and social performance [27]. As such, these manufacturers need to know the lean practices that have positive effects on all three aspects of sustainability, and not only one aspect. Second, most of the previous studies have tested the impact of overall lean manufacturing on firm performance [23,25]. As lean manufacturing practices are diverse in different areas of a firm, investigations of the relationship between these practices and sustainable performance provide a clear picture of the practices that have the best effect on firms' sustainable performance. Thus, this study investigates the effect of lean manufacturing practices on sustainable performance.

To successfully transform towards lean manufacturing, companies must develop a lean culture, which is a time-consuming process [20,28]. Lean culture could be viewed as an organizational culture and refers to the employees' awareness of lean practices, combined with the real things that are done [29]. The spread of lean culture among employees can assist management in implementing lean manufacturing practices effectively and efficiently and consequently in achieving lean manufacturing aims. Womack and Jones [30] found that waste reduction and continuous culture were prerequisite factors for achieving the aim of lean manufacturing. Although previous studies have highlighted the important role of lean culture in the implementation of lean practices, to the best of our knowledge, there is a lack of study on the role of lean culture in strengthening the impacts of lean practices on sustainable performance. As the organizational culture of manufacturing firms varies [31,32], testing the moderating effect of lean culture helps to generalize the results and achieve more accurate findings. Furthermore, the results of studies on the impact of lean manufacturing on financial and environmental performance are inconsistent in the literature. For example, although Bergmiller and McCright [33] and Dues et al. [34] found a positive relationship between lean practices and environmental performance, Carvalho et al. [35] found no relationship between these two concepts. Lean culture may explain the difference between success and failure in achieving the sustainability aim of lean implementation. As such, to fill this gap, in the present study the moderating effect of lean culture is investigated.

This paper contributes to the literature in two ways. First, a conceptual framework was developed linking the six lean practices and sustainable performance of the manufacturing firms. Second, we empirically assessed the moderating effect of lean culture on the relationship between lean manufacturing practices and environmental performance. Such a moderating effect has not been assessed in the literature and is important to refine our conceptual understanding of the linkage between lean manufacturing practices and sustainable performance. The paper also has a managerial contribution, because its results can guide managers in adopting suitable lean practices to enhance their firms' sustainable performance.

2. Literature Review

2.1. Lean Manufacturing Practices and Sustainable Performance

The lean manufacturing concept was started from Toyota production systems (TPS) with the aim of reducing cost and improving quality through abolishing waste or non-value-adding activities [20]. Its focus was on inventory management approaches and just-in-time production and later was extended to the entire manufacturing management process [36]. It involves reducing inventories and lead time

and improving quality and productivity [37]. There is a long discussion in the literature about the ways in which lean manufacturing contributes to environmental protection. Several studies have shown the positive effect of lean manufacturing on waste management [38–40]. According to Ohno [41], lean manufacturing reduces non-value-adding waste such as motion, inventory, transport, waiting, over-processing, overproduction, and defects. Other studies have shown the positive effect of lean manufacturing on energy management [42], emissions management [43], water management [8], and chemical management [44]. Some researchers believe that the goals of green and lean paradigms are somehow the same. Campos and Vazquez-Brust [45] mentioned that there are some differences between waste reduction in green practices and lean manufacturing. According to Tice et al. [46], although environmental wastes are targeted in green manufacturing, they are not targeted in lean manufacturing. Thanki et al. [12] explained the difference between lean and green manufacturing as follows: "Lean has the goal of reducing operational waste through non-value adding activities, while green manufacturing targets environmental waste reduction." However, currently, researchers agree that although both lean and green paradigms contribute to firms' environmental performance, they have some differences, raising the question of whether there are synergic benefits to applying both. To answer this synergic concern, Dues et al. [34] described this synergy with "the equation 1 + 1 = 3," meaning that "combined practices have greater results than the sum of the separate performances".

The previous literature also discussed the relationship between lean manufacturing and financial performance as another aspect of sustainability. Corbet and Klassen [47] concluded that the contribution of lean manufacturing to the environment can lead to financial returns by acquiring new customers, competitive differentiation, and reducing cost through waste reduction. According to King and Lenox [43], lean manufacturing contributes to financial performance by bringing down the managerial cost of reducing pollution, either by providing information on the importance and value of pollution reduction, or by lowering the cost of implementing environmental improvement. In summary, the positive relationship between lean manufacturing and financial performance has been proved in the literature [25,26].

Social responsibility is another aspect of sustainability which has received less attention in the literature. These days, due to customers' demand for social responsibility from firms, the adoption of lean manufacturing to improve financial and environmental results is not enough. It is also essential for managers to pay particular attention to how to effectively manage social performance and to be aware of the impacts of lean practices on social performance. The evaluation of literature on the relationship between lean manufacturing and its social consequences does not provide conclusive results. On the one hand, some authors found that lean practices reduce stress [48], increase responsible autonomy [49], and lead to intrinsic motivation [50]. On the other hand, some other researchers highlighted the fact that lean manufacturing leads to more intense work stress [15,51].

2.2. Lean Culture

Culture is one of the important factors that shapes the way that things are done in a firm and is affected by the management system [29]. Culture shows the personality of a firm and reflects the norms and values of a company's employees and the way that they behave [52]. Schein [53] defined culture as "a pattern of shared basic assumptions that has been learnt whilst solving problems, that has worked well enough to be considered valid, and therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems." This definition illustrates that culture penetrates into the thinking, feeling, and perception of a firm's employees.

