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Sustainability Considerations in Manufacturing and Operation Management

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Abstract

Operation managers and engineers are now faced with new challenges in integrating issues of sustainability in to the production system, perhaps they are often worried by the question "How can we design and manufacture more sustainable products?" The aim of this study is to provide a holistic appraisal of sustainability in manufacturing, giving its background definitions and current issues and approaches on how to develop sustainable products with a lowest environmental impact as possible. To do that special considerations are given to triple bottom line (3BL), recycling, design for environmental (DfE) ISO14001 standard, Environmental Management System and Standards (EMS) and life cycle assessment. While reviewing the previous studies on sustainable manufacturing, this paper proposes a more robust structure of interlinked pillars of sustainability to offer appropriate options to the manufacturing systems that can answer the question of how to develop and manufacture more sustainable products.

Keywords: Sustainability, sustainable manufacturing, Sustainable product.

1. Background

The study on sustainability has advanced over the years and authors have defined sustainability in different ways. Earliest definition of sustainability was found to be given by a report published by the World Commission on Environment and Development (WCED) in 1987. The report featured sustainability as: "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" [1]. Later on, various definitions have emerged over the past two decades which steered an on-going debate on the actual meaning of sustainability. Regardless of the contest, a few common principles tend to be emphasized. [2] The first is a commitment to equity and fairness (prioritizing improving the conditions of the world's poorest and accounting for the rights of future generations). The second is a long-term view that emphasizes the precautionary principle. And the third, sustainable development embodies integration, and understanding and acting on the complex interconnections that exist between the environment, economy, and society. Advancement in the Academic and corporate interest in sustainability has risen considerably in recent years. This can be seen by the number of papers published and in particular by journal special issues.

2. Sustainable manufacturing: Definition

There are numerous definitions and descriptions for sustainable manufacturing. However, almost all such definitions are showing interconnectivity between certain pillars that emphasis equitability, bearable and sustainability. In his argument on the definition of sustainability, [3] opined that sustainability definition should reflect on the need for dynamic efficiency and total welfare. He maintained that policy in this regard should include the concept of 'non-wastefulness' and represent consumption of goods and services. Contributing to this argument, [4] deduced that, the future of sustainable manufacturing is to manufacture products that are completely recyclable and its manufacturing process has no or less detrimental effects upon the environment. To achieve sustainable production while maintaining /or improving the product and process quality, [5] stressed that each of these three integral elements highlighted by [2] is expected to demonstrate:

i. Reduced negative environmental impact,
ii. Offer improved energy and resource efficiency
iii. Minimum quantity of waste generate
iv. Adequate provide operational safety, and
v. offer improved personal health

The integrated definition of sustainable manufacturing is focusing on product, process and system levels must ultimately enable sustainable value creation for all stakeholders taking account of the dependencies between the producer, the consumer as well as the product/service and the wider social and natural environment.

3. Development of sustainable manufacturing

While companies advanced their core capabilities, the future of Earth and the populace that are within or outside the companies are factors that are made important. As stakeholder deliberate the criticality of cost and benefits of sustainable regulations, it is viewed that sustainable development and sustainable regulations can provide aggressive return for companies, such as better employees performance, cost savings (conserve energy and reduce waste), and improved relations with stakeholders and

increase sales and revenues. [6] Adding to this, [7] present a case of canvassing for regulations by companies because they have developed an environmentally friendly technology and believe that regulations requiring their technology would give them a competitive advantage. On societal demand and expectations, [8] found that many companies have introduced a variety of sustainable development enthusiasm to attend to the prospects of the society. They further established that sustainability strives to address ecological goals by creating a proper balance between economic and social aims. Sustaining shareholder value and prestige, expanding economic growth, corporate reputation, customer relationships, and improving the quality of products and services are further identified as contributors to making businesses more profitable. The onus here is, throughout the world community pressure and the treat to liability have been demanding enhanced and holistic execution on sustainability. The question for companies has become not whether to commit to a strong environmental, health, and safety record, but how to do so in the most cost-effective manner [7]. In an attempt to provide solution to the lingering contempt of environmentally conscious manufacturing and production, we must enlarge our perspective in Production Operation Management POM, to include invest in sustainable technologies, operations, and supply chains.

