A Review of Sustainable Maintenance in the Manufacturing Companies

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***Abstract*— Owing to the incorporation of sustainability in most organizational activities and processes, their integration into maintenance activities has become a necessity in manufacturing companies. By supporting the implementation of sustainable manufacturing practices, sustainable maintenance will help in improving the sustainability performance of manufacturing companies. The purpose of this study is to review the previous studies related to sustainable maintenance (SMa) in the manufacturing sector in developed and developing countries. Performing content analysis with various past studies conducted in developed and developing countries with several research settings, this study classified SMa into four dimensions that are technical dimension, economic dimension, environmental dimension, and social and safety dimension. Most of the studies in SMa were conducted using qualitative research design especially case studies while the quantitative studies were still lacking. Besides, the studies more focus on large manufacturing companies compared to Small and Medium Enterprises (SMEs), especially in Malaysia. Therefore, this study presented a research direction on studying the effect of SMa on the sustainability performance of manufacturing SMEs in Malaysia.**

***Keywords*—** *Maintenance, sustainable maintenance, sustainability performance, manufacturing, SMEs*

1. Introduction

Maintenance is one of the critical components of an organizational structure in most of the companies. Regardless of the industrial types and products being produced, all industrial companies have technical resources including machines and equipment that need maintenance [1]. Similarly, according to Graisa [2], maintenance is a vital function of every system necessary to operate efficiently. Besides, the timing of the maintenance is dependent on the company's plans and policies; it may take place before production, during production, after production, weekends, or specific period determined by the company [3]. Also, maintenance is multi-disciplinary and involves many functional levels such as managers, supervisors, engineers, technicians, operators, and others [4].

The issue of sustainability has become a topic of great interest to researchers and practitioners [5] both in developed and developing countries. This is because it leads to customer, shareholder, and community satisfaction [6]. Sustainable maintenance (SMa) has arisen because of increased community awareness and social and safety pressures. Besides, the shift in the manufacturing paradigm to sustainable manufacturing necessitating a change towards SMa [7]. Likewise, the maintenance system gradually develops based on the manufacturing system [8]. Thus, companies need to give attention to SMa because they consider the social and safety dimension in addition to technical, economic, and environmental dimensions.

Numerous published studies in maintenance focused on the single dimension of maintenance such as technical dimension [e.g., 9, 10], and an economic dimension (also called lean maintenance) that emphasized on the maintenance costs reduction and the elimination of waste [e.g., 11, 12, 13]. Various past studies also have focused on green maintenance that studied both economic and environmental dimensions of maintenance [e.g. 14, 15, 16]. Meanwhile, the extant literature always

neglected the social and safety dimension of maintenance and played down the importance of SMa [17].

Extant literature also rarely considered altogether the four dimensions of maintenance that are economic, technical, environmental, and social and safety [18]. Amrina and Aridharma [19] pointed to the need to study on SMa. Zhang, Kim [20] stressed that the literature on SMa is the most limited. Similarly, Ararsa [21] noted that studies on SMa are still in infancy. Consequently, there is still a need to study SMa with its four dimensions: technical, economic, environmental, and social and safety.

Previous studies have reported that the prominence of the majority of the research work on SMa in several industries by developed economies such as United Kingdom [e.g., 22], Poland [e.g., 23], United States of America [e.g., 24], France [e.g., 25] and Italy [e.g., 26]. In addition to some developing countries such as Malaysia [e.g., 27], Korea [e.g., 28], Indonesia [e.g., 19], Hong Kong [e.g. 29], Nigeria [e.g., 17] and Morocco [e.g., 30]. Moreover, these studies have been conducted in different industries. However, to the best of the researcher's knowledge, there is no study on SMa performed in Malaysia in the manufacturing Small and Medium Enterprises (SMEs). Therefore, the aim of this research consists of two parts. First, review the previous studies related to SMa of the four technical, economic, environmental and social and safety dimensions in developed and developing countries. Second, suggest research direction About the new area of research for issues related to SMa implementation.

2. Literature Review

2.1 An Overview of Maintenance

There are contradictory views among many researchers about the feasibility of maintenance. Traditionally, over the past decades, the negative perspective of maintenance has been as a “necessary evil” [31] and source of cost [32]. Nonetheless, over time, academicians and practitioners changed their idea about the maintenance and its role [33]. The negative perspective has gradually been replaced by developing a perspective that maintenance plays a significant role in the progress of the company and achieves its objectives [1]. This role is that maintenance contributes to achieving profitability [31]. In the same way, several researchers and practitioners emphasised that maintenance omission or inefficiency lead to high losses for the company [32]. This is because measuring the efficiency and effectiveness of maintenance justifies investment in it [34]. Therefore, achieve efficiency and effectiveness of maintenance is a necessary action.