The AberdeenGroup [54] studied companies that implemented lean practices and reported that companies that developed lean culture throughout the organization implemented lean practices in a more effective way in comparison to those with low lean culture adoption, which had applied lean practices merely on the shop floor. Previous studies have introduced the lack of a lean culture as one of the main causes of lean failure in firms [55,56]. As such, it is expected that lean culture moderates

the impacts of lean manufacturing practices on sustainable performance, which is investigated in the present study.

3. Conceptual Framework and Hypotheses Development

The conceptual framework, shown in Figure 1, is developed to investigate the effect of lean practices (process and equipment, manufacturing planning and control, human resources, product design, supplier relationship, and customer relationship) on the sustainable performance of manufacturing firms. In addition, the moderating effect of lean culture was proposed in this study.

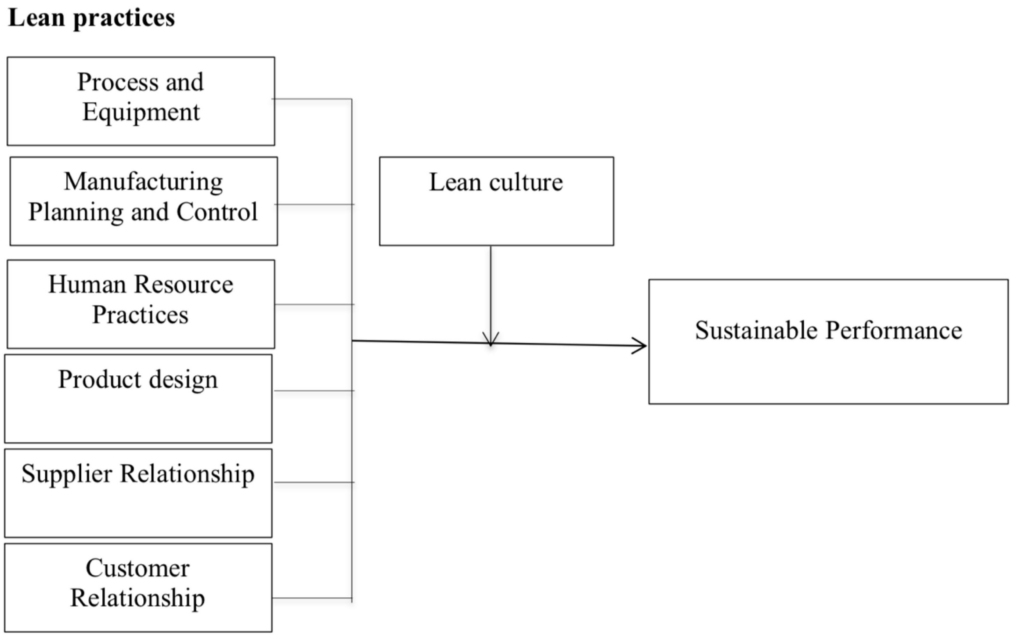


Figure 1. Proposed conceptual framework.

3.1. Process and Equipment

Processes and equipment are representative of improvement capabilities and practices such as the use of "error proof" equipment, cycle time reduction, availability and reliability of machines, use of cellular manufacturing, and shortening set-up times with the purpose of creating a regular and uniform flow within production processes over time [21]. Incorrect processing and over-processing lead to waste of material and defects [9]. Over-processing causes additional movement of operators and consequently results in motion waste. Machinery usage in over-processing also results in generating hazardous materials and emissions, increasing water consumption, and wasting energy [22]. According to Fliendner [57], process and equipment practices lead to fewer defects and energy usage, provide a methodology for sustaining and better organizing the work environment, and help to identify spills and leaks more quickly and consequently decrease the usage of chemicals and materials and pollution production. In summary, process and equipment practices can enhance the environmental and financial performance by reducing the material and energy usage and waste production. The social performance is expected to be enhanced due to a reduction in the environmental impacts of firms' activities, leading to improvements in the community's and employees' health. Therefore, it is hypothesized that:

Hypothesis 1 (H1). *The process and equipment used in process practices affect sustainable performance.*

3.2. Planning and Control

The planning and control practices in lean manufacturing are typically related to the scheduling strategies, with the purpose of production and market demand coordination [21]. This goal can be achieved through pull-flow control, overlapped production, visual control of the shop floor, small lot sizing, under-capacity scheduling, mixed model scheduling, synchronized scheduling, and levelled production. In comparison to traditional manufacturing, lean planning and control contributes significantly to waste in scheduling and reductions in raw materials and manpower utilization, which are the main areas of waste [58]. Inventory reduction, work-in-process reduction, resource use optimization, and meeting customer orders are the results of effective schedules [5]. Smoother flow of production by eliminating imbalances in the production line is another consequence of small lot sizing. Pull methods such as Kanban and lot size reduction can reduce inventories and storage and consequently decrease waste from overproduction [59]. According to Rothenberg et al. [24], planning and control practices lead to a reduction in materials and components used throughout the manufacturing operations, without affecting the delivery time. Vinodh et al. [60] also mentioned that the pull approach reduces work in process and floor space utilization and eliminates wastage as a consequence of damaged products. In summary, planning and control practices may lead to higher financial performance by reducing in-process waste and faulty materials and improving the work conditions. Accordingly, the following hypothesis is posited:

Hypothesis 2 (H2). *Manufacturing planning and control practices affect sustainable performance.*

3.3. Human Resources

The focus of human resource practices is to support lean objectives through human capital development and creating a proper work environment. This includes employees' empowerment, involvement, autonomous problem solving, self-directed work teams, problem solving groups, and formal training programs. Continuous quality improvement plans, which are the foundation of successful lean manufacturing implementation, are highly dependent on human resources [61]. According to Florida [62] and King and Lenox [43], human resource practices play a significant role in waste and pollution reduction efforts. Trained and educated employees have a better understanding about appropriate solutions for waste reduction and the effective ways of using materials [63]. Furthermore, other human resource practices, including employees' empowerment and involvement, give them the authority to reduce waste and pollution by taking proper action, which can enhance firms' environmental and financial performance. This leads to the following hypothesis:

Hypothesis 3 (H3). *Human resources practices affect sustainable performance.*

3.4. Product Design

In lean manufacturing, product design refers to practices such as multifunctional design teams, design for manufacturability, product modularization, and parts standardization [64]. The aim of product design practices is to simplify the process of product development by minimizing the amount of material used in a product, which streamlines the assembly and manufacturing process [64] and consequently optimizes the usage of firms' resources [65]. Furthermore, product design also leads to less energy usage by ensuring the compatibility of the product design with the current manufacturing processes and procedures. This helps to optimally leverage a company's resources [66]. In addition, in order to achieve efficiency as the main aim of lean practices, all types of waste throughout the entire process need to be eliminated [67]. Jayaram et al. [66] found a positive relationship between product design and firms' economic outcome. As such, the following hypothesis is developed:

Hypothesis 4 (H4). *Product design practices affect firms' sustainable performance.*

3.5. Supplier Relationship

Supplier relationship refers to the extent of interaction with the supplier to address quality concerns and ensure just-in-time delivery through considering the number of suppliers, long-term relationships, and supplier involvement in the product design and development process and by providing feedback on suppliers' performance [21,64,68]. Since firms should be responsible for their suppliers' environmental issues, there has been an urgency to implement supplier relationship practices such as face-to-face planning and communication with suppliers about performance expectations and social and environmental issues in order to achieve sustainable performance [69]. Relationships with suppliers assist the adoption and development of innovative technologies, which will lead to better environmental, social, and financial performance [70]. Furthermore, joint productivity and environmental performance enhancement are affected by supplier relationship practices [62]. As stated by Shah and Ward [68], the main focus of supplier relationship practices is reducing waste of excess capacity or excess inventory by eliminating the variety in supply. Less energy usage, less scrap, and fewer defects as a consequence of supplier relationship practices lead to waste reduction and consequently to more sustainable performance [57]. Closer relationships with suppliers provide a chance to enhance suppliers' skills, which contribute to better environmental performance through the implementation of innovative processes and materials [16]. Therefore, it is hypothesized that:

Hypothesis 5 (H5). *Supplier relationship practices affect sustainable performance.*

3.6. Customer Relationships

Customer relationships refer to the way in which companies interact with customers with the aim of building long-term relationships with them, enhancing customer satisfaction, and managing customer complaints. Close contact with customers, involving them in product design, and exchanging information with customers as practices of customer relationships lead to identifying the needs of customers and consequently sustaining their loyalty through product, service, process differentiation from competitors, and strive to add value (Li et al., 2005). Innovative relationships with customers are one of the results of implementing a lean manufacturing concept [68,71]. Customers play a central role in developing innovative production systems [21]. As such, a good relationship with customers may lead to the diffusion of socially and environmentally conscious manufacturing practices that will increase environmental and social performance. Customer demand for social and environmental practices indicates the importance of strategies toward social and environmental practices in order to achieve high performance [62]. Furthermore, Florida [62] also showed that cleaner production is facilitated by close relationships between suppliers and customers. Moreover, the interaction of suppliers, staff and customers, joint research and development, and partnership agreements lead to enhancement in social, environmental, and financial performance [72–74]. As such, the following hypothesis is developed:

Hypothesis 6 (H6). *Customer relationship practices affect sustainable performance.*

3.7. Lean Culture

Organizational culture is one of the key organizational assets that facilitate the successful implementation of strategies [75]. Zheng et al. [76] argued that organizational culture is closely related to firm performance and determines the effectiveness of firms' strategy implementation. The impact of culture on successful strategy implementation has been demonstrated in various contexts [75,77].

For example, Kurniawan et al. [77] found that risk culture moderates the impact of supply chain visibility and supplier development as two risk mitigation strategies on supply chain effectiveness. Soltero and Waldrip [78] also indicated that a culture of continuous improvement in a firm can facilitate the adoption of environmental management practices and principles. Some practitioners and specialists believe that the degree to which the cultural values are shared determines the impact of a company's capabilities and resources on its performance [79,80].

Fundamental changes in norms, priorities, and values are needed in order to move from traditional manufacturing management to lean management. Without changing the culture of companies, achieving the potential benefits of lean practices is not possible. Womack and Jones [30] indicated that reducing waste and enhancing the manufacturing process is not achievable only through the implementation of lean manufacturing; rather, a culture of continuous improvement and waste reduction is needed in the company. However, many firms consider lean manufacturing as a process instead of a philosophy, which leads to low rates of success in lean manufacturing implementation [28,81].