4. Sustainable manufacturing paradigm

Manufacturing in a simple term can refer to production of essential commodities and services that are necessary for maintaining the quality of human life and development of the economy. In actuality, the scope of manufacturing is further than production, it involve all the kinds of services in manufacturing chain that defines the heart of industrial economies. Emphasizing on the role of manufacturing in wealth generation and societal well-being [5] believed that the national economy of any country heavily depends on the manufacturing capacity and the diversity of products and processes developed for its population, and for marketing to other nations. This assertion is proven by the critical role played by the manufacturing sector of the developed and developing nations in job creation, societal well-being and national economic advancement. The above nexus clearly show the influence of manufacturing on the economy and the society, but when we look at the aftermath of manufacturing on the environment in light of huge energy consumption in raw materials processing as well as emission of harmful gases necessitate that sustainable manufacturing has to do also with the environment. [9] Assessed the manufacturing system of printed circuit board industries, considering the need for design for environment (DfE) in order to achieve the goal of generating less waste and emission. The contribution of [10] has opened a product development approach that consolidates the environmental requirement in every stage of product life cycle. Reviewing the characteristics of sustainable manufacturing system, [11] focused on Achieving sustainability in manufacturing. He emphasis that enhancing sustainability in manufacturing sector requires a comprehensive analysis that is not limited to the product design and the manufacturing routes involved in its fabrication, but also the entire manufacturing systems. All discussion presented above relates to the gospel preached by [12] where he emphasis the three dimension of sustainability: environmental, social and economical, otherwise known as the triple bottom line (TBL). The principle is also known as the three pillars; profit, planet and people received a wide acceptance in sustainability discuss figure 1. As stated by [13] The Triple Bottom Line is a concept that brings together three important dimensions: the economic; the social and the environmental. These three dimensions are important in addressing sustainability in business operations.

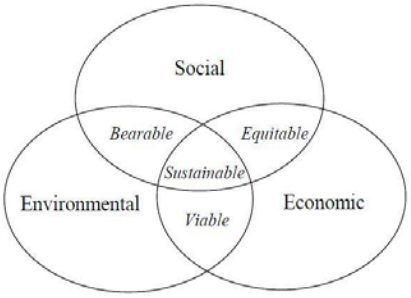

Fig 1 The three pillars of sustainability (TBL) Adopted from [11]

Other researchers [14-16] consider technology as a compassionate dimension in sustainable manufacturing. They advocated that technology be considered as a component of sustainable manufacturing model. Their argument proved that technology has the ability to positively influence the socials, environmental and economical components of sustainable manufacturing. [5] Reiterates that, sustainable manufacturing must be based on the strength of partnership among the major participants. The societal and environmental benefits, along with the economic gains, are achievable with this strategic partnership, which brings in education and technology as the major linkage. [17] Added that, education must no longer be seen as an end, but the means to generate sustainable value. The need to disseminate knowledge skills and know-how to facilitate sustainable manufacturing as well as more sustainable consumption patterns are identified as one of the core-requirements for reorienting educational needs not only in developing countries, but also in developed regions of the world. [16]

In their effort toward improving sustainable manufacturing, [4] argued that ethical and accountability are essential enablers to environmental progress and sustainability. They further proposes a new frame work for