Over the years, the significance of maintenance function has grown widely (Garg & Deshmukh, 2006). Also, it has become a core function in companies (Stuchly & Jasiulewicz-Kaczmarek, 2014) and it is essential in various industries (Al-Turki, Ayar, Yilbas, & Sahin, 2014). The maintenance is important because it offers various benefits including eliminate equipment failure, prolong asset life and reduce work injuries (Iqbal, Tesfamariam, Haider, & Sadiq, 2017), minimise equipment downtime (Kurniati, Yeh, & Lin, 2015), improve the efficiency and productivity of equipment (Duran, Capaldo, & Acevedo, 2017), ensuring continuity of system assets (Telford, Mazhar, & Howard, 2011), increase the availability of equipment (Iqbal et al., 2017) and creating value for internal and external stakeholders (Malgorzata Jasiulewicz-Kaczmarek, 2014).

Overall, there is a significant agreement on the definition of maintenance. Maintenance is defined as “the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function” [35]. British Standards Institution defined maintenance as “combination of all technical and administrative actions, including supervisory actions, intended to retain an item in, or restore it to, a state in which it can perform a required function” [36]. The current study is more consistent with the first definition which focused on “the life cycle of an item”. It is because they are too comprehensive and fully compatible with sustainable manufacturing practices from the point of view of the product lifecycle. Likewise, specifically in the context of sustainable manufacturing, maintenance is carried out on both industrial equipment that incorporate all manufacturing process requirements and industrial products that include maintenance activities at all stages of the product lifecycle [37].

In addition, in the context of manufacturing, maintenance management can be defined as "the process of directing maintenance organisation effectively by utilizing administrative, human, financial, and material resources in an efficient and effective way through planning, scheduling, executing and monitoring their own progress for continuous improvement" [1]. Maintenance management is an essential function especially for companies that use large and numerous machinery and equipment [38].

2.2 Sustainable Maintenance (SMa)

These days, it is essential for academicians and practitioners to focus not only on the technical aspect of maintenance activities but as an integrated set of technical, economic, environmental, and social dimensions [39]. This is because the maintenance activities and breakdowns in industrial companies result in harmful emissions, waste, dangerous accidents, and consumption of energy and resources [40, 41]. The adoption of SMa by companies will make a significant difference in the economic, environmental, social and safety, and technical [42]. Likewise, besides the economic and environmental dimensions, SMa included social and safety dimension and worked to achieve a balance among these three dimensions [43]. Companies that interest in sustainable manufacturing face a new challenge in their implementation of SMa [44]. This is because of the complexity of manufacturing practices and processes [45], the need to make changes in policies and procedures of maintenance, attention to environmental and social and safety aspects as well as financial aspects [46], competition pressure in manufacturing [47] and the government regulations towards sustainable development in manufacturing [48]. However, in recent years, changes in manufacturing paradigms have forced companies and managers to recognize the changing role of maintenance regards sustainability [49]. In recent years, the importance of incorporating sustainability into maintenance function has been recognized [27]. This is due to it provides lost costs and energy consumed during the product lifecycle [50]. Therefore, companies that adopt a sustainability approach in their business must implement SMa.

Jasiulewicz-Kaczmarek [51] defined SMa "as proactive maintenance operations striving for providing balance in social (welfare and satisfaction of operators and maintenance staff), environmental and financial (losses, consequences, benefits) dimensions". Whereas, this study defined SMa as "all maintenance activities that support the sustainability of the company, through the reduction of environmental impact, the safety and social and safety welfare of employees, the implementation of technical factors at the highest possible level and reducing maintenance costs" [52].

The implementation of SMa effectively cannot be achieved without specifying the dimensions required for it. Most researchers agreed that SMa could be measured by sustainable dimensions of economic, environmental and social and safety [43]. Amrina and Aridharma [19], Jasiulewicz-Kaczmarek [43] emphasised that these three dimensions are interrelated and that any variation in the aims of one of them leads to a massive impact in the other dimensions. However, many researchers stressed that the effectiveness and efficiency of SMa come through adopting the technical dimension in addition to the three dimensions of sustainability [17, 48]. Therefore, SMa involves four dimensions: the technical dimension, the economic dimension, the environmental dimension and the social and safety dimension.

