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A Model for Manufacturing Sustainability in Manufacturing Operations

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ABSTRACT: This Economically, environmentally, and societally are the integrated three pillars of sustainability. Thus, it is important for manufacturing companies to recognise the elements of sustainability in their operations. To this date, there is still a lack of studies on the fundamental elements of sustainability in the context of manufacturing operations. Therefore, this study aims to develop a model of MS in manufacturing operations. A thorough statistical analysis on literature review of sustainability that is relevant to manufacturing operations was done in order to determine the fundamental elements of MS. Pareto 80-20 rule was applied in determining the most significant fundamental elements of MS. As a result, a model of MS has been developed based on the concept of Input-Output system (I-O system) in manufacturing that consist of three major paths: (i) Input, (ii) Process, and, (iii) Output. Here, the fundamental elements of MS are categorised by the major path. In this case, the fundamental elements are divided into four different paths: (i) Sustainability Drivers as the input, (ii) Sustainability Enablers and (iii) Sustainability Measures as the process/operation, and (iv) Sustainability Impacts as the output.

KEYWORDS: Fundamental element, Manufacturing, Operation, Sustainability.

1. INTRODUCTION

In today's industrial development, sustainability is an important requirement for manufacturing companies. Therefore, sustainable development is part of the key objectives of companies' missions that drives improvement in competitive edge. The adoption of sustainable manufacturing practices is a viable option in addressing the production concerns [1].

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Earlier, Rosen and Kishawy [2] clarified that recognition of the relationship between manufacturing operations and the natural environment plays an important role in the decision-making of the industrial societies. The need for growth and development in the rapidly changing industry nowadays has brought about a number of studies related to the development of sustainable manufacturing companies [3, 4, 5].
However, there is still a dearth of understanding of the factors that can contribute to MS. Thus, understanding the definition and the concept of sustainability is crucial in order to clarify the factors that can be presented as the fundamental elements of MS in the context of manufacturing operations. Schroeder [6] describes manufacturing operations as a transformation system (or process) that converts inputs into outputs.

Hence, the purpose of this paper is to highlight the understanding of MS through the development a model of sustainability in the context of manufacturing operations. The model consists of fundamental elements of sustainability which manufacturing companies should understand and acquire in order to have sustainable operations.

This paper consists of four major parts; (i) Literature review, (ii) Methodology, (iii) Result and discussion, and (iv) Conclusion. The highlight point from this paper is the proposed integration model between responsiveness and sustainability.

2. LITERATURE REVIEW

This section is divided into two parts; definition of sustainability and existing models of sustainability. It is crucial to understand the definition of sustainability in different views through the literature study. The existing models of sustainability are studied thoroughly in order to focus on manufacturing operation.

1.1 DEFINITION OF SUSTAINABILITY

The World society, and (iii) a sound economy. Diesendorf [8] is of the view that the definition emphasises the long-term aspect of sustainability concept and also introduces the ethical principle of achieving equity between present and future

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generations. Due to these reasons, the definition has been widely cited until today. From the definition by WCED, sustainability consists of three pillars that are environmental, economic, and the social.Commission on Environment and Development (WCED) [7] defined sustainable development as development that meets the needs of the present generations without compromising the ability of the future generations to meet their own needs. The definition embeds 'own needs' into three main aspects: (i) environment, (ii) economy, and (iii) social.

Environmental sustainability has been defined as a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing the biological diversity [9-10]. In the context of social sustainability, there are two aspects: (i) as a positive condition within communities and (ii) as a process within communities that can achieve a life-enhancing condition [11]. Thus, social sustainability considers how individuals, communities, and societies live with each other in harmony. From an economic standpoint, Foy [12] states that sustainability requires the current economic activities to be proportionately balanced and not a burden to the future generations.

In manufacturing industry, the concept of sustainability has been adopted and known as sustainable manufacturing or sustainable production. O'Brien [13] determines that sustainable production is mainly concerned with resources, energy, material, waste, and emissions. He also claims that economic sustainability in manufacturing companies occurs when they have a preferred percentage of their production below their preferred minimum operating cost standard level. Kopac [14] defines sustainable production as the creation of goods and services, using processes and systems that are non-polluting, conserving energy and natural resources, economically viable, socially and creatively rewarding for all working people, and safe and healthful for employees.Mukherjee and Mukherjee [15] believe that optimal use of material and human resources for the long term is the key to the success of the concept of sustainable manufacturing goals.