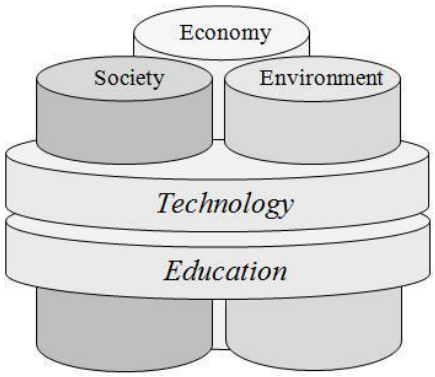

Fig 2 Technology and Education facilitating sustainable manufacturing [16]

sustainable manufacturing development and advocate that only highly educated people can apply technology with ethical and accountability for more productive solution to sustainable problems. Social ethics ensure manufacturing on the moral dimensions and accountability ensures that manufacturing companies are accountable to the social and environmental concerns.

5. Current issues and trends in sustainable manufacturing

The resultant continuous and increasing awareness and the need for sustainable products and processes are demanding a robust engineering and sustainability principles for societal, economic and environmental benefits. [14] Reviewed the current methods of sustainable product development and identified four basic problems which are endemic to sustainable manufacturing as:

- Over-consumption
- Resource utilization
- Pollution
- Over population

He argued that overconsumption in the area of energy, packaging and transportation has a serious impact in the long run. [15] Established that machine tools used in manufacturing system utilized enormous amount of energy. He therefore upheld that understanding and characterizing task-oriented energy consumption is significantly essential to explore the potential on energy-saving. [16] Established that in the 2010's the energy consumed in the manufacturing sector is up to 50% the entire energy in the world. In addition to this, [17] emphasis that the energy efficiency of machine tools is below 30%. Supporting the afore mentioned, [18] made a summation that manufacturing is responsible for above 38% of the direct and indirect Co emission worldwide. The paradox here is at what level or stage of manufacturing exactly is this high energy consumption happening? An answer to this surfaces from the work of [19] which explain that a huge unsustainable impact of manufacturing comes from the operational phase which include pollution, and waste. Examples of such industries that generate high amount of waste are metal industries, refining/recycling, painting or chemical and food industries. Going by the above discussion, it is imperative therefore, to note that even though manufacturing is not the prime handler of sustainability, the fact and figures warrants holistic strategies for manufacturing operations to contribute to global sustainability. Such strategies should be in the broader sustainability perspective, to cover the entire production system. [5] Lamented that strategy for global sustainability would require full understanding of the total life-cycle effects involving innovative methods for products, processes and systems of manufacturing. Similarly, [11] emphasis that to make manufacturing more sustainable, sustainability issues at all relevant levels of product, process, and system must also consider. This inter connectivity can be simplified as in figure 3.

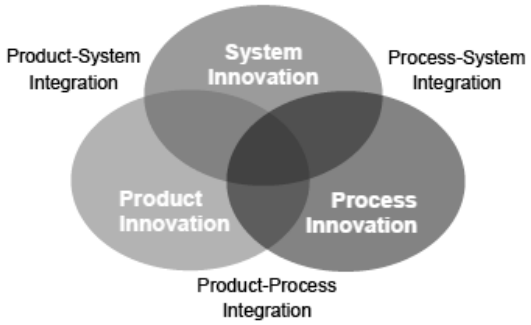

Fig 3 Integrated product, process and system levels

The approach is focusing on product, the process and system levels by eventually guaranteeing sustainable value creation for all stakeholders taking account of the dependencies between the producer, the consumer as well as the product/service and the wider social and natural environment.

6. Holistic and integrated approach to sustainability manufacturing

The holistic and integrated sustainable manufacturing is a unique and innovative approach away from the traditional manufacturing approach. The traditional manufacturing practices where the quality and performance characteristics are measured and quantified independently, often with no consideration of the effects of other integral elements. The holistic and integrated approach is a modified integrated manufacturing approach which is known to be based on concurrent engineering, but the

there is adequate interdisciplinary coordination. The territorial boundaries and responsibilities with varying reporting structures of team members is broken such that there is a free crossing of boundaries in order to work together for achieving a common objectives with total commitment. In a nutshell this approach enables innovation in sustainable manufacturing. [5] Advocates that the innovation derived must enable developing a value system for sustainable manufacturing with abundant value-contributing factors focusing on product, process and system levels: as described in the figure 4 below.

