

# Implementation of lean manufacturing practices and six-sigma among Malaysian manufacturing SMEs: intention to implement IR 4.0 technologies

Intention to  
implement  
IR 4.0  
technologies

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Received 9 March 2022  
Revised 3 February 2023  
14 May 2023  
Accepted 6 June 2023

## Abstract

**Purpose** – In this paper, the implementation of lean manufacturing and six sigma practices among Malaysian manufacturing SMEs toward achieving sustainable performance was investigated. Furthermore, intention to implement IR 4.0 technologies among manufacturing SMEs was also examined.

**Design/methodology/approach** – The primary data were collected from 120 manufacturing SMEs across Malaysia using organization as the unit of analysis. The data were collected using the six-point Likert scale questionnaire.

**Findings** – Based on research findings, about 86% Malaysian manufacturing SMEs implement 6s. Nevertheless, lean and 6s has an influence on sustainable performance among Malaysian manufacturing SMEs. Only about 32.5% Malaysian manufacturing SMEs have the intention to implement IR 4.0 technologies. This study results imply that IR 4.0 technologies implementation among Malaysian manufacturing SMEs are still at infant stage though lean and 6s concept is known by the manufacturing SMEs.

**Research limitations/implications** – This study has implications for future researchers to explore application of IR 4.0 technologies among manufacturing SMEs. Therefore, there is need to create awareness about the application of IR 4.0 technologies suitable for manufacturing SMEs in order to remain sustainable for local and foreign competitors. From the perspective of system theory, there is an interconnection network across each department in a whole system. More so, sustainable performance can continuously change and improve the system in any organization.

**Practical implications** – From the view of SMEs policy makers, this study should be use to encourage SMEs to adopt technologically inclined practices. Accordingly, this research recommends government bodies to help support the implementation of sustainable practices due to their sizes and inadequate resources involved. Therefore, the role of government in providing suitable policies that could be beneficial to manufacturing SMEs toward achieving sustainable practices cannot be overlooked. Through proper government support, Malaysian manufacturing SMEs will be able to survive both locally and internationally and also gain competitive advantage.

**Originality/value** – The main contribution of this paper includes integrated effect of lean manufacturing practices and six sigma implementation among manufacturing SMEs and prioritizing implementation of IR 4.0 technologies to be executed by manufacturing SMEs.

**Keywords** Sustainable performance, Lean manufacturing practices, Six-sigma, Small and medium enterprises, Industrial revolution 4.0 technologies

**Paper type** Research paper

## 1. Introduction

Sustainable performance can be realized through implementation of continuous improvement such as lean manufacturing practice (LMP) and Six-Sigma (6σ).

**Funding:** Researchers did not acquire a research grant from any funding organizations or non-profit organizations.



Introduction of LMP and 6 $\sigma$  into any organization is quite difficult and complex due to its process and procedure. In other words, implementation of LMP and 6 $\sigma$  by some small and medium enterprises (SMEs) were considered as an uneasy journey. Therefore, transforming manufacturing SMEs into LMP and 6 $\sigma$  practicing factory requires systematic thinking through step by step procedures. Manufacturing SMEs are believed to be one of the firms that encounter several sustainability challenges due to its market demands for range of products, frequent delivery and reduced cost. As investigated by [Papadopoulos et al. \(2021\)](#) in a study, manufacturing practice issues which include economic, social and environmental elements are majorly caused by firms due to poor practices of LMP and six sigma by developing nations. Nevertheless, such challenges can be conquered through the successful implementation of sustainable practices into manufacturing firm process. Therefore, Malaysia as a country should rely completely on sustainable practices through continuous improvement to encounter the challenges of manufacturing firms in transition to modern and smart state.

Manufacturing SMEs are considered as one of the most important sectors that face difficulties for the provision of product varieties with fast shipment and low-cost ([Prashar, 2021](#)). It is surprising that manufacturing SMEs were not given enough attention toward the implementation of LMP and 6 $\sigma$ . Basically, the effect of SMEs through economic, environmental and social perspectives are the fundamentals of forging ahead for sustainable development goals as stated by the United Nations ([Khattak, 2020](#)). Specifically, [Yadav et al. \(2020\)](#) stated in a study that in order for manufacturing SMEs in developing nations to survive in this global environment, there is need to implement LMP and Six Sigma by considering customer requirements through cost, quality, value added activities, delivery time, waste elimination and zero defect. Nevertheless, the rapid technological changes and market competition has put manufacturing firms under the pressure of implementing sustainable practices toward a moderate balance among environmental, economic and social performance. According to this study, LMP and six sigma are already known by manufacturing SMEs. Unfortunately, only about 32.5% intended to implement IR 4.0 technologies. The reason behind this will be explained further in this study. Besides that, this study developed a new model on how to implement LMP and six sigma and intention to implement IR 4.0 technologies among manufacturing SMEs. However, it highlights the novelty of this study. Hence, this study promotes LMP and six sigma practices and explain the benefit of implementing IR 4.0 technologies which at the end will benefit the whole manufacturing SMEs and support its sustainability.

SMEs are said to be major driver of Malaysia's economy and according to the 11th Malaysia Plan 2016–2020 report, SMEs contributed about 41 % toward the country GDP in the year 2020. Basically, the goal of Malaysia Government is to push the economy forward toward increased productivity, more entrepreneurial start up and increase job opportunities. However, these goals cannot be actualized without digital transformation of manufacturing SMEs in Malaysia ([Rusly et al., 2020](#)). The digital transformation in terms of implementing LMP and six sigma among manufacturing SMEs is given less attention by researchers. Furthermore, the transformation through intention to implement IR 4.0 technologies among manufacturing SMEs is not yet fully explored. This leaves a gap that is needed to highlighted in this study. Therefore, in order for firms to be digitalized and innovative, manufacturing SMEs need to leverage more for technology capabilities through implementation of lean six sigma practices. Manufacturing SMEs along with its efforts to achieve sustainability should be more concentrated on since larger firms have more capital, knowledge and technology to improve businesses in order to be economically, environmentally and socially friendly. Nevertheless, there is need for Malaysian manufacturing SMEs to adopt technologically-inclined practices for

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the growth of company performance both locally and internationally. However, research questions are generated as thus:

- RQ1.* Do implementation of LMP have impact on sustainable performance among Malaysian manufacturing SMEs?
- RQ2.* Do implementation of Six-Sigma have impact on sustainable performance among Malaysian manufacturing SMEs?
- RQ3.* Do intention to implement industrial revolution 4.0 technologies have impact on sustainable performance among Malaysian manufacturing SMEs?

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The instrument for collection of data employed in this study is survey questionnaire. The data was collected from the employees of the companies who are middle managers which include production and operations officers, procurement officers and process engineers of manufacturing SMEs. The survey was administered individually to the respondents of the companies. This implies that responses deducted are from the individual's perception of the reality of the work environment and its distinctiveness.

The impact of LMP, and 6 $\sigma$  implementation on sustainable performance of Malaysian manufacturing SMEs were studied. Recently, IR 4.0 technologies are seriously emphasized among manufacturing SMEs in Malaysia due to the large number of its contribution toward the manufacturing sector at large. Transition of manufacturing SMEs from conventional manufacturing methods to LMP and six sigma through the implementation of IR 4.0 technologies could be beneficial. It is beneficial toward the generation of revenue, customer satisfaction, increased productivity, reduced waste and low-quality design cost. Therefore, the intention to implement IR 4.0 technologies through the application of LMP and 6 $\sigma$  practices toward sustainable performance were discussed. Furthermore, this paper also employed system theory to explain the connection of systems in an organization and how it influences company operations and practices toward decision making. The findings of current research study offer concrete practical and managerial support for sustainable performance, and recommendation toward achieving a sustainable practice among Malaysian manufacturing SMEs.

With primary data obtained through questionnaire developed from existing literature from manufacturing SMEs in Malaysia, this study simultaneously investigated the implementation of LMP and six sigma among Manufacturing SMEs. In this regard SMEs in Malaysia are defined according to number of employees as stated on Malaysian SMEs directory. Since the unit of analysis was manufacturing SMEs, Harman's single factor test (Podsakoff and Organ, 1986) was examined to check common method bias issue. The results of the analysis demonstrated that Harman's single factor of about of the total variance. In other words, there were no biasness issue in this study model.

This paper is also organized into six sections. However, the present research paper is structured as follows; The literature was discussed in part 1 to develop the research questions in accordance with the research issue while review of literatures was carried out in part 2 to develop the research model. Research methodology, measures and sampling techniques were discussed in part 3. Part 4 contains the analysis aspect of the study. Section 5 of this research discussed the result. Furthermore, section 6 outline the conclusion, study implications and recommendations on the study area.

## 2. Literature review

In this research, the literature review covered Scopus indexed journals published between 2018 and 2022. The key words used include lean manufacturing practices, Six sigma, IR 4.0

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technologies, sustainable performance, sustainability and manufacturing SMEs. Thorough checks were done through titles and abstract. About 102 papers were generated key word search and 47 papers were related after scrutiny. Nevertheless, recent publications were used to explain current issues and challenges in LSS practice and sustainable performance.