Without appropriate change management and understanding of their philosophy, lean initiatives will be doomed to fail. This change should involve managers actively leading the deployment of lean practices throughout the system. Bergmiller [22] noted that lean manufacturers who have a fine infrastructure can identify and eliminate waste through total employee involvement, adequate training, and continuous improvement of employees' knowledge and skills, along with continuous commitment of management and direct personal involvement of senior management with the operating workforce concerning lean practices. Lean culture may motivate employees to implement lean manufacturing practices effectively, creating an opportunity for firms to safeguard their lean operations. Eventually, a performance-oriented and process-driven organizational atmosphere may result in higher levels of sustainable performance [22]. As such, the following hypotheses are developed:

Hypothesis 7 (H7). *Lean culture positively moderates the impacts of (a) process and equipment, (b) planning and control, (c) human resources, (d) product design, (e) supplier relationship practices, and (f) customer relationship practices on sustainable performance.*

4. Methodology

4.1. Measurement of Constructs

A structured questionnaire was used to collect data from respondents. The items of study constructs were adapted from previous studies and measured using five-point Likert scales ranging from "strongly disagree" to "strongly agree". Items were adapted from previous studies to ensure content validity (Appendix A). The scales for lean practices were adapted from Panizzolo [21], Shah and Ward [68], and Puvanasvaran et al. [82]; the scales for environmental, social, and financial performance were adapted from Zailani et al. [2].

4.2. Data Collection and Sample

All manufacturing firms in Malaysia that implement lean practices form the sampling frame of this study. The data were collected from the managers of manufacturing firms in Malaysia. Due to their direct involvement in the manufacturing process, they have knowledge and experience of their firms' lean manufacturing practices and consequently can respond to the items of this study. The managers were selected from different organizational departments, as lean is a multidimensional approach that gradually extended from manufacturing operation to other business functions such as support of production functions, downstream customers, and upstream suppliers [16]. The sampling list was obtained from the Federation of Malaysian Manufacturers (FMM) directory, 2017. Questionnaires were

mailed to 700 target respondents in the manufacturing firms and 187 usable responses were collected, resulting in an effective response rate of 26.71% (187/700).

According to the descriptive analysis, around 52.4% of the respondents were from manufacturing and the rest were from the rubber and plastics industry (9.6%), the chemical industry (7.0%), the metal industry (5.9%), the textile industry (3.2%), and others (20.9). The data were mostly collected from large companies with more than 1000 employees (81.3%). Around 77.5% of the firms had been operating for more than 10 years.

4.3. Analysis

The collected data were analyzed using the partial least squares (PLS) technique. This analysis method was used due to the exploratory nature of the study [83]. To analyze the data, a two-step approach was used [84]. In the first step, which is called the measurement model, the validity and reliability of the variables were investigated [85–87]. In the second step, the hypotheses were tested.

5. Results

5.1. Measurement Model

The reliability and validity of the constructs were assessed (Table 1). Composite reliability (CR), average variance extracted (AVE), and factor loadings were above 0.7, 0.5, and 0.4 respectively [88–90], thus confirming the convergent validity and reliability of constructs [84].

Table 1. Measurement model evaluation.

Constructs	Items	Factor Loadings	CR	AVE
Process and Equipment (PE)	Set up reduction	0.642	0.874	0.538
	Continuous flow of production	0.803		
	Order and cleanliness (5S)	0.707		
	Cycle time reduction	0.761		
	Value stream mapping	0.771		
	Error proofing techniques/Pokayoke	0.706		
Manufacturing Planning and Control (MPC)	Pull system/Kanban	0.654	0.859	0.608
	Planning and scheduling strategies	0.712		
	Lot size reduction	0.859		
	Visual control of shop floor	0.871		
Human Resource Practices (HRP)	Has multifunctional (multi skill) workers	0.556	0.888	0.534
	Gives workers a broader range of tasks	0.608		
	Workers undergo cross-functional training	0.769		
	Expansion of autonomy and responsibility	0.805		
	Workers involved in continuous improvement efforts	0.768		
	Shop floor employees are key to problem solving teams	0.827		
	Team members opinion and ideas (suggestions) are considered before making decisions	0.739		
Product Design (PD)	Implement parts standardization	0.811	0.897	0.686
	Implement product modularization	0.871		
	Implement design for manufacturability	0.840		
	Multifunctional design teams	0.788		