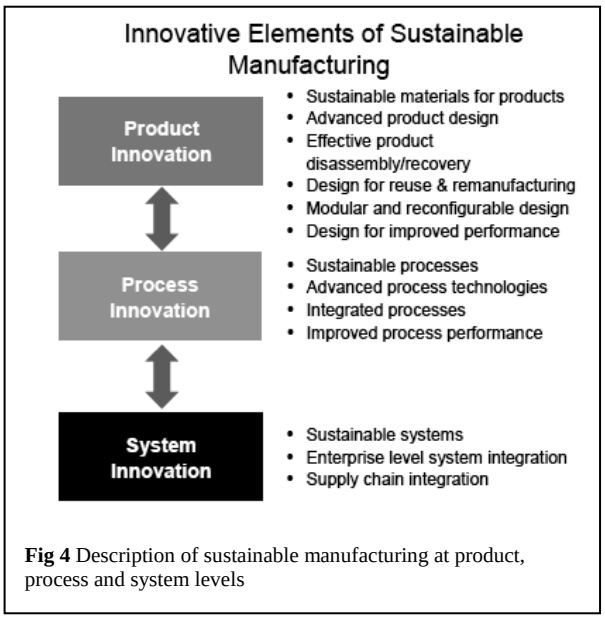

Fig 4 Description of sustainable manufacturing at product, process and system levels

Since there is many value-contributing factors in product, process and system levels of sustainable manufacturing, products design and manufacturing processes must consider these production stages using a more innovative approach, that can enable us make an all-inclusive systems model to cover products, processes and systems.

6.1 Product Sustainability

Many approaches were applied in definitions of sustainable product, but most definitions of sustainable products showed a mixture of understanding among researchers on whether or not the world is a sustainable system by existence. For example the simple definition that said a sustainable product is a product, which will give as little impact on the environment as possible during its life cycle. The definition here has three main issues that are not clearly defined such as

- The quantity of impact (of the product) on the environment
- The description or measure of the impact
- The total life cycle (raw material processing, manufacturing, utilization and recycling).

It is expected that a good sustainable product must be able to provide as much satisfaction as possible for the consumer. Therefore, a good strategy required that when launching sustainable products to the market, people should be enlightened to the reasons and criterion a product must meet to be sustainable or not [14].

6.2 Product sustainability evaluation

It is reasonable to consider comprehensive evaluation of product sustainability to obtain analytical and scientific analysis of product sustainability. Environmental, economic and societal effects of products, functionality, manufacturability and reusability are important factors to consider. In a study on sustainable product evaluation, [20] present a framework for a comprehensive total life-cycle evaluation matrix for product that shows the following six product sustainability elements

i. Environmental Impact
ii. Societal Impact (Safety, Health, Ethics, etc.)
iii. Functionality
iv. Resource Utilization and Economy
v. Manufacturability
vi. Product's Recyclability/Remanufacturability

The study further advocate full study of these interacting elements and sub-elements effects on product sustainability. Triple Bottom Line (TBL) proposed by John Elkington is known as a framework for rating corporate performance alongside economic, social and environmental parameters [12]. The TBL concept involves environmental protection, social equity and economic growth [21]. In new product development for sustainability, [14] advised to follow a harmonic move between the three spot of the bottom line in order to obtain a suitable equilibrium to fulfill each category in the best way.