Hence, this paper defines MS as the resilience of systems and processes in manufacturing operations that leads to a healthy environment, employee welfare, and firm economy. In this regard, reliance on the three pillars of sustainability is actually crucial for the survival of manufacturing companies to compete in the dynamic and rapidly changing marketplace.

EXISTING MODELS OF SUSTAINABILITY

To date, only a handful of sustainability models have been developed in the manufacturing environment. For instance, Liyanage [16] proposes a model of production and manufacturing assets to streamline Operation and Management performance from a sustainability perspective. The model describes drivers of corporate social performance, actions that managers can take to achieve certain level of performance and the consequences of those actions on corporate, social and financial performances in a company. Meanwhile, Koho et al. [17] developed models for sustainable development. Both models emphasise the concept of sustainable development and the factors required in the manufacturing industry. Pham and Thomas [5] introduced a model of sustainable manufacturing operations for determining the manufacturing fitness. A model of sustainable manufacturing systems and manufacturing processes was developed by Haapala et al. [18] to observe interactions between the manufacturing systems.

Although numerous sustainable conceptual models have been developed, there is still lacking a model that focus on manufacturing operations. Manufacturing on relevant topics such as sustainable development, cleaner production, and sustainable operation is the backbone of a manufacturing company. Therefore, it is important for companies to maintain manufacturing operations in order to justify their existence.

3. METHODOLOGY

This study consists of four stages. In the first stage, the objective of literature study is to determine the fundamental elements and the components for MS. In this study, A minimum of 50 articles must be reviewed in this literature study manufacturing. The analysis is done by using Pareto's 80/20 rule to select the significant components of MS.

In the second stage, a model of MS is developed based on the concept of I-O system in manufacturing. The basic concept of I-O system is applied since manufacturing operations need inputs to produce outputs. Thus, the model consists of three major paths: (i) Input, (ii) Operations/Processes, and (iii) Output. Then, the fundamental elements of MS are categorized based on the three major paths.

In the third stage, the developed model is verified by industrialist through surveys and interviews. Here, a total of 30 surveys and 5 interviews are targeted for the sample size, as the process is time-consuming and it is fairly difficult to get hold of the right personnel of

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these companies. The targeted individuals interviewed include directors, managers, engineers and other managerial staff who are experts in the manufacturing operations. The questionnaire is divided into five sections as follows: (i)Respondent profiles, (ii)Sustainability drivers, (iii) Sustainability enablers, (iv)Sustainability measures, and (v) Sustainability impacts.

In the final stage, the developed model is improved based on the verified results. Model improvement is the finalisation of the components of the fundamental elements for MS. The results are analysed using the majority rule. Majority rule is referred to as a decision rule that chooses an alternative which has a majority, that is, more than half of the votes [19].

Thus, finalisation of the components of the fundamental elements are based on three conditions as follows: (i) If ≥ 50% of respondents agree, the proposed fundamental elements and their components will remain in the model; (ii) If ≥ 50% of respondents partly agree, the proposed fundamental elements and their components will be improved in terms of their descriptions; and (iii) If ≥ 50% of respondents disagree, the proposed fundamental elements and their components will be taken out from the model.

4. RESULT AND DISCUSSION

A total 62 relevant journals on MS are thoroughly studied to determine the components of the fundamental elements for MS. The main components are determined using the Pareto's 80/20 rule. Example of the results of the analysis is shown in Figure 2. The components are grouped with the fundamental elements accordingly into the same category based on their similarities in descriptions.

Based on the results, customers, supplier, competitors, and laws and regulations are the sustainability driver as these components drive the companies to be sustainable. Meanwhile, there are four components of sustainability enabler which are categorised based on their ability to enable the companies' sustainability process: (i) metrics to quantify sustainability, (ii) top management awareness and support, (iii) awareness towards sustainable practices, and (iv) collaborative relationships.

The components of sustainability's Measure are determined as the following: (i) energy consumption, (ii) emission/pollution, (iii) production waste, (iv) safety and health, (v) production cost, (vi) profit, and (vii) employee's education/training. These are based on their characteristics to measure sustainability performance in the companies' operations.