Table 1. *Cont.*

Constructs	Items	Factor Loadings	CR	AVE
Supplier Relationships (SR)	Establish the long-term relationship with our suppliers	0.750	0.846	0.527
	Key suppliers deliver to plant on the just-in-time (JIT) basis	0.776		
	Suppliers are directly involved in the new product development process	0.800		
	Key suppliers are located in close proximity to our plant	0.544		
	Evaluate suppliers on the basis of total cost and not per-unit price	0.732	0.871	0.628
Customer Relationships (CR)	In close contact with our customers	0.778		
	Customers are actively involved in product design development	0.770		
	Customers frequently share current and future demand information with marketing department	0.857		
	Customers frequently give us feedback on quality and delivery performance	0.762		
Lean Culture (LC)	Meaningful incentives that reward lean progress are in place	0.771	0.935	0.673
	A non-blaming, performance oriented, process-driven organizational atmosphere exists	0.760		
	Regular, direct personal involvement by senior management with operating workforce concerning lean practices	0.824		
	Employees are provided with adequate training on lean practices and lean philosophy is communicated to all	0.783		
	Work area management encourage work area employees to apply continuous improvement knowledge and skills	0.875		
	Senior managers are actively leading the deployment of lean practices	0.870		
	Lean progress targets are defined and have been effectively communicated	0.851		
Environmental Performance (EP)	Minimized the emission of hazardous substances or waste	0.820	0.897	0.594
	Minimized the consumption of energy	0.790		
	Minimized the consumption of direct or indirect usage of material	0.829		
	Minimized the consumption of hazardous materials	0.704		
	Improved its overall environmental situation	0.745		
	Improved the compliance to environmental regulations and standards	0.726		
Financial Performance (FP)	Increased the market share and growth rate	0.762	0.884	0.604
	Increased the growth in profit margin	0.829		
	Increased the level of productivity	0.817		
	Increased the growth in sales	0.734		
	Lower the cost of production or production cost per unit	0.738		
Social Performance (SP)	Improved the overall customer satisfaction	0.634	0.898	0.599
	Improved the overall customer retention and loyalty	0.765		
	Enhanced its green image	0.834		
	Paid important concern to the health and safety of the society	0.851		
	Paid important concern to the society wellbeing in all operations	0.676		
	Paid important concern to how the society response towards firm's action	0.854		

CR—Composite Reliability; AVE—Average Variance Extracted.

Heterotrait-monotrait (HTMT) criteria, suggested by Henseler et al. [91], were used to test the discriminant validity (Table 2) and as all values were less than 0.85, the requirement for discriminant validity was fulfilled [92].

Table 2. Discriminant validity.

	PE	MPC	HRP	PD	SR	CR	LC	EP	FP	SP
PE										
MPC	0.839									
HRP	0.774	0.802								
PD	0.554	0.674	0.690							
SR	0.577	0.658	0.707	0.643						
CR	0.648	0.734	0.658	0.545	0.527					
LC	0.823	0.811	0.800	0.659	0.604	0.567				
EP	0.703	0.708	0.625	0.467	0.610	0.584	0.719			
FP	0.661	0.699	0.642	0.691	0.576	0.657	0.686	0.769		
SP	0.634	0.729	0.579	0.586	0.516	0.682	0.640	0.711	0.843	

5.2. Assessment of the Structural Model

The model can explain 61.0% of the sustainable performance. Furthermore, the Stone–Geisser Q^2 was 0.414, which is higher than zero [93] and indicates that the model has high predictive relevance [94–96]. As the model exhibited acceptable fit, the hypotheses were tested using bootstrapping with 2000 replications [97]. According to the results (Table 3), out of six lean practices, process and equipment ($\beta = 0.235$, $p < 0.01$), product design ($\beta = 0.167$, $p < 0.05$), supplier relationship ($\beta = 0.121$, $p < 0.05$), and customer relationship ($\beta = 0.281$, $p < 0.001$) have significant effects on sustainable performance. Therefore, H1, H4, H5, and H6 are supported, whereas H2 and H3 are not supported.

Table 3. Path coefficient and hypothesis testing.

Hypothesis	Relationships	Path Coefficients	Decisions
H1	PE $\geq$ SUP	0.235 **	Supported
H2	MPC $\geq$ SUP	0.114	Not Supported
H3	HRP $\geq$ SUP	0.072	Not Supported
H4	PD $\geq$ SUP	0.167 *	Supported
H5	SR $\geq$ SUP	0.121 *	Supported
H6	CR $\geq$ SUP	0.281 ***	Supported

* $p < 0.05$, ** $p < 0.01$, ***$p < 0.001$ (two tailed).

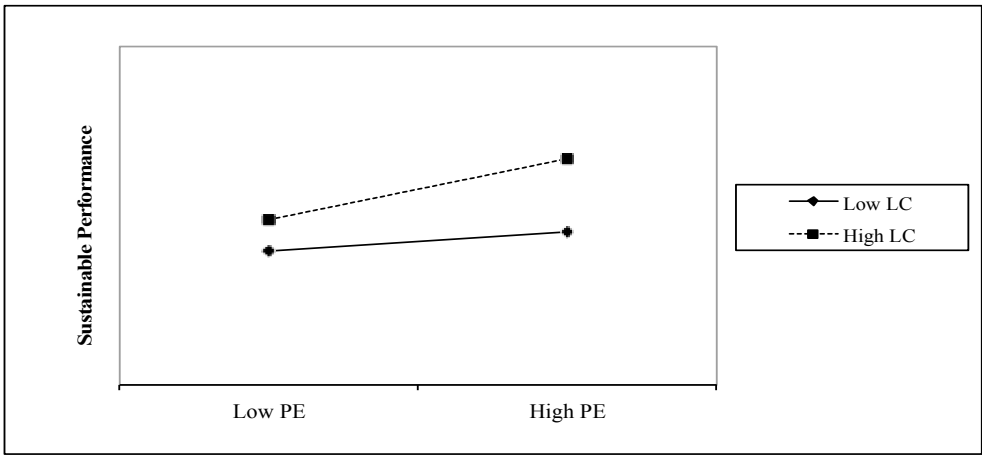
The product indicator approach was employed to create the interaction construct [84]. According to the results (Table 4), lean culture moderates positively the impacts of process and equipment ($\beta = 0.235$, $p < 0.01$) and supplier relationship (process and equipment ($\beta = 0.235$, $p < 0.01$) on sustainable performance. As such, H7a and H7e are supported and the rest are rejected.