Fig 5 Relationship between the three spots of bottom line

6.3 Process Sustainability

Sustainability evaluation of manufacturing process has attracted the attention of researcher and there are several manufacturing processes that are usually very different

with respect to characteristics of the manufactured product and the method of manufacturing. In a simple product manufacturing process one should expect to identify a few clearly defined production stages such as; product design, material selection, forming or fabrication, finishing, packaging, storage and/or transporting. These stages, either directly or indirectly can influence the sustainability of manufacturing process. The general factors considered in evaluating the process sustainability include; the level of energy consumption in the process, which can lead to questioning the environmental impact, the magnitude and impact of waste generation and disposal, personal health of the operators and the operational safety which may play a significant role on the later. The manufacturing cost is also a major factor for consideration.

Reporting a study to develop sustainable products and sustainable manufacturing processes, [20] describe a case study on machining methods such as dry cryogenic and minimum quantity lubrication (MQL) machining, to have significantly improved product sustainability, in terms of performance, quality and life. While the work of [5] proposed a methodology for producing sustainable products from sustainable processes as shown in figure 6.

Fig 6 Proposed a methodology for producing sustainable products. Adopted from [5]

6.4 Sustainability of the System

Historically, the manufacturing system have been designed and managed with the main emphasis being on maximizing profit [11] while developing a mental models that support a manufacturing system transition to sustainability, [21] described it as a technical systems embedded within social systems. Sustainable manufacturing systems and supply chains ought to be planned and managed as holistic socio-techno-environmental systems from a total life-cycle perspective [22], which required the ability to think and communicate systematically, or systems thinking, becomes an important capability that must be developed to increase the capability to design and manage such systems[21]. Given the above context and the synergy between the methods and technical models, sustainability evaluation of the system performance from these aspects therefore will require comprehensive sustainability metrics at the plant, enterprise and supply chain levels. Studying the sustainability evaluation of systems based on the methods and technical models [23] develop a methodology for sustainable value stream mapping (Sus-VSM) and present its application and implications (economic, environmental and social) on other interdependent systems.

7. Strategies for sustainable manufacturing

7.1 Sustainable design and development of product

Principles of design for Sustainability focused on functionality, cost, environmental and societal impact, manufacturability/remanufacturability, materials selection and utilization. In a sustainability embedded design, product designer have to make a mindful attempt to consolidate the sustainability machinery into the structure of the product. Disassembly established product design is complicated because its application is hinged to space availability and manufacturability constraints [24]. Remanufacturing revamped already used products to an equal to, or better than conditions of a new product [25]. The benefit of remanufacturing over recycling is the fact that remanufacturing process preserves the initial shape (geometry) of the parts, practices that eliminates or reduce carbon footprint emission during refining and processing. Eco-efficiency design otherwise called design for environment[14] emphasis the following strategies for sustainable product design: selection and utilization of materials with low environmental impact, designing for reuse and recycling, waste management and exploiting the efficiency of the energy used in production process.

7.2 Sustainable Product and Service Development

This is a sustainable product development strategy intended to give more pragmatic direction to the manufacture. The work of [26] produce a scheme for implementing SPSD during the entire lifecycle of a product or service as simplified by [27] which include:

- Ascertain the functionality at early concept stage.
- Establish all the stages of product life cycle.
- Determine all supply chain companies.
- Optimize the impacts of sustainability.

[14] summed up the criteria for optimizing the sustainability in products and services as proposed by [26] as follows: functionality, environmental impacts, social impacts, economic impacts, market demand, quality, customer requirements, technical feasibility, compliance with legislation and different specifications.

7.3 Cultural and belief aspects

The raw material used for the manufacture of a product itself defines the sustainability of such product. In order to develop sustainable product, it is therefore very imperative to know the cultural values and norms of the targeted consumers. In Malaysia and other Arabian countries, Halal food is preferred and controlled by law. Despite the fact that concrete floor is stronger and can resist wear, wooden floors are more preferred by some people. Another instance of a culturally influenced preference if stone kitchen benches in the Mediterranean countries as compared to stainless steel or laminated wood in northern countries.

7.4 Fashion and trends

A sustainable product must be a successful product; it must give satisfaction to the user. Despite been sustainable, a