### *2.1 System thinking theory and sustainable performance*

From the perspective of system thinking, sustainability refers to a state in which human are able to develop, grow and improve within the same environment with other living organisms for continuity (Ehrenfeld, 2012). Therefore, sustainable performance is not just an end state, but a practice that is continuously changing, updating and improving the system in an organization (Gaziulusoy *et al.*, 2013). In the same vein, institutions maintain mutual internal relationship of impact and interdependence for smaller and larger system. It also offers services for organizations to create values toward solving (Winn and Pogutz, 2013). As reported by Maull *et al.* (2012), integration of systems thinking toward firm decision making can help overcome boundaries and hierarchies in management operations and processes. Therefore, system thinking plays a crucial role in organization decision making toward achieving sustainable practice.

### *2.2 SMEs and sustainable performance*

SMEs contribute immensely and importantly toward the growth of Malaysian economy at large. SMEs created increased job opportunities and increased income hence changing the lives of the population at large. Nevertheless, SMEs are becoming a major economic development catalyst to have increased Malaysia revenue in the year 2020. SMESs are considered as a key source for economic development of any nation (Umi Nadirah *et al.*, 2019).

### *2.3 Sustainable performance*

Sustainable performance of a firm includes making shareholders and customer or consumer happy and more importantly, working toward economic, social and environment benefits (Hassan *et al.*, 2018). Sustainable performance help solves critical performance issues through maintaining employee welfare, employee participation and employee freedom (Jabbour *et al.*, 2020). Sustainability help create balance protecting environment, social needs and continuous enhancement for economic values of an organization (Yadav and Gahlot, 2022).

### *2.4 Lean manufacturing practices*

LMP is a methodology which primary focus is on waste elimination (Aadithya *et al.*, 2022). Samanta *et al.* (2023) in a recent study also define LMP as a practice that focuses on reducing waste such as defects overproduction and waiting time. LMP improves product quality through waste abolishment and other non-value-added activities or procedures, that do not add-up value for any production and process.

### *2.5 Lean manufacturing practice and sustainable performance*

LMP and sustainable performance had previously been studied since they both aid on waste elimination and increasing productivity. In same vein, LMP is the one of the best techniques needed to take care of environment and social aspect of any organization (Sahoo, 2019). In sustainable performance, the integration of lean with economic, social and environmental system is important. It brings about the reduction of costs of production through dispersion of toxic compound, pollution control, improved working environment and resource efficiency (Kumar *et al.*, 2018).

## 2.6 Six sigma

Six sigma ( $6\sigma$ ) practice was initiated by Bill Smith in the 1980s by Motorola Inc. as a manufacturing technique for errors and variation reduction in products or processes.  $6\sigma$  highlights the importance of statistical methods and data analysis techniques through developing an improvement procedure in such way that variability among of goods is reduced to 99% efficacy rate (Antony *et al.*, 2017). Nevertheless,  $6\sigma$  operates a combination of structured procedures, specialists and performance metrics to achieve reduced variability and errors in production (Antony *et al.*, 2018; Sánchez-Rebull *et al.*, 2020).

## 2.7 Six sigma and sustainable performance

Few studies have recommended the benefit of implementing  $6\sigma$  for sustainable practices using quantitative techniques and structured models to solve variation problems and yield optimal product results. Similarly, Şişman (2022) in a research study affirm that  $6\sigma$  and sustainable performance have important keys to minimizing cost and maximizing cost reduction. As investigated by Siegel *et al.* (2019) in a study,  $6\sigma$  practices are widely implemented by manufacturing firms through statistical tools for the purpose of decreasing process variety to reduce production cost without affecting product quality.

## 2.8 Lean six sigma

Lean six sigma is considered as a blended methodology for the objective of waste reduction and quality improvement. Lean six sigma specifically reduces non-value-added activities, defects and wastes during production or process (Yadav *et al.*, 2018). Therefore, for total achievement of waste reduction and elimination of defect in production or process, lean six sigma is considered as a smooth methodology.

## 2.9 Industrial revolution 4.0 technologies

Industrial Revolution 4.0 technologies are digitalized manufacturing systems integrated with information technologies, production processes and several techniques. The major objective of Industrial Revolution 4.0 is to enhance firm responsiveness toward integrated manufacturing systems (Fatorachian and Kazemi, 2021). Therefore, IR 4.0 technologies manage the synchronization of data between different systems. Nevertheless, traditional methods should be replaced with innovative systems in order to meet up with IR 4.0 standards (Bag *et al.*, 2021). Nevertheless, IR technologies such as Internet of things can help enable production without waste hence meeting with customer demands. Furthermore, additive manufacturing help in the proactiveness of factory maintenance thus control energy and resources usage (Bag *et al.*, 2021).

## 2.10 Industrial revolution 4.0 technologies and sustainable performance

Industrial Revolution 4.0 technologies play a crucial role in pushing industrial and social organizations toward achieving sustainable performance (de Sousa Jabbour *et al.*, 2018). Industrial Revolution 4.0 technologies enhance the achievement of standardized process and system integration with the aim of improving sustainable practices (Kamble *et al.*, 2018). From economic dimension, the digitization and automation features of Industrial Revolution 4.0 technologies drive organizations toward the reduction in lead times, improved quality product and low manufacturing costs (Reyes *et al.*, 2021). From environmental aspect, data are gathered from several value chain partners to help manufacturing firms efficiently allocate the best materials, energy and machines. From the social perspective, IR 4.0 provide adequate chances for its employees to explore new techniques and technologies, hence

increasing employee’s motivation and morale (Kamble *et al.*, 2018). Therefore, Industrial revolution 4.0 technologies proposed a sustainable practice for the SMEs survival.

2.11 Use of IR 4.0 technologies among manufacturing SMEs

IR 4.0 tech enables production systems which provides massive amounts of data, store data, analyze data and share data. Big data analytics (BDA) refers to the collection of data with the involvement of analytical devices and computer algorithms for organization making decisions. Manufacturing firms using BDA develops their BDA capabilities by exploiting the importance of virtual manufacturing systems among manufacturing SMEs (Bhat *et al.*, 2021). Therefore, BDA contributes significantly to sustainable practices implementation among manufacturing SMEs. Hereby aiding manufacturing SMEs in keeping up with competitive advantages toward achieving sustainable performance.

In respect to smart manufacturing, automated factory operates with less human involvement, the use of sensor networks and automated guided vehicles (AGVs) for remote operations. Furthermore, the sensors monitor the working conditions, reports situation at work and trigger alarm with regards to abnormalities in production line (Al-Hakimi *et al.*, 2023). Hence, system and production engineers in manufacturing SMEs can control and guide the robots from a far.

3. Methodology

3.1 Data collection

In this study, a quantitative approach was employed and survey questionnaire was used for data collection. The data were collected from 120 SMEs for a period of 4 months across Malaysia using organization as the unit of analysis. The data were collected from SMEs’ production and operations executive, procurement executive, sales officers, quality assurance executive, research and development executive and process engineers using the six-point Likert scale questionnaire. This study employed google form whereby all questions where asterisked in order to avoid missing data. A research cover letter describing the aim of this study was distributed through emails. From this quantitative approach survey, researchers came up with research framework and three hypotheses as shown in Figure 1. On the other hand, Figure 2 shows the Research methodology flowchart.

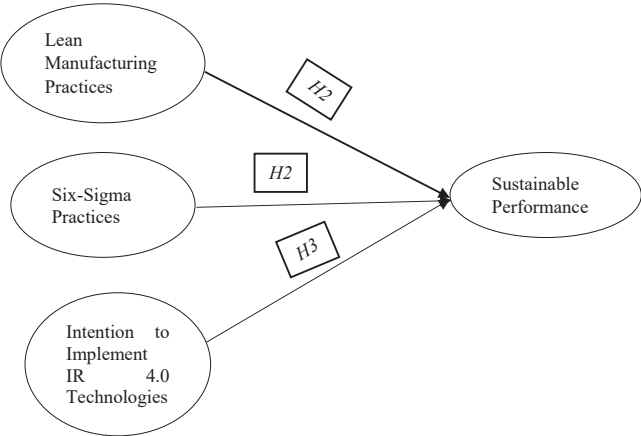


Figure 1.  
Research framework  
and hypothesis

Source(s): Author’s work

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- Conducted Literature Review Related to LMP, Six sigma, IR 4. Technologies, Sustainable Performance using Keyword Search
  - Define Research Variables (LMP, Six sigma, IR 4. Technologies, Sustainable Performance)
  - Generate Questionnaire from Reviewed Literatures and Design a Questionnaire in responds to the Literatures
  - Review of Questionnaire by Experts and Update Questionnaire Based on Experts Comments.
  - Distribute Questionnaire Cover Letter and Questionnaire to Respondents (production and operations officers, procurement officers, sales officers, quality assurance officers, R&D officers and process engineers)
  - Analyse Data using SPSS and PLS, Discuss Results and Recommend Future Study

**Source(s):** Author's work

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**Figure 2.**  
Research methodology  
flowchart

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### 3.2 Measures

Nemoto and Beglar (2014) suggested that six-point scales should be used as they permit the possibility of increased measurement precision. In this research, the selection of six-point scale is the appropriate scale due to its high measurement precision. Respondents were engaged with questionnaires which show the level of agreement using six-point Likert scale. Past studies recommended Likert scale as the best scale (Pearse, 2011). Hence, this study employed six-point Likert as the questionnaire scale from strongly disagree to strongly agree as shown in Table 1.