In a nutshell, SMa consists of four dimensions: the technical dimension, the economic dimension, the environmental dimension, and the social and safety dimension. The successful implementation of the SMa is achieved by considering all these dimensions in the implementation of maintenance activities, and not to overlook any dimension of those dimensions, because it can be negatively reflected on other dimensions during implementation.

2.3 Maintenance Interaction with Production and Operations

Although most manufacturers consider maintenance to be an essential part of production activities [53], maintenance has become an integral function rather than a sub-function of the production function [33]. These days, with a highly competitive environment, the integration of maintenance and production has received increasing interest from researchers [54]. Zhao,

Wang [55] reported that decisions on maintenance and production independently as known to academicians and practitioners did not result in a comprehensive improvement in performance. However, planning and proper coordination in maintenance and operations decisions are crucial [45]. Accordingly, Tsutsui and Takata [56] in their study of oil refineries in Japan, emphasised that maintenance planning should be carried out by taking into account the interaction between maintenance and operations. In this regard, the maintenance function works in parallel with the production function [32]. This parallelism creates a state of cooperation between production and maintenance, which in turn leads to improve quantity and quality of products, people safety and environmental factors [57]. Likewise, from the view of leanness, Blanco and Dederichs [58] asserted that achieving better performance to production depends on coordination with the maintenance function. Therefore, to ensure the success of the production function should pay attention to its integration with the maintenance function.

Many case studies have explained that maintenance interacted with production and operations and supported them positively, as shown in Table 1. For instance, Aghezzaf and Najid [59] advanced a mathematical model that integrates production planning with preventive maintenance. The researchers proved the workability of the model in achieving integration. Moreover, Ayed, Sofiene [60] studied the issue of how production rate and demand uncertainty is appropriately managed by analysing production and maintenance policies. They have presented an optimal production plan that reduces machine degradation, production costs and costs of inventory and maintenance. Beheshti-Fakher, Nourelfath [61] investigated the integrated planning of production, maintenance and quality in degraded systems. The researchers established a numerical model in which the costs of the maintenance and production system were reduced.

Besides, Biondi, Sand [62] developed a model that integrates maintenance and production scheduling for process plants. The model has been validated in achieving integration. Bouslah, Gharbi [63] developed a mathematical model based on simulation modeling. From the model, the production and inventory levels were improved and the total costs were reduced by up to 20%. Dellagi, Dellagi, Chelbi [64] examined a model for the integration of maintenance and production policy by controlling production rates. The study concluded that the proposed method achieved well. Furthermore, there are other studies on the interaction and integration of decisions and policies of scheduling maintenance and production operations [e.g. 65, 66, 67].

Table 1. Summary of the Case Studies about Interaction of Maintenance with Production and Operations

Author (Year)	Contribution	Variables	Result
Aghezzaf and Najid [59]	Model	Production planning; Preventive maintenance	Proved the workability of the model in achieving integration.
Ayed, Sofiene [60]	Model	Maintenance policies; Production policies	Presented an optimal production plan that reduces machine degradation, production costs, and costs of inventory and maintenance.
Beheshti-Fakher, Nourelfath [61]	Model	Planning of production; Maintenance	Established a numerical model in which the costs of the maintenance and production system were reduced.
Biondi, Sand [62]	Model	Maintenance; Production scheduling	The model has been validated in achieving integration.
Bouslah, Gharbi [63]	Model	Production; Maintenance of deteriorating production systems	They achieved through their model improved production and inventory levels and reduced total costs by up to 20%.
Dellagi, Chelbi [64]	Model	Production policy; Maintenance policy	Concluded that the proposed method achieved well.

2.4 Benefits of Sustainable Maintenance

The SMa of equipment and assets is of great importance [68]. This importance emerged from its significant impact on the material, costs, energy and stakeholders in the company [69]. Also, an essential contributor to improve the sustainability of companies [70]. Consequently, it is crucial to implement SMa in the company [19]. Significantly, SMa offers many benefits for companies. These benefits include a decrease in overall operational costs [48], increase the profitability and productivity of the company [71] and reduce energy consumption and resources during product life cycles [72]. Moreover, reducing environmental impacts [72], reducing life-cycle costs and the promotion of economic and social and safety well-being [72]. Besides, the safety of personnel and disposal of waste [1]. There are many studies in the literature that prove the outputs achieved from implementing SMa as shown in Table 2.