Table 4. Moderating effect of lean culture.

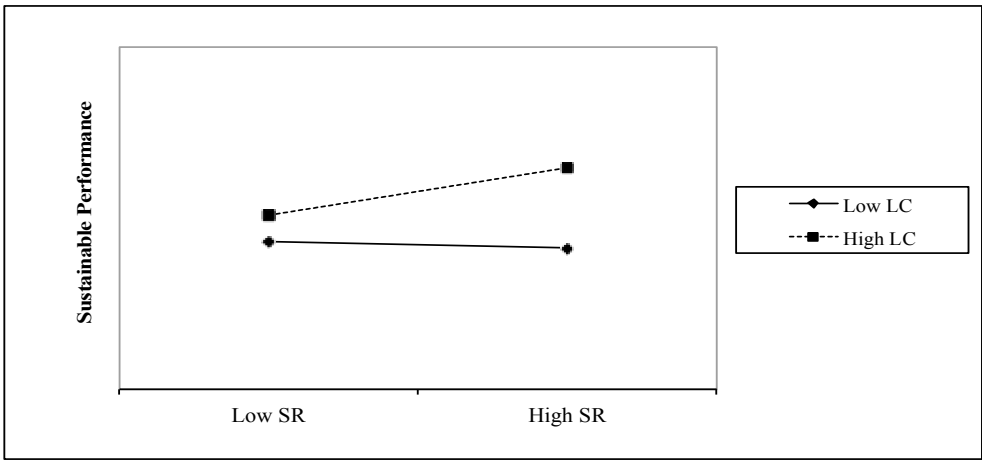
Hypothesis	Relationships	Path Coefficients	Decisions
–	LC $\geq$ SUP	0.310 ***	–
H7a	PE $\times$ LC $\geq$ SUP	0.125 *	Supported
H7b	MPC $\times$ LC $\geq$ SUP	0.081	Not Supported
H7c	HRP $\times$ LC $\geq$ SUP	0.067	Not Supported
H7d	PD $\times$ LC $\geq$ SUP	0.001	Not Supported
H7e	SR $\times$ LC $\geq$ SUP	0.157 *	Supported
H7f	CR $\times$ LC $\geq$ SUP	−0.037	Not Supported

* $p < 0.05$, *** $p < 0.001$ (one tailed).

Figure 2 illustrates that lean culture strengthens the effect of process and equipment and supplier relationships on sustainable performance. The impacts of both process and equipment and supplier relationships on sustainable performance are higher among firms with high lean culture.



(**a**)



(**b**)

Figure 2. Interaction effect of PE, SR, and LC on environmental performance. (**a**): Interaction with PE; (**b**): Interaction with SR.

6. Discussion

The significant impact of process and equipment on sustainable performance is in line with the findings of studies conducted by Panizzolo [21] and Bergmiller [22], who claimed that over-processing and the resultant machinery usage results in a waste of energy and resources and also increases the generation of emissions. Some practices, including cycle time reduction, shortening set-up times, order and cleaning (5S approach), and the use of "error proof" equipment are required to create the regular and uniform flow within production processes [21]. Value stream mapping through fewer defects, lower energy usage, and less scrap across the company increases the environmental benefits of lean manufacturing. The 5S approach provides a methodology for better sustaining, developing, cleaning, and organizing of the work environment, which leads to quicker identification of leaks and spills and reduction in chemicals and materials usage. Furthermore, lowering inventories means that less floor space is needed, which will lead to lower energy usage [57]. Therefore, manufacturing firms can improve their sustainable performance by implementing process and equipment practices.

The results showed that manufacturing planning and control practices have no significant effect on sustainable performance. One potential reason for this non-significant relationship might be due to some negative impacts of these practices on the environment which trade off against their positive impacts. For example, according to King and Lenox [43], lot size reduction as a manufacturing and control practice needs frequent changeover, which leads to more disposal of unused process

material and also causes higher pressure on employees. According to Biggs [98], the side-effects of planning and control practices, such as Kanban and visual control, are more than their benefits to the environment. In contrast to the findings of King and Lenox [43] and Biggs [98], Fliedner [57] believes that manufacturing planning and control practices, such as the pull approach, may reduce post-process and in-process inventory, which leads to fewer damaged products and consequently to sustainable performance improvement. Vinodh et al. [60] also highlighted proper waste management and chemical handling as the consequences of visual control, which contribute to environmental performance. Waste reduction and energy saving can lead to higher financial performance. EPA [99] also indicated that enhancement of the work environment for employees is one of the consequences of waste reduction goals in lean practices.