### 3.3 Sampling techniques

This research utilized probability sampling using simple random sampling techniques due to large number of population. In this sampling technique, each sample have the equal chance of being chosen from the target population. Random sampling selection is derived from the list of population across all manufacturing SMEs which includes food and beverages, electronics, iron and steel, aerospace, clothing and textiles, construction, health and pharmaceutical, automobile, chemical, wood and telecommunication as derived on the list of manufacturing SMEs. Therefore, there is probability of selecting among the mentioned sectors of manufacturing SMEs. The target population includes manufacturing SMEs in Malaysia (SME Corp Malaysia Directory, 2021). The population in this study includes Malaysia SMEs as derived from SMEs Directory. This study employed power analysis to determine an appropriate sample size. Priori power analysis was used to determine the appropriate sample size for the study. Sample size determination was conducted using G-power software (Faul *et al.*, 2009). Therefore, 132 sample size was derived as the minimum sample size for this study, however 120 valid responses were analyzed. It was affirmed by Kotrlik and Higgins (2001) from previous studies that population data usually achieve low response or incomplete response rate. More so, previous study suggests 120 as minimum number required for regression analysis (Robertson *et al.*, 1984).

| Construct                    | Sub dimensions                             | Cronbach alpha | Reference                           |
|------------------------------|--------------------------------------------|----------------|-------------------------------------|
| Sustainable Performance      | Economic Sustainable Performance           | 0.97           | Kamble <i>et al.</i> (2019)         |
|                              | Social Sustainable Performance             | 0.91           |                                     |
|                              | Environmental Sustainable Performance      | 0.87           |                                     |
| Lean Manufacturing Practices | Supplier Involvement                       | 0.77           | Shah and Ward (2007)                |
|                              | Supplier Development                       | 0.74           |                                     |
|                              | Customer Involvement                       | 0.85           |                                     |
|                              | Continuous Flow                            | 0.75           |                                     |
|                              | Total Preventive Maintenance               | 0.77           |                                     |
|                              | Pull System                                | 0.88           |                                     |
|                              | Statistical Process Control                | 0.86           |                                     |
|                              | Employee Involvement                       | 0.83           |                                     |
|                              | Set up Time Reduction                      | 0.75           |                                     |
| Six Sigma Practice           | Six Sigma Role Structure                   | 0.89           | García-Alcaraz <i>et al.</i> (2018) |
|                              | Six Sigma Structured Improvement Procedure | 0.89           |                                     |
|                              | Six Sigma Focus on Metrics                 | 0.89           |                                     |
| IR 4.0 Technologies          | Industrial Revolution Technologies         | 0.74           | Kamble <i>et al.</i> (2019)         |

**Table 1.**  
List of referred constructs and sub dimensions for each variable

**Source(s):** Author's work

## 4. Analysis and results

### 4.1 Reliability and validity analysis

In terms of reliability, SEM approach take measurement errors into consideration by clearly adding into its analysis. Hence, the conclusions on the relationship between the variables are similar to perfect reliability and with no bias of measurement error. As confirmed by Hair *et al.* (2012) in a study, SEM approaches are more superior to regression analyses and bivariate correlations because SEM allows simultaneous examination of causal relationships between constructs in a study. Hence, this study employed SEM approach for its quantitative analysis in order to examine causal relationship and measurement error. The selection of PLS-SEM as the quantitative analysis approach is best applicable to model development as this study developed a model for manufacturing SMEs. However, SPSS could be used as a tool for this analysis but unfortunately it won't be suitable for model development. More so, PLS-SEM is best applicable to large data size.

Reliability analysis was also employed to test measurement consistency. As affirmed in a study by Hair *et al.* (2012), reliability test is an estimation of consistency level among numerous measurements of each construct used in the study. In this regard, reliability and validity analysis of this research were buttressed in subsequent subsections.

**4.1.1 Construct and indicator reliability.** The common way of evaluating and measuring reliability among social science researchers is Cronbach alpha technique. One of the widely suggested measures for reliability analysis is composite reliability analysis (CR). In exploratory analysis, 0.7 value is least standard value for Cronbach alpha measurement (Nunnally, 1978). Majorly for all variables employed in this study, for Cronbach alpha values to be at the satisfactory level of consistency, it must be more than 0.7. Nevertheless, Nunnally and Bernstein (1994) asserted that the majority of alpha coefficient value of all constructs must be above the satisfactory level of alpha (0.70). In this research, alpha values for 16 constructs used were greater than 0.7. However, the derived values surpass the reliability requirement which indicates the instruments to be internally reliable. Besides, Jadhav *et al.* (2019) proposed that each standardized factor loadings should be at least the value of 0.5 or above 0.6. The results were shown in Table 2.

| Variable                                     | Indicators | Standardized factor loadings | Alpha value | AVE   | CR    |
|----------------------------------------------|------------|------------------------------|-------------|-------|-------|
| Economic Sustainable Performance (ESP)       | ESP1       | 0.76                         | 0.886       | 0.561 | 0.910 |
|                                              | ESP2       | 0.566                        |             |       |       |
|                                              | ESP3       | 0.779                        |             |       |       |
|                                              | ESP4       | 0.815                        |             |       |       |
|                                              | ESP5       | 0.773                        |             |       |       |
|                                              | ESP6       | 0.799                        |             |       |       |
|                                              | ESP7       | 0.722                        |             |       |       |
|                                              | ESP8       | 0.75                         |             |       |       |
| Social Sustainable Performance (SSP)         | SSP1       | 0.812                        | 0.892       | 0.650 | 0.918 |
|                                              | SSP2       | 0.854                        |             |       |       |
|                                              | SSP3       | 0.827                        |             |       |       |
|                                              | SSP4       | 0.811                        |             |       |       |
|                                              | SSP5       | 0.82                         |             |       |       |
|                                              | SSP6       | 0.708                        |             |       |       |
| Environmental Sustainable Performance (EvSP) | EvSP1      | 0.791                        | 0.862       | 0.592 | 0.897 |
|                                              | EvSP2      | 0.773                        |             |       |       |
|                                              | EvSP3      | 0.756                        |             |       |       |
|                                              | EvSP4      | 0.828                        |             |       |       |
|                                              | EvSP5      | 0.719                        |             |       |       |
|                                              | EvSP6      | 0.745                        |             |       |       |
| Supplier Involvement (SI)                    | SI1        | 0.778                        | 0.743       | 0.663 | 0.855 |
|                                              | SI2        | 0.781                        |             |       |       |
|                                              | SI3        | 0.88                         |             |       |       |
| Just in Time (JIT)                           | JIT1       | 0.851                        | 0.801       | 0.715 | 0.883 |
|                                              | JIT2       | 0.831                        |             |       |       |
|                                              | JIT3       | 0.855                        |             |       |       |
| Supplier Development (SD)                    | SD1        | 0.828                        | 0.894       | 0.654 | 0.919 |
|                                              | SD2        | 0.79                         |             |       |       |
|                                              | SD3        | 0.832                        |             |       |       |
|                                              | SD4        | 0.796                        |             |       |       |
|                                              | SD5        | 0.776                        |             |       |       |
|                                              | SD6        | 0.829                        |             |       |       |
| Customer Involvement (CI)                    | CI1        | 0.732                        | 0.797       | 0.551 | 0.86  |
|                                              | CI2        | 0.695                        |             |       |       |
|                                              | CI3        | 0.746                        |             |       |       |
|                                              | CI4        | 0.809                        |             |       |       |
|                                              | CI5        | 0.724                        |             |       |       |
| Continuous Flow (CF)                         | CF1        | 0.865                        | 0.845       | 0.683 | 0.896 |
|                                              | CF2        | 0.785                        |             |       |       |
|                                              | CF3        | 0.792                        |             |       |       |
|                                              | CF4        | 0.861                        |             |       |       |
| Pull System (PS)                             | PS1        | 0.818                        | 0.848       | 0.688 | 0.898 |
|                                              | PS2        | 0.843                        |             |       |       |
|                                              | PS3        | 0.845                        |             |       |       |
|                                              | PS4        | 0.81                         |             |       |       |
| Total Preventive Maintenance (TPM)           | TPM1       | 0.81                         | 0.812       | 0.639 | 0.876 |
|                                              | TPM2       | 0.806                        |             |       |       |
|                                              | TPM3       | 0.804                        |             |       |       |
|                                              | TPM4       | 0.779                        |             |       |       |
| Statistical Process Control (SPC)            | SPC1       | 0.834                        | 0.863       | 0.646 | 0.901 |
|                                              | SPC2       | 0.815                        |             |       |       |
|                                              | SPC3       | 0.801                        |             |       |       |
|                                              | SPC4       | 0.803                        |             |       |       |
|                                              | SPC5       | 0.763                        |             |       |       |
| Employee Involvement (EI)                    | EI1        | 0.729                        | 0.841       | 0.680 | 0.894 |
|                                              | EI2        | 0.837                        |             |       |       |
|                                              | EI3        | 0.874                        |             |       |       |
|                                              | EI4        | 0.849                        |             |       |       |
| Set up Time Reduction (STR)                  | STR1       | 0.864                        | 0.842       | 0.759 | 0.904 |
|                                              | STR2       | 0.878                        |             |       |       |
|                                              | STR3       | 0.872                        |             |       |       |