Table 2. Summary of the Case Studies Related to Benefits of Sustainable Maintenance

Author (Year)	Contribution	Context	Country	Result
Zhang, Kim [20]	Model	Port infrastructures	Japan	Used of technology in equipment maintenance has positive effects on all of sustainability performance dimensions.
Mahmood, Abdullah [73]	Model	Manufacturing firms	Malaysia	The implementation of maintenance and overall equipment effectiveness has a positive impact on economic development and the protection of the environment and social welfare.
Chiang, Zhou [74]	Model	Residential buildings	Hong Kong	Used seven scenarios as contributing to the improvement of economic, social, and environmental sustainability objectives.
Chiang, Li [29]	Methodology	Residential buildings	Hong Kong	Used green technology in the maintenance would improve the economic, environmental, and social aspects.
Amrina and Aridharma [19]	Model	Cement industry	Indonesia	Achieved the best sustainable performance and high competitiveness.
Sodangi, Khamdi [75]	Criteria	Heritage buildings	Malaysia	Achieved environmental sustainability.

Table 2 shows empirical studies on maintenance literature and its relationship with sustainability performance. All these studies used mathematical models excluding Miidom, Nwuche [76]. Most of the studies were conducted in East Asian countries. Although Miidom, Nwuche [76] investigated maintenance and sustainability performance and used the quantitative method in the oil and gas industry, the sample included only five companies and did not address SMa. Based on the discussion and the arguments in the above, SMa has a significant positive relationship with the economic, environmental, and social sustainability of companies.

3. Discussion and Research Direction

Based on the extensive review of previous studies related to SMa and its benefits, most studies were case studies and mathematical models were used. The results of these studies were mainly dependent on the outputs of these models. Therefore, it is clear that there is a lack of previous studies in investigating SMa using the quantitative method. Nowadays, SMa is an important and contemporary research agenda for researchers and practitioners[77]. Also, it gained great importance in large companies in developed countries [78].

Nevertheless, studies are still limited to investigate the adoption and implementation of SMa in developing countries, especially manufacturing SMEs in Malaysia. Therefore, the research agenda will be on manufacturing SMEs in the context of Malaysia to contribute to the extension of research literature for SMa in more depth and determine the extent of their impact on the performance of sustainability. Indeed, the reason for choosing manufacturing SMEs in Malaysia is because they contribute significantly to GDP, employment, exports, and added value. For instance, in 2017, SMEs made up 98.5% of total establishments [79], 37.1 of GDP, 66% of total employment, and 17.3% of total exports, it was the largest proportion from the manufacturing sector [80]. Further, value-added grew to 5.5% [81]. The research direction of the current study is presented in Figure 1.

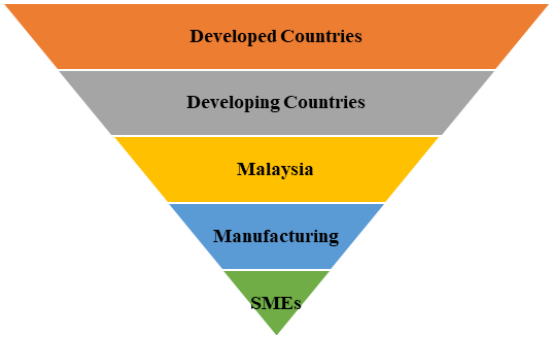

Figure 1. Research direction

4. Conclusion

The present paper provides a review of previous studies related to SMa and produces future research directions in this regard. Although previous studies in the literature, which were mostly case studies, addressed the topic of SMa in developed and some developing countries, there is still a need to investigate the topic in manufacturing SMEs in Malaysia. Especially since a study like this will contribute to enriching literature by enhancing researchers' understanding of SMa and its impact on the performance of sustainability. In addition, it will contribute to raising awareness among practitioners about measuring and determining the extent of implementing SMa in their companies in a manner consistent with achieving the fourth strategic thrust in "Eleventh Malaysia Plan" (11th MP) emphasized the pursuit of economic, environmental and social sustainability through the adoption of the concept of sustainable consumption and production via all sectors and households [82].

Acknowledgments

The authors wish to thank the Ministry of Higher Education Malaysia in funding this study under the Fundamental Research Grant Scheme (FRGS), S/O code 14385, and Research and Innovation Management Centre, Universiti Utara Malaysia, Kedah for the administration of this study.

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