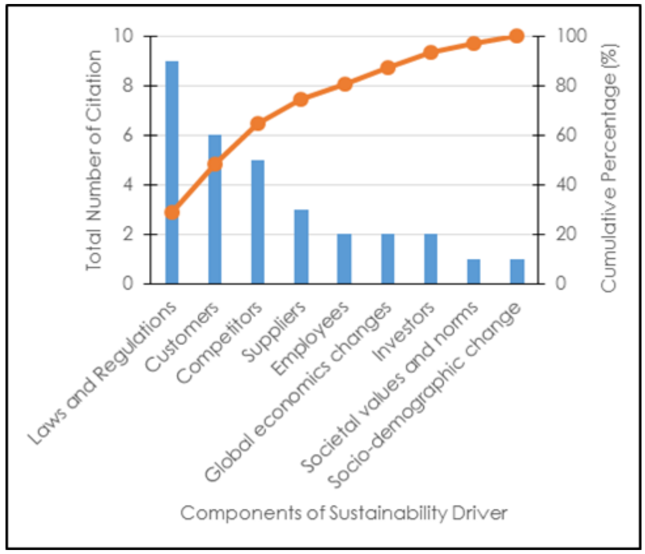

Figure 2: Pareto Diagram for the Components of Sustainability

The components' sustainability impact and components of sustainability are based on the strong effects on the companies when they perform sustainable manufacturing operations which are grouped into three areas: (i) sustainable economy, (ii) sustainable environment, and (iii) sustainable society. Table 1(a) presents the descriptions of each component ofMS fundamental elements that is sustainabilitydriver. Customer, Suppliers, Competitors, and Laws & Regulation are the inputs for the sustainability system. In this regard, manufacturing companies have to determine their customer demand pattern, reliability of their suppliers, challenges made by their competitors and also the changes in laws and regulations that relevant to their industry. Table 1(b) presents another fundamental element of MS that is sustainability enabler.

There are four components of sustainability enabler; (i) Top management where their commitment and support is necessary, (ii) Collaborative relationships is needed in order to build ability to collaborate with other segments (i.e. purchasing, production, engineering, etc.) in the companies, (iii) Metrics in quantifying sustainability is required for monitoring the level of company sustainability, and (iv) awareness on sustainable practices is important in order to ensure the sustainability of the company. Table 1(c) shows the components of fundamental element for sustainability that is sustainability measure.

There are six components for sustainability measures; (i) Production cost refers to the total

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Sustainability Measure

Components	Descriptions	Authors
Production cost	Total costs of production.	[4], [21], [23], [46], [55], [56], [57], [58]
Profit	Profits of companies.	[3], [55], [59], [60]
Emission/ Pollution	Total emission or pollution produced by production.	[2], [9], [21], [23], [46], [55], [56], [57], [58], [60], [61]
Production waste	Total production waste.	[4], [21], [23], [55], [56], [57], [58], [60], [61], [62], [63]
Employee's Education/ Training	Total training provided to employees.	[4], [9], [23], [56], [62], [64]
Energy Consumption	Consumption of energy or power.	[2], [4], [9], [21], [23], [26], [46], [55], [56], [57], [58], [61], [60], [63]
Employee's Education/ Training	Total training provided to employees.	[4], [9], [23], [56], [62], [64]

production cost, (ii) Profit refers to net profit of company, (iii) The total emission/pollution resulted from company's operations, and (iv) Wastes produced by production of company, (v) Energy consumption that mostly refers to electricity, and (vi) Employee's education that can be measured through total training provided to the employee. Table 1 (d) presents the forth fundamental element of sustainability that is sustainability impact. Sustainability impacts represent the outputs of sustainability inputs, sustainability enablers, and sustainability measures.