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**Table 2.**  
Measurement of  
(continued) research model results

| Variable                                         | Indicators | Standardized factor loadings | Alpha value | AVE   | CR    |
|--------------------------------------------------|------------|------------------------------|-------------|-------|-------|
| Six-Sigma Role Structure (SSR)                   | SSR1       | 0.681                        | 0.771       | 0.522 | 0.845 |
|                                                  | SSR3       | 0.755                        |             |       |       |
|                                                  | SSR4       | 0.72                         |             |       |       |
|                                                  | SSR7       | 0.741                        |             |       |       |
|                                                  | SSR8       | 0.713                        |             |       |       |
| Six-Sigma Structured Improvement Procedure (SSS) | SSS1       | 0.733                        | 0.770       | 0.522 | 0.845 |
|                                                  | SSS2       | 0.733                        |             |       |       |
|                                                  | SSS3       | 0.703                        |             |       |       |
|                                                  | SSS4       | 0.685                        |             |       |       |
|                                                  | SSS5       | 0.755                        |             |       |       |
| Six-Sigma Focus on Metrics (SSF)                 | SSF2       | 0.719                        | 0.599       | 0.556 | 0.789 |
|                                                  | SSF4       | 0.793                        |             |       |       |
|                                                  | SSF6       | 0.722                        |             |       |       |
|                                                  | IR1        | 0.812                        |             |       |       |
| Industrial Revolution 4.0 Technologies (IR)      | IR2        | 0.944                        | 0.874       | 0.606 | 0.900 |
|                                                  | IR3        | 0.917                        |             |       |       |
|                                                  | IR4        | 0.684                        |             |       |       |
|                                                  | IR5        | 0.591                        |             |       |       |
|                                                  | IR6        | 0.654                        |             |       |       |

**Table 2.** Source(s): Author's work

As seen on [Table 2](#), the factor loadings were above the minimum benchmark indicating satisfactory reliability. Therefore, the constructs are valid and supports the hypotheses.

**4.1.2 Convergent validity.** Validity of each construct refers to level in which each constructs represent theoretical intent ([Carmines and Zeller, 1979](#)). As stated by [Fornell and Larcker \(1981\)](#), the three parameters of convergent validity analysis should include: (1) factor loadings value must be more than 0.5; (2) composite reliability (CR) value should surpass 0.7; and last but not the least, the Average Variance Extracted (AVE) should surpass measurement error variance for each variable used in this study. Consequently, we employed Confirmatory Factor Analysis (CFA) to examine validity of research model. As stated by [Anderson and Gerbing \(1988\)](#) in a study, CFA majorly confirms whether theoretical model in this study attains a satisfactory fit to the data at hand. However, for each construct in this study as stated on [Table 2](#), the loadings vary between 0.92 and 0.566 meeting the minimum requirement value of 0.5. In the same vein, the values of AVE were greater than 0.5 and it ranges between 0.522 and 0.759 as shown on [Table 2](#). As discussed in the result of this study, it is concluded that the result measurement model fit without a bit of convergent validity difficulty.

**4.1.3 Discriminant validity.** As proposed by [Duarte and Restuccia \(2010\)](#), discriminant validity is the degree to which one latent construct may be distinguished from others of its kind. In the current study, discriminant validity was determined by AVE value, as Fornell and Larcker had proposed (1981). This was accomplished by examining the relationships among the latent constructs and contrasting those findings with the square roots of the average variance taken out ([Fornell and Larcker, 1981](#)). Discriminant validity was assessed using [Chin's \(1998\)](#) criterion by comparing the indicator loadings with other reflective indicators in the cross loadings table. This was done to establish whether or not the indicators were viable discriminators. The use of an AVE with a score of 0.50 or higher or higher is recommended by [Fornell and Larcker \(1981\)](#) as a rule of thumb for evaluating the discriminant validity of a test. [Fornell and Larcker \(1981\)](#) further recommend that the square root of the AVE should be bigger than the correlations across latent components in order to obtain appropriate discriminant validity. This is necessary in order to achieve adequate discriminant validity.

The Fornel-Larcker criteria of the latent constructs was compared with the square root of the average variances retrieved, as well as the Heterotrait-Monotrait Ratio, in the below Table 3. As shown below, the square roots of the average variances recovered were all higher than the correlations among the latent components, which is evidence that the discriminant validity was satisfactory.

According to Hulland (1999), discriminant validity indicates the variance between one constructs to another within measurement model. The two proposed method of revealing discriminant validity as proposed by researchers include maximum shared variance (MSV) and average variance extracted (AVE). Nevertheless, researchers affirmed that MSV need not surpass AVE and also AVE square root should not be more than inter construct correlations (Hair *et al.*, 2013). Hence, AVE square roots from the result shown on Table 4 are greater than inter construct correlations which assure that all 17 constructs in the present study are well interrelated.

Therefore, Table 4 show the correlations among 17 constructs used in this study. Nevertheless, the model measurement is reliable, well founded and set for structural model testing.

**4.1.4 Correlations.** As examined by Fowler *et al.* (2002) in a study, there is necessity for correlations testing between the constructs. Hence, the value of correlations should not surpass the value of 0.7, thus, it reveals multi-collinearity (Vogt, 2007). The correlations between variables are shown in Table 5 below.

As seen on Table 5, the results displayed significant correlations at 0.01 level of 2-tailed between 17 constructs employed in this study and the correlation coefficients were below the value of 0.7 validating no multi-collinearity issues for the constructs.

#### 4.2 Structural model and hypothesis testing

This research evaluated results using structural equation modeling (SEM) approach. Previous studies recommended at least between 100 to 150 response in order to determine a model parameters (Ding *et al.*, 1995). However, 120 substantial responses employed in this study meet up with minimum required responses. In this study, the direct impacts were investigated taking into consideration the standardized path coefficients ( $\beta$ ). As stated on Table 6, it summarized structural equation model path coefficients and *p*-value for each construct. However, two standardized constructs were found to be significant while one standardized construct was found to be insignificant and their weights are shown on Figure 3.

The result on the Table 6 highlighted a positive direct impact of LMP toward sustainable performance (0.712) and also a positive direct impact of 6 $\sigma$  toward sustainable performance. H1 and H2 was supported in this study, which implies that LMP and six sigma practices could influence sustainable performance. On the other hand, H3 was not supported in this study. It implies that the intention to implement IR 4.0 technologies does not influence sustainable performance in this study. Nevertheless, other studies supported the relationship between IR 4.0 technologies and sustainable performance. Hence, intention to implement IR 4.0 technologies was not supported in this study since it focused on only intention to implement.

| Constructs              | LMP   | Six sigma | Sustainable performance |
|-------------------------|-------|-----------|-------------------------|
| LMP                     | 0.712 |           |                         |
| Six Sigma               | 0.506 | 0.638     |                         |
| Sustainable Performance | 0.609 | 0.507     | 0.691                   |