The relationship between human resource practices and sustainable performance was not supported. This result is not consistent with King and Lenox's [43] findings, which indicated that human resource practices lead to lower pollution and waste generation. The important role of workers in preventing pollution was also highlighted by Florida [62]. The team approach, comprising engineers, managers, and production workers, can play a critical role in the reduction of wastage and improving environmental outcomes [62]. Rothenberg et al. [24] also supported the importance of human resource policies and mentioned that involving employees in environmental practices and providing them with environmental education and training will lead to environmental efficiency. They explained the rationale for this relationship and stated that trained workers have better understanding of materials and have the ability to propose appropriate solutions which will lead to less material wastage. Regarding the social perspective, according to Womack et al. [100], involving employees in problem-solving activities and work function diversification has a positive effect on the work environment. However, some other studies have shown that human resource practices have a negative effect on employees due to higher work pressure as a result of more responsibility and a higher degree of standardization [101]. As such, the positive and negative effects of lean human resource practice offset each other and consequently the results show no relationship between lean human resource practice and sustainable performance.

The findings of the study confirmed the positive relationship between product design and sustainable performance. Product design practices with the main aim of eliminating unnecessary process steps and simplifying the production process [64,102] can contribute to optimization or resource usage and enhance the levels of quality and efficiency by decreasing non-value-adding activities and wastage throughout the entire process [66] and may also lead to reduced work pressure. To prevent waste generation, companies implement product design practices [67] and as King and Lenox [43] stated, the main focus of methods to reduce environmental impact is on waste elimination.

According to the results, supplier relationship practices also have a positive effect on sustainable performance. This result is consistent with Florida's [62] finding of supplier relationship as a driver of environmental performance. According to Shah and Ward [68], supply management practices eliminate waste of excess capacity and excess inventory by diminishing the variability in supply. Working closely with suppliers from the early stages of product development will help to enhance process quality and reduce waste. The exchange of knowledge through collaboration may enhance suppliers' capability to meet the requirement of social standards in the industry, especially for those suppliers with limited resources and lack of both knowledge and awareness of social issues. Furthermore, supplier relationships can also enhance firms' reputation in the eyes of suppliers and customers [103]. A long-term relationship with suppliers enables the manufacturer and supplier to share technologies, rewards, and risk and consequently to achieve higher operational and financial performance. Involving suppliers in product design and development and paying attention to their concerns and feedback can indicate a firm's responsibility toward ethical business [103]. Previous studies have also shown a positive relationship between supplier relationships sand firms' financial performance [104,105].

The results confirm that customer relationships have a positive effect on sustainable performance. Florida [62] also emphasized the critical role of customers in pushing firms to be environmentally friendly. Florida [62] showed that the customer relationship is one of the drivers of the adoption and diffusion of environmentally conscious manufacturing practices. A good relationship with customers and meeting their requirements is essential to satisfy them and compete with the firm's competitors. As such, customer demands for social and environmental practices can explain the relationships between social and environmental strategies and the financial performance of firms [62]. Meeting customers' social and environmental demands will enhance customer satisfaction and consequently will lead to higher financial performance.

As highlighted by Bhasin and Burcher [28], in order to successfully implement lean manufacturing practices, the development of a lean culture is needed. Therefore, a lean culture is essential for the implementation of lean manufacturing practices and for better sustainable performance. Thus, the study proposed that lean culture may interact with lean practices and enhance their effects on the sustainable performance of manufacturing firms. The results show that lean culture moderates the relationships between process and equipment practices and supplier relationship practices and sustainable performance. These results imply that, by having a stronger lean culture in the firm, the effects of the process and equipment practices and supplier relationships on sustainable performance will be higher. Hence, it is crucial for managers of manufacturing firms to do the necessary work to enhance their employees' awareness toward lean practices, to create a lean workplace, and to make lean practices a norm for all employees. The moderating effect of lean culture on the effects of process and equipment practices and supplier relationship practices on sustainable performance was significant because, in comparison to other lean manufacturing practices, implementing process and equipment practices and establishing long-term relationships with suppliers require greater involvement from both top management and employees. Furthermore, another potential reason why most of the hypotheses on the moderating effect of lean culture are not significant could be due to the fact that lean culture is still at a very early stage among manufacturing firms in Malaysia. This is supported by Zailani et al. [75], who stated that in the early stage of its development, an organizational culture cannot show its real power in successful strategy implementation.

7. Conclusions

The aim of this study was to identify the relationship between lean manufacturing practices and the sustainable performance of manufacturing firms in Malaysia by considering lean culture as a moderator. Our findings suggest that process and equipment, product design, supplier relationships, and customer relationships have a positive and significant effect on sustainable performance. Moreover, the moderating effect of lean culture was confirmed by the effects of process and equipment and supplier relationships on sustainable performance.

The findings of this study have practical contributions for the managers of manufacturing firms. They can understand the lean manufacturing practices that may enhance the sustainable performance of manufacturing firms. The results are especially useful in helping manufacturing firms' managers to revise the current lean manufacturing model by considering the selected lean manufacturing practices, which make a greater contribution to the sustainable performance of firms. The significant effects of process and equipment, product design, supplier relationships, and customer relationships on environmental performance suggest that these practices should be integrated to improve the current sustainable performance of the firm, as they have positive, significant effects on sustainable performance. In addition, managers should give special attention to lean culture development in order to enhance the impacts of process and equipment practices and supplier relationships on sustainable performance. From an academic perspective, this study extends the literature on lean manufacturing by recognizing the role of lean manufacturing practices in enhancing firms' sustainable performance. The study also extends the literature by testing the impacts of interactions between lean culture and lean manufacturing practices on sustainable performance.