Table 1(a): Descriptions of sustainability components (Driver)

Sustainability Driver

Components	Descriptions	Authors
Customers	Customer demand patterns have driven companies to be sustainable.	[16], [26], [35], [36], [37][38]
Suppliers	Reliable suppliers have driven companies to be sustainable.	[26], [35], [36]
Competitors	Challenges from the competitors have driven companies to be sustainable.	[4], [17], [26], [35], [36]
Laws and Regulations	Local laws and regulations are barriers to companies from being sustainable.	[4], [16], [17], [26], [35][36], [37], [38], [39]

Table 1(b): Descriptions of sustainability components (Enabler)

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	Components	Descriptions	Authors
Sustainability Enabler	Top management commitment and support	Sustainability needs for good top management commitment and support to establish highly sustainable companies.	[17], [20], [28], [40], [41], [42]
	Collaborative relationships	Sustainability needs for the ability to collaborate with other segments in the companies.	[41], [43], [44], [45]
	Metrics to quantify sustainability	Sustainability needs for the ability to quantify the sustainability metrics to check the sustainability level.	[3], [20], [46], [47], [48], [49], [50]
	Awareness towards sustainable practices	Sustainability needs for ability to be aware of the sustainable practices	[34], [51], [52], [53], [54]

Table 1(c): Descriptions of sustainability components (Measure)

	Components	Descriptions	Authors
Sustainability Impact	Sustainable economy	Being sustainable will increase sustainable economy of companies that correspond to: Economic growth Competitive advantage Decrease in manufacturing cost Increase in profitability Improvement of company image	[4], [20], [34], [58], [63], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76], [77]
	Sustainable environment	Being sustainable will increase sustainable environment of companies that correspond to: Low environmental impacts Improved product quality	[4], [26], [58], [63], [69], [74], [78], [71], [79]
	Sustainable society	Being sustainable will increase sustainable society of companies that correspond to: Maximisation of customer satisfaction Improvement of safety and health of employees	[34], [63], [71], [74], [75], [80]

Table 1(d): Descriptions of sustainability components (Impact)

The sustainability impacts refer to the three pillars of sustainability; Economy, Environment, and Social [81]. In the context of economy, sustainable economy of manufacturing company relies of

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its economic growth, manufacturing costs, profit, competitive advantages, and reputation. Sustainable environment of manufacturing companies refers to low environmental impact (i.e. emission/pollution) and improved product quality that brings to reduction in production wastes. Sustainable social indicated through customer satisfaction and a good safety and health of the employee [82].

Figure 3 presents a model of MS developed through the basic concept of I-O system in the context of manufacturing operations [83]. The developed model consists of three major paths represents the fundamental elements and its components which are: (i) Input, (ii) Operations/Processes, and (iii) Output.

5. CONCLUSION

The developed model of MS presents the concept of manufacturing sustainability that consists of fundamental elements and its components. In this regard, there are four fundamental elements in the model: (i) sustainability driver as the input, (ii) sustainability enabler as the processes, (iii) sustainability measure also part of the processes, and (iv)sustainability impact as the output. This study determines the components for each fundamental element that needed for manufacturing company to achieve MS. Hence, this paper proposes a model of MS as shown in Figure 3. Future research will focus on the integration between the main components of MS and the main components of manufacturing responsiveness (MR) in the context of manufacturing operations.

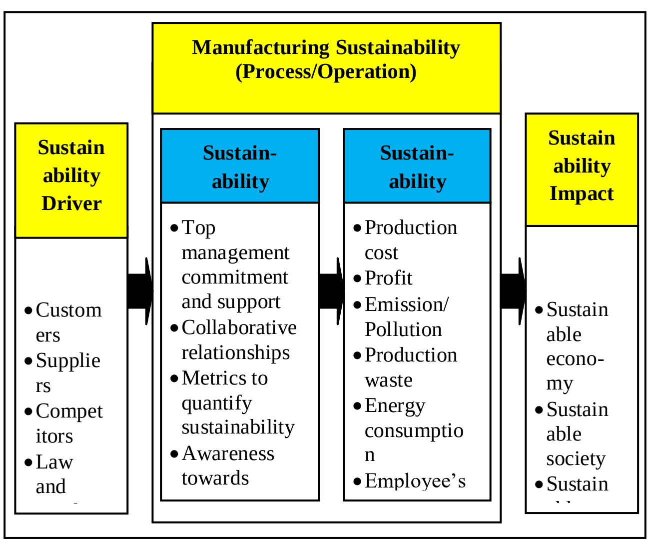

Figure 3: A Model of Manufacturing Sustainability

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