**Source(s):** Author's work

**Table 3.**  
Discriminant validity  
(Fornel-Larcker  
criterion)

|                          | AVE   | IR 4.0 | CF    | CI    | ESP   | EI    | EVP   | SSF   | JIT   | PS    | SSS   | STR   | SS    | SSP   | SPC   | SSS   | SD    | SI    | SP    | TPM   |
|--------------------------|-------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| IR 4.0 Technologies      | 0.606 | 0.779  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|                          | 0.683 | 0.469  | 0.827 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|                          | 0.551 | 0.537  | 0.817 | 0.743 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|                          | 0.561 | 0.348  | 0.684 | 0.601 | 0.749 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|                          | 0.680 | 0.459  | 0.803 | 0.777 | 0.673 | 0.824 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|                          | 0.592 | 0.288  | 0.533 | 0.507 | 0.706 | 0.492 | 0.769 |       |       |       |       |       |       |       |       |       |       |       |       |       |
|                          | 0.556 | 0.326  | 0.448 | 0.446 | 0.370 | 0.392 | 0.421 | 0.745 |       |       |       |       |       |       |       |       |       |       |       |       |
|                          | 0.715 | 0.361  | 0.743 | 0.628 | 0.672 | 0.725 | 0.576 | 0.331 | 0.846 |       |       |       |       |       |       |       |       |       |       |       |
|                          | 0.688 | 0.455  | 0.793 | 0.729 | 0.689 | 0.795 | 0.573 | 0.397 | 0.753 | 0.829 |       |       |       |       |       |       |       |       |       |       |
|                          | 0.522 | 0.373  | 0.411 | 0.455 | 0.450 | 0.436 | 0.481 | 0.656 | 0.400 | 0.361 | 0.722 |       |       |       |       |       |       |       |       |       |
| Six-Sigma Role Structure | 0.759 | 0.504  | 0.662 | 0.706 | 0.611 | 0.708 | 0.486 | 0.399 | 0.570 | 0.694 | 0.376 | 0.871 |       |       |       |       |       |       |       |       |
|                          | 0.650 | 0.531  | 0.639 | 0.618 | 0.716 | 0.631 | 0.595 | 0.387 | 0.625 | 0.662 | 0.429 | 0.546 | 0.539 | 0.806 |       |       |       |       |       |       |
|                          | 0.646 | 0.513  | 0.830 | 0.806 | 0.708 | 0.835 | 0.584 | 0.406 | 0.715 | 0.802 | 0.406 | 0.699 | 0.569 | 0.720 | 0.804 |       |       |       |       |       |
|                          | 0.522 | 0.375  | 0.451 | 0.486 | 0.393 | 0.418 | 0.509 | 0.691 | 0.378 | 0.477 | 0.705 | 0.403 | 0.902 | 0.439 | 0.450 | 0.722 |       |       |       |       |
|                          |       |        |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|                          |       |        |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Improvement              | 0.654 | 0.513  | 0.861 | 0.801 | 0.712 | 0.839 | 0.613 | 0.389 | 0.769 | 0.844 | 0.383 | 0.722 | 0.564 | 0.716 | 0.855 | 0.449 | 0.809 |       |       |       |
|                          | 0.663 | 0.537  | 0.710 | 0.740 | 0.667 | 0.780 | 0.491 | 0.403 | 0.687 | 0.715 | 0.49  | 0.648 | 0.609 | 0.685 | 0.725 | 0.485 | 0.724 | 0.814 |       |       |
|                          | 0.639 | 0.492  | 0.759 | 0.755 | 0.658 | 0.728 | 0.543 | 0.427 | 0.633 | 0.711 | 0.379 | 0.681 | 0.555 | 0.747 | 0.790 | 0.440 | 0.764 | 0.712 | 0.738 | 0.800 |
|                          |       |        |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Source(s): Author's work |       |        |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |

|                                                                                                                       | IR 4.0 | CF    | CI    | ESP   | EI    | EvSP  | SSF   | JIT   | PS    | SSR   | STR   | SSP   | SPC   | SSS   | SD    | SI    | TPM |
|-----------------------------------------------------------------------------------------------------------------------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----|
| IR 4.0                                                                                                                | 1      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |     |
| CF                                                                                                                    | 0.464  | 1     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |     |
| CI                                                                                                                    | 0.590  | 0.992 | 1     |       |       |       |       |       |       |       |       |       |       |       |       |       |     |
| ESP                                                                                                                   | 0.362  | 0.785 | 0.702 | 1     |       |       |       |       |       |       |       |       |       |       |       |       |     |
| EI                                                                                                                    | 0.490  | 0.950 | 0.940 | 0.778 | 1     |       |       |       |       |       |       |       |       |       |       |       |     |
| EvSP                                                                                                                  | 0.316  | 0.628 | 0.616 | 0.805 | 0.578 | 1     |       |       |       |       |       |       |       |       |       |       |     |
| SSF                                                                                                                   | 0.452  | 0.632 | 0.660 | 0.511 | 0.554 | 0.592 | 1     |       |       |       |       |       |       |       |       |       |     |
| JIT                                                                                                                   | 0.393  | 0.898 | 0.776 | 0.789 | 0.885 | 0.695 | 0.483 | 1     |       |       |       |       |       |       |       |       |     |
| PS                                                                                                                    | 0.475  | 0.932 | 0.875 | 0.792 | 0.942 | 0.674 | 0.558 | 0.909 | 1     |       |       |       |       |       |       |       |     |
| SSR                                                                                                                   | 0.418  | 0.505 | 0.579 | 0.552 | 0.542 | 0.589 | 0.960 | 0.501 | 0.443 | 1     |       |       |       |       |       |       |     |
| STR                                                                                                                   | 0.573  | 0.781 | 0.854 | 0.706 | 0.840 | 0.576 | 0.561 | 0.691 | 0.819 | 0.469 | 1     |       |       |       |       |       |     |
| SSP                                                                                                                   | 0.557  | 0.731 | 0.726 | 0.798 | 0.726 | 0.676 | 0.531 | 0.734 | 0.759 | 0.515 | 0.627 | 1     |       |       |       |       |     |
| SPC                                                                                                                   | 0.522  | 0.971 | 0.960 | 0.803 | 0.981 | 0.680 | 0.562 | 0.856 | 0.936 | 0.497 | 0.818 | 0.820 | 1     |       |       |       |     |
| SSS                                                                                                                   | 0.418  | 0.559 | 0.620 | 0.485 | 0.521 | 0.630 | 0.014 | 0.481 | 0.589 | 0.915 | 0.499 | 0.529 | 0.552 | 1     |       |       |     |
| SD                                                                                                                    | 0.513  | 0.988 | 0.942 | 0.792 | 0.968 | 0.701 | 0.536 | 0.905 | 0.968 | 0.459 | 0.830 | 0.801 | 0.974 | 0.542 | 1     |       |     |
| SI                                                                                                                    | 0.621  | 0.896 | 0.960 | 0.812 | 0.988 | 0.617 | 0.602 | 0.888 | 0.901 | 0.644 | 0.818 | 0.840 | 0.906 | 0.638 | 0.888 | 1     |     |
| TPM                                                                                                                   | 0.524  | 0.914 | 0.926 | 0.767 | 0.877 | 0.651 | 0.610 | 0.778 | 0.855 | 0.48  | 0.822 | 0.874 | 0.943 | 0.557 | 0.893 | 0.918 | 1   |
| <b>Note(s):</b> *Correlation is statistically significant at 0.01 level (2-tailed)<br><b>Source(s):</b> Author's work |        |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |     |