Although the study meets its objectives, there are certain limitations that need to be considered in terms of generalizing its findings. First, the study is cross-sectional in nature and cannot show the dynamic nature of sustainable performance. As such, a longitudinal study is needed to provide a better picture of the extent to which lean manufacturing practices affect sustainable performance. Furthermore, the study sample is limited to Malaysia and the data were collected from different industries. Future studies can test the conceptual framework of this study in other countries, which will help to generalize the results. Furthermore, future research needs to limit the target population to a specific industry, as the relationship between lean manufacturing practices and sustainable performance may depend on the industry in which manufacturing firms operate.

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Appendix A : Questionnaire

Not at All	Low Extent	Moderate Extend	High Extent	Very High
NA	LE	ME	HT	VH

Process and Equipment

My firm does implement	NA	LE	ME	HE	VH
Set up reduction	1	2	3	4	5
Continuous flow of production	1	2	3	4	5
Order and cleanliness (5S)	1	2	3	4	5
Cycle time reduction	1	2	3	4	5
Value stream mapping	1	2	3	4	5
error proofing techniques/ Pokayoke	1	2	3	4	5

Manufacturing Planning and Control

My firm does implement	NA	LE	ME	HE	VH
Pull system/Kanban	1	2	3	4	5
Planning and scheduling strategies	1	2	3	4	5
Lot size reduction	1	2	3	4	5
Visual control of shop floor	1	2	3	4	5

Human Resource Practices

	NA	LE	ME	HE	VH
My firm has multifunctional (multi skill) workers	1	2	3	4	5
My firm gives workers a broader range of tasks.	1	2	3	4	5
In my firm, workers undergo cross functional training	1	2	3	4	5
In my firm we have expansion of autonomy and responsibility	1	2	3	4	5
In my firm, workers involve in continuous improvement efforts	1	2	3	4	5
In my firm, shop floor employees are key to problem solving teams	1	2	3	4	5
In my firm, team members opinion and ideas (suggestions) are considered before making decisions	1	2	3	4	5

Product Design

	NA	LE	ME	HE	VH
My firm do implement parts standardization	1	2	3	4	5
My firm do implement product modularization	1	2	3	4	5
My firm do implement design for manufacturability	1	2	3	4	5
My firm has multifunctional design teams	1	2	3	4	5

Supplier Relationships

	NA	LE	ME	HE	VH
We strive to establish the long-term relationship with our suppliers	1	2	3	4	5
Our key suppliers deliver to plant on the just-in-time (JIT) basis	1	2	3	4	5
Suppliers are directly involved in the new product development process	1	2	3	4	5
Our key suppliers are located in close proximity to our plant	1	2	3	4	5
We evaluate suppliers on the basis of total cost and not per unit price	1	2	3	4	5

Customer Relationships

	NA	LE	ME	HE	VH
We are in close contact with our customers	1	2	3	4	5
Our customers are actively involved in product design development	1	2	3	4	5
Our customers frequently share current and future demand information with marketing department	1	2	3	4	5
Our customers frequently give us feedback on quality and delivery performance	1	2	3	4	5

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
SD	DA	NE	AG	SA

Lean Culture

In my firm … … …	SD	DA	NE	AG	SA
Meaningful incentives that reward Lean progress are in place	1	2	3	4	5
A non-blaming, performance oriented, process-driven organizational atmosphere exists	1	2	3	4	5
There is regular, direct personal involvement by senior management with operating workforce concerning Lean practices	1	2	3	4	5
Employees are provided with adequate training on lean practices and lean philosophy is communicated to all	1	2	3	4	5
Work area management encourage work area employees to apply continuous improvement knowledge and skills	1	2	3	4	5
The firm's senior managers are actively leading the deployment of lean practices	1	2	3	4	5
Lean progress targets are defined and have been effectively communicated	1	2	3	4	5

Environmental Performance

During the last three years, my firm has substantially … ..	SD	DA	NE	AG	SA
Minimized the emission of hazardous substances or waste	1	2	3	4	5
Minimized the consumption of energy	1	2	3	4	5
Minimized the consumption of direct or indirect usage of material	1	2	3	4	5
Minimized the consumption of hazardous materials	1	2	3	4	5
Improved its overall environmental situation	1	2	3	4	5
Improved the compliance to environmental regulations and standards	1	2	3	4	5

Financial Performance

During the last three years, my firm has substantially … ..	SD	DA	NE	AG	SA
Increased the market share and growth rate	1	2	3	4	5
Increased the growth in profit margin	1	2	3	4	5
Increased the level of productivity	1	2	3	4	5
Increased the growth in sales	1	2	3	4	5
Lower the cost of production or production cost per unit	1	2	3	4	5
Improved the overall customer satisfaction	1	2	3	4	5

Social Performance

During the last three years, my firm has	SD	DA	NE	AG	SA
Substantially improved the overall customer retention and loyalty	1	2	3	4	5
Substantially enhanced its green image	1	2	3	4	5
Constantly paid important concern on the health and safety of the society	1	2	3	4	5
Constantly paid important concern on the society well being in all operation	1	2	3	4	5
Constantly paid important concern on how the society response towards firm's action	1	2	3	4	5

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