Intention to  
implement  
IR 4.0  
technologies

Table 5.  
Correlations

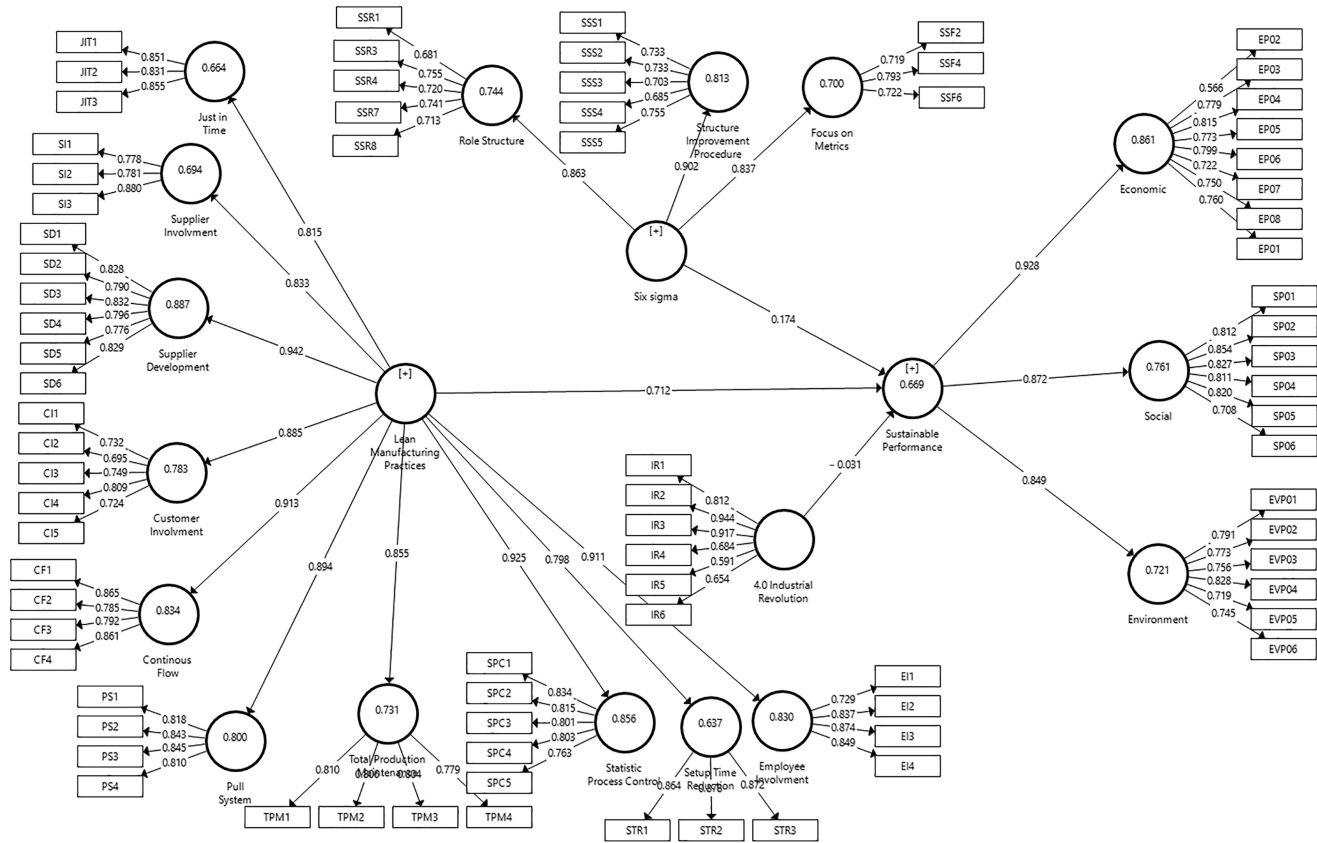
**Source(s):** Author's work

The findings of this study validate LMP and  $6\sigma$  as dominant factors influencing positively on sustainable performance as shown on Table 6. All of the manufacturing SMEs respondents implement LMP in their manufacturing activities. Hence, LMP is fully implemented among SMEs. However, the effectiveness of this implementation is not fully studied among manufacturing SMEs in Malaysia. Therefore, implementation of LMP among other manufacturing SMEs should be fully established in order to attain sustainable practice.

Only 32.5% Malaysian manufacturing SMEs have the intention to implement IR 4.0 technologies. The findings are in line with the intent to implement IR 4.0 technologies. It does not have influence on sustainable performance although the intent to implement IR 4.0 technologies among Malaysian manufacturing SMEs is still at the infant stage. In other word, SMEs in Malaysia are still in the process of adopting and integrating IR 4.0 technologies into their manufacturing practices. Thus, the study results imply that IR 4.0 technologies implementation among Malaysian manufacturing SMEs are still at infant stage but lean and 6 $\sigma$  is nothing new to the manufacturing SMEs. IR 4.0 technologies are currently implemented by large firms due to the cost of its implementation. On the hand, manufacturing SMEs have no full capacity to implement IR 4.0 technologies due to cost and its requirement for implementation. In a nutshell, lean and 6 $\sigma$  implementation is implemented by manufacturing SMEs while IR 4.0 technologies is still new to manufacturing SMEs.

Our findings support the influence of LMP and 6σ on sustainable performance through the triple bottom line perspective. However, the result demonstrates that Malaysian manufacturing SMEs cannot forsake the economic aspect of sustainable performance. Nevertheless, economic sustainable performance will help to leverage on the reduction in costs of production, inventory and purchasing raw materials. Furthermore, the results have shown environmental sustainability performance can be achieved through enhancement of the best working conditions with low work pressure for employees, improved workplace safety to advance employee wellbeing. Lastly, result of current research study has demonstrated substantially that environmental sustainability performance can be acquired fully through the reduction of waste generated from manufacturing firms, enhanced control

| Hypothesis                      |                                                           | Direct<br>( $\beta$ ) | Std<br>error | <i>T</i> -<br>value | <i>p</i> -<br>value | Result        |
|---------------------------------|-----------------------------------------------------------|-----------------------|--------------|---------------------|---------------------|---------------|
| H1                              | LMP $\rightarrow$ Sustainable Performance                 | 0.712                 | 0.079        | 8.997               | 0.000               | Supported     |
| H2                              | Six-Sigma $\rightarrow$ Sustainable Performance           | 0.174                 | 0.101        | 1.726               | 0.087               | Supported     |
| H3                              | IR 4.0 Technologies $\rightarrow$ Sustainable Performance | -0.031                | 0.086        | 0.365               | 0.716               | Not Supported |
| <b>Source(s):</b> Author's work |                                                           |                       |              |                     |                     |               |



Source(s): Author's work

**Figure 3.**  
Testing of the  
structural model

Intention to  
implement  
IR 4.0  
technologies

of sunlight at workplace and proper ventilation system. Therefore, integrating economic, social and environmental perspectives toward achieving sustainable practice is important.

According to a study by [Bhat \*et al.\* \(2021\)](#), lean six sigma (LSS) complements the implementation of LMP and six sigma by utilizing right tools and techniques in such a structured manner to eliminate waste and reduce variation hence improving sustainable performance. Therefore, integrating the implementation of LMP and six sigma aid waste elimination and reduction in variation simultaneously. Although the study by [Bhat \*et al.\* \(2021\)](#) focused on micro small medium and enterprises in India, hence, LSS was aimed at eliminating waste and reducing variation simultaneously supporting the result of this current study.

The benefit of IR 4.0 technologies implementation in the manufacturing sector cannot be overemphasized. Its importance can help to create competitive advantage over other competitors. Therefore, the benefit of implementing and integrating advance technologies into manufacturing practices is majorly key and essential to achieve sustainable goals among manufacturing firms. Arguably, IR 4.0 technologies help in the enhancement of the production. IR 4.0 technologies also provide solutions to organizations, offers optimized production and also facilitate the growth of business, however, the aim of these solutions rendered is to act as catalyst toward competing with competitors in this manufacturing firms, hence supporting economic, environmental and social performance.

Furthermore, there is need to create awareness about the application of IR 4.0 technologies suitable for Malaysian manufacturing SMEs in order to remain sustainable for local and foreign competitors. Malaysia as a developing nation, manufacturing SMEs contributed about 41% to Malaysia GDP ([Rusly \*et al.\*, 2020](#)). On the same vein, manufacturing SMEs contribute majorly to the economic growth of any developing nation. Hence, it could be generalized to other developing nations since SMEs are considered to key contributor to economic growth. The role of IR 4.0 technologies in the implementation of LMP and 6 $\sigma$  cannot be overemphasized. In order for Malaysian manufacturing SMEs to attain substantial sustainable practice status, there is need to fully implement LMP and 6 $\sigma$  for proper waste and defect reduction. Nevertheless, the awareness of IR 4.0 technologies implementation should be created among Malaysian manufacturing SMEs.

## 6. Conclusions and recommendation

### 6.1 Concluding remarks

It is concluded that the implementation of LMP and 6 $\sigma$  have an impact on sustainable performance. It is crucial that other SMEs in Malaysia implements either LMP or 6 $\sigma$  in their manufacturing processes, hence supports sustainable performance. Failure to implement may result poor performance among Malaysian manufacturing SMEs. Therefore, implementation of LMP or 6 $\sigma$  helps manufacturing SMEs to remain sustainable. This research has revealed the extent of implementation of LMP and 6 $\sigma$  among Malaysian manufacturing SMEs. In a nutshell, present research study deduced that Malaysian manufacturing SMEs are fully familiarize with LMP implementation. Nevertheless, 6 $\sigma$  implementation is not fully familiarized by Malaysian manufacturing SMEs at large.

In a similar vein, intention to implement IR 4.0 technologies among Malaysian manufacturing SMEs is still at an infant stage. Currently, Malaysian manufacturing SMEs do not see the importance of IR 4.0 technologies. Therefore, there is an urgent need to create the awareness about the importance of IR 4.0 technologies implementation in Malaysian manufacturing SMEs. Thus, the importance of application of IR 4.0 technologies toward achieving sustainable practice cannot be overemphasized in the manufacturing sector. In other words, integrating IR 4.0 technologies into LMP and 6 $\sigma$  implementation can help upgrade SMEs manufacturing practices. Hence, awareness about achieving sustainable performance through the IR 4.0 technologies should be created among Malaysian manufacturing SMEs.

Nevertheless, literature has shown relationships between LMP, 6σ, IR 4.0 technologies constructs toward sustainable performance. This study also revealed that both LMP and 6σ can be optimized by the reduction of error; defect, though, where to address change initiatives. It also identifies issues in LMP and 6σ implementation may be addressed by using suitable technologies. Therefore, sustainability issues can be solved through the implementation of LMP, 6σ and integration of IR 4.0 technologies into manufacturing practices.

Furthermore, there are several challenges encountered through implementation of IR 4.0 technologies in LSS practice. Several challenges toward implementing IR 4.0 in LSS were highlighted in a study by Bakos *et al.* (2020). These challenges include lack of knowledge about IR 4.0 technologies, poor innovative ideas among employees and lack of funding among LSS implementer. Other challenges among SMEs include limited resources, resistance to change among employees and organization size. Manufacturing SMEs need to strategize on how they can embark on the adoption and implementation of IR 4.0 technologies. Hence, manufacturing SMEs need to create a progressive mindset among its employees before they can embark on implementation of IR 4.0 Technologies.

Few studies on concentrated on several sectors in developing nations, however, this study focus on manufacturing SMEs in Malaysia. Antony *et al.* (2023) in a study explore LMP and six sigma methodologies among national health service (NHS) considering its benefits and critical factors. Antony *et al.* (2023) concluded in their study that continuous improvement practice is an established part of NHS's operations. NHS professionals considered lean six sigma practices as the one of the most effective methodology for continuous improvement. Specifically, this current study focused on manufacturing SMEs toward achieving sustainable performance through the implementation of lean and six sigma practices.

Even though this study explored Malaysian manufacturing SMEs, LSS guideline has the potential to be implemented by all manufacturing SMEs throughout the world according to their country's manufacturing SMEs condition. This will promote LSS among other SMEs in other nations as it need minor modifications based on countries. Hence, this will definitely promote LSS researchers and LSS practices throughout the world.

There is need to consider the similarities and differences between LMP and six sigma practices. These similarities and differences will also provide a better scenario to understand the practices that are of importance and of no importance to SMEs. The similarities between these practices can be combined to integrate a hybrid practice that can be suitable for manufacturing SMEs sustainability. Is a hybrid lean Six-Sigma implementation important for Malaysian manufacturing SMEs competitiveness or sustainability? In a nutshell, considering the similarities between LMP and 6σ, there might be need to hybrid both practices together by considering part of the practice that are not relevant to manufacturing SMEs. Nevertheless, there is need for Malaysian manufacturing SMEs to adopt technologically-inclined practices for growth and survival of the firm both locally and internationally.

## 6.2 Theoretical and managerial implications

System thinking theory as an underpinning theory in this research explains how the implementation of LMP and 6σ affect the organizational system. Basically, system thinking presents a possible solution to business organizations. It provides a more holistic approach to investigate role of management within social, economic and environmental system. In other words, the system thinking approach is method use to understand importance of social, economic and environmental systems in an organization.

From the perspective of system theory, there is an interconnection network across each department in a whole system. There is also a connection between social, economic and

environmental performance where the influence of sustainable practice affects all the factors. More so, sustainable practice can continuously change and improve the system in any organization. Therefore, achieving cost reduction, conducive environment and reduced pollution through economic, social and environmental sustainable practices respectively can also help to improve the organization system. On the other hand, there is need for an organizational system to be sustainably influenced in order to influence organizational decision. However, the decision in choosing the right manufacturing practice might influence the whole system in the organization. Therefore, sustainable practice plays a vital role in managing and improving interconnected systems in an organization.

When we talk about IR 4.0 technologies implementation, there will be need to talk about digitalization and technology transformation in order to know how new technologies can be play effective role both in adoption and implementation. Therefore, with digital transformation, it is very important for firms to adapt their business strategy toward new technology and majorly the adaptation is for the purpose of process and operations. Specifically, this digitalization allows organizations to use data derived from production and service for product and process improvement.

#### *6.3 Researchers, practitioners and policy makers implications*

SME managers and practitioners may also utilize the outcome of this study to get an overview of Lean Six Sigma (LSS) practice to progress deeper details of this implementation. This implementation may aid to effectively sustain businesses on its own. Furthermore, this study motivates manufacturing SMEs managers and practitioners to identify feasible hotspots that need instant attention to enhance the sustainability of manufacturing firms. Researchers contributes more to the body of knowledge in regards to lean six sigma practices among manufacturing SMEs. Researcher help explore more on the usage of system theory toward sustainable performance among manufacturing SMEs.

From the view of SMEs policy makers, this study should be use to encourage SMEs to adopt technologically inclined practices. Accordingly, this research recommends government bodies to help support the implementation of sustainable practices due to their sizes and inadequate resources involved. Therefore, the role of government in providing suitable policies that could be beneficial to manufacturing SMEs toward achieving sustainable practices cannot be overlooked. Through proper government support, Malaysian manufacturing SMEs will be able to survive both locally and internationally and also gain competitive advantage.

#### *6.4 Future research direction*

Although, the result of the study also provides the implication of theory and influence on managerial aspect, research limitations and a future research domain. Firstly, the implementation of LMP and 6 $\sigma$  can both be examined through an integrated approach in other nations for future research and can present a deep reflection on manufacturing SMEs sustainable performance. Secondly, to broaden current study scope and have a complex and novel model, a larger scale of manufacturing SMEs in Malaysia may be employed. Future study could explore qualitative methodological approach in order to have more in-depth view about this study. Nevertheless, a mixed methodological approach is encouraged.

#### *6.5 Limitations*

This study focused majorly on manufacturing SMEs leaving out service sector. This is due to current challenges being faced by manufacturing firms in the process of transforming into a technology inclined. Additionally, the model of this study focused on Malaysian manufacturing SMEs however, future study might explore other nations.

## References

- Aadithya, B.G., Asokan, P. and Vinodh, S. (2022), "Lean manufacturing in fabrication industry: literature review and framework proposal", *International Journal of Quality and Reliability Management*, Vol. 40 No. 6, pp. 1485-1517.
- Al-Hakimi, M.A., Goail, M.M., Al-Hattami, H.M., Murshid, M.A., Saleh, M.H. and Moghalles, S.A.M. (2023), "Improving operational performance of manufacturing SMEs: the interactive effect of technical and human lean practices", *International Journal of Quality and Reliability Management*, Vol. 40 No. 4, pp. 1092-1110.
- Anderson, J. and Gerbing, W. (1988), "Structural equation modelling in practice: a review and recommended two stage approach", *Psychological bulletin*, Vol. 27 No. 1, pp. 5-24.
- Antony, J., Snee, R. and Hoerl, R. (2017), "Lean Six Sigma: yesterday, today and tomorrow", *International Journal of Quality and Reliability Management*, Vol. 34 No. 7, pp. 1073-1093.
- Antony, J., Lancaster, J., McDermott, O., Bhat, S., Parida, R. and Cudney, E.A. (2023), "An evaluation of Lean and Six Sigma methodologies in the national health service", *International Journal of Quality and Reliability Management*, Vol. 40 No. 1, pp. 25-52, doi: [10.1108/IJQRM-05-2021-0140](https://doi.org/10.1108/IJQRM-05-2021-0140).
- Antony, J., Palsuk, P., Gupta, S., Mishra, D. and Barach, P. (2018), "Six Sigma in healthcare: a systematic review of the literature", *International Journal of Quality and Reliability Management*, Vol. 35 No. 5, pp. 1075-1092.
- Bag, S., Yadav, G., Dhamija, P. and Kataria, K.K. (2021), "Key resources for industry 4.0 adoption and its effect on sustainable production and circular economy: an empirical study", *Journal of Cleaner Production*, Vol. 281, 125233.
- Bakos, J., Siu, M., Orengo, A. and Kasiri, N. (2020), "An analysis of environmental sustainability in small & medium-sized enterprises: patterns and trends", *Business Strategy and The Environment*, Vol. 29 No. 3, pp. 1285-1296.
- Bhat, V.S., Bhat, S. and Gijo, E.V. (2021), "Simulation-based lean six sigma for Industry 4.0: an action research in the process industry", *International Journal of Quality and Reliability Management*, Vol. 38 No. 5, pp. 1215-1245.
- Carmines, E.G. and Zeller, R.A. (1979), *Reliability and Validity Assessment*, SAGE Publications, OH.
- Chin, W.W. (1998), "The partial least squares approach to structural equation modeling", *Modern Methods for Business Research*, Vol. 295 No. 2, pp. 295-336.
- de Sousa Jabbour, A.B.L., Jabbour, C.J.C., Foropon, C. and Godinho Filho, M. (2018), "When titans meet – can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors", *Technological Forecasting and Social Change*, Vol. 132, pp. 18-25.
- Ding, L., Velicer, W. and Harlow, L. (1995), "Effect of estimation methods, number of indicators per factor and improper solutions on structural equation modeling fit indices", *Structural Equation Modeling: A Multidisciplinary Journal*, Vol. 2, pp. 119-143.
- Duarte, M. and Restuccia, D. (2010), "The role of the structural transformation in aggregate productivity", *The Quarterly Journal of Economics*, Vol. 125 No. 1, pp. 129-173.
- Ehrenfeld, J.R. (2012), "Beyond the brave new world: business for sustainability", in Bansal, P. and Hoffman, A.J. (Eds), *Oxford Handbook of Business and the Natural Environment*, Oxford University Press, Oxford, pp. 611-619.
- Fatorachian, H. and Kazemi, H. (2021), "Impact of Industry 4.0 on supply chain performance", *Production Planning and Control*, Vol. 32 No. 1, pp. 63-81.
- Faul, F., Erdfelder, E., Buchner, A. and Lang, A.G. (2009), "Statistical power analyses using G\*Power 3.1: tests for correlation and regression analyses", *Behavior Research Methods*, Vol. 41 No. 4, pp. 1149-1160.
- Fornell, C. and Larcker, D.F. (1981), "Evaluating structural equation models with unobservable variables and measurement error", *Journal of Marketing Research*, Vol. 18 No. 1, pp. 29-50.

- 
- Fowler, J., Jarvis, P. and Chevannes, M. (2002), *Practical Statistics for Nursing and Health Care*, John Wiley & Sons, West Sussex.
- García-Alcaraz, J.L., Alor-Hernández, G., Sánchez-Ramírez, C., Jiménez-Macías, E., Blanco-Fernández, J. and Latorre-Biel, J.I. (2018), "Mediating role of the Six Sigma implementation strategy and investment in human resources in economic success and sustainability", *Sustainability*, Vol. 10 No. 6, p. 1828.
- Gaziulusoy, İ., Boyle, C. and McDowall, R. (2013), "System innovation for sustainability: a systemic double-flow scenario method for companies", *Journal of Cleaner Production*, Vol. 45, pp. 104-116.
- Hair, J.F., Sarstedt, M., Ringle, C.M. and Mena, J.A. (2012), "An assessment of the use of partial least squares structural equation modeling in marketing research", *Journal of the Academy of Marketing Science*, Vol. 40 No. 3, pp. 414-433.
- Hair, J.F., Ringle, C.M. and Sarstedt, M. (2013), "Partial least squares structural equation modeling: rigorous applications, better results and higher acceptance", *Long Range Planning*, Vol. 46 Nos 1-2, pp. 1-12.
- Hassan, M.G., Akanmu, M.D. and Yusoff, R.Z. (2018), "Technological integration and sustainable performance in manufacturing firms", *International Journal of Technology*, Vol. 9 No. 8, pp. 1639-1650.
- Hulland, J. (1999), "Use of partial least squares (PLS) in strategic management research: a review of four recent studies", *Strategic Management Journal*, Vol. 20 No. 2, pp. 195-204.
- Jabbour, A.B.L.D.S., Song, M. and Godinho Filho, M. (2020), "Sustainability implications for operations management: building the bridge through exemplar case studies", *Production Planning and Control*, Vol. 31 Nos 11-12, pp. 841-844.
- Jadhav, A., Orr, S. and Malik, M. (2019), "The role of supply chain orientation in achieving supply chain sustainability", *International Journal Production Economics*, Vol. 217, pp. 112-125.
- Kamble, S.S., Gunasekaran, A. and Gawankar, S.A. (2018), "Sustainable Industry 4.0 framework: a systematic literature review identifying the current trends and future perspectives", *Process Safety and Environmental Protection*, Vol. 117, pp. 408-425.
- Kamble, S., Gunasekaran, A. and Dhone, N.C. (2019), "Industry 4.0 and lean manufacturing practices for sustainable organizational performance in Indian manufacturing companies", *International Journal of Production Research*, Vol. 58 No. 5, pp. 1319-1337.
- Khattak, M.S. (2020), "Does access to domestic finance and international finance contribute to sustainable development goals? Implications for policymakers", *Journal of Public Affairs*, Vol. 20 No. 2, p. e2024.
- Kotrlík, J.W.K.J.W. and Higgins, C.C.H.C.C. (2001), "Organizational research: determining appropriate sample size in survey research appropriate sample size in survey research", *Information Technology, Learning, and Performance Journal*, Vol. 19 No. 1, p. 43.
- Kumar, P., Maiti, J. and Gunasekaran, A. (2018), "Impact of quality management systems on firm performance", *International Journal of Quality and Reliability Management*, Vol. 35 No. 5, pp. 1034-1059.
- Mauil, M., Gerdali, J. and Johnston, R. (2012), "Service supply chain: a customer perspective", *Journal of Supply Chain Management*, Vol. 48 No. 4, pp. 72-86.
- Nemoto, T. and Beglar, D. (2014), "Developing likert-scale questionnaires", in Sonda, N. and Krause, A. (Eds), *JALT2013 Conference Proceedings*, JALT, Tokyo.
- Nunnally, J.C. (1978), "An overview of psychological measurement", in *Clinical Diagnosis of Mental Disorders*, Springer, Boston, MA, pp. 97-146.
- Nunnally, J.C. and Bernstein, I.H. (1994), *Psychometric Theory*, McGraw-Hill, New York, The role of university in the development of entrepreneurial vocations: a Spanish study.
- Papadopoulos, T., Singh, S.P., Spanaki, K., Gunasekaran, A. and Dubey, R. (2021), "Towards the next generation of manufacturing: implications of big data and digitalization in the context of industry 4.0", *Production Planning and Control*, Vol. 33, pp. 101-104.

- 
- Pearse, N. (2011), "Deciding on the scale granularity of response categories of Likert type scales: the case of a 21-point scale", *Electronic Journal of Business Research Methods*, Vol. 9 No. 2, pp. 159-171.
- Podsakoff, P.M. and Organ, D.W. (1986), "Self-reports in organizational research: problems and prospects", *Journal of Management*, Vol. 12 No. 4, pp. 531-544.
- Prashar, A. (2021), "Eco-efficient production for industrial small and medium-sized enterprises through energy optimisation: framework and evaluation", *Production Planning and Control*, Vol. 32 No. 3, pp. 198-212.
- Reyes, J., Mula, J. and Díaz-Madroñero, M. (2021), "Development of a conceptual model for lean supply chain planning in industry 4.0: multidimensional analysis for operations management", *Production Planning and Control*, pp. 1-16.
- Robertson, J.L., Smith, K.C., Savin, N.E. and Lavigne, R.J. (1984), "Effects of dose selection and sample size on the precision of lethal dose estimates in dose-mortality regression", *Journal of Economic Entomology*, Vol. 77 No. 4, pp. 833-837.
- Rusly, F.H., Taliba, Y.Y.A., Abd Mutaliba, H. and Hussina, M.R.A. (2020), "Developing a digital adaptation model for Malaysian manufacturing SMEs", *Proceedings of the 4th UUM International Qualitative Research Conference (QRC 2020)*, Vol. 1, p. 3.
- Sánchez-Rebull, M.V., Ferrer-Rullan, R., Hernández-Lara, A.B. and Niñerola, A. (2020), "Six Sigma for improving cash flow deficit: a case study in the food can manufacturing industry", *International Journal of Lean Six Sigma*, Vol. 11 No. 6, pp. 1105-1126.
- Sahoo, S. (2019), "Lean manufacturing practices and performance: the role of social and technical factors", *International Journal of Quality and Reliability Management*, Vol. 37 No. 5, pp. 732-754.
- Samanta, M., Virmani, N., Singh, R.K., Haque, S.N. and Jamshed, M. (2023 In press), "Analysis of critical success factors for successful integration of lean six sigma and Industry 4.0 for organizational excellence", *The TQM Journal*.
- Shah, R. and Ward, P.T. (2007), "Defining and developing measures of lean production", *Journal of Operations Management*, Vol. 25 No. 4, pp. 785-805.
- Siegel, R., Antony, J., Garza-reyes, J.A., Cherra, A. and Lameijer, B. (2019), "Integrated green lean approach and sustainability for SMEs: from literature review to a conceptual framework", *Journal of Clean Production*, Vol. 240, pp. 118-205.
- Şişman, G. (2022), "Implementing lean six sigma methodology to reduce the logistics cost: a case study in Turkey", *International Journal of Lean Six Sigma*, Vol. 14 No. 3, pp. 610-629.
- SME Corp Malaysia Directory (2021), "Permohonan untuk mendapatkan senarai syarikat dalam Industri Kecil dan Sederhana (IKS)", *SME Corp Official Website*, available at: <https://www.smecorp.gov.my> (accessed 20th of October 2021).
- Umi Nadirah, Y., Nolila, M.N., Nitty Hirawaty, K. and Norsida, M. (2019), "Implementation of sustainable practices among food and beverage SMEs in peninsular Malaysia", *International Journal of Agriculture, Environment and Bioresearch*, Vol. 4 No. 5, pp. 143-161.
- Vogt, W.P. (2007), *Quantitative Research Methods for Professionals*, Pearson, Boston.
- Winn, M.I. and Pogutz, S. (2013), "Business, ecosystems, and biodiversity: new horizons for management research", *Organization and Environment*, Vol. 26 No. 2, pp. 203-229.
- Yadav, V. and Gahlot, P. (2022), "Green Lean Six Sigma sustainability-oriented framework for small and medium enterprises", *International Journal of Quality and Reliability Management*, Vol. 39 No. 7, pp. 1787-1807.
- Yadav, G., Seth, D. and Desai, T.N. (2018), "Application of hybrid framework to facilitate lean six sigma implementation: a manufacturing company case experience", *Production Planning and Control*, Vol. 29 No. 3, pp. 185-201.

Yadav, G., Luthra, S., Jakhar, S.K., Mangla, S.K. and Rai, D.P. (2020), "A framework to overcome sustainable supply chain challenges through solution measures of industry 4.0 and circular economy: an automotive case", *Journal of Cleaner Production*, Vol. 254, 120112.

**Further reading**

Bhat, S., Gijo, E.V., Rego, A.M. and Bhat, V.S. (2021), "Lean Six Sigma competitiveness for micro, small and medium enterprises (MSME): an action research in the Indian context", *The TQM Journal*, Vol. 33 No. 2, pp. 379-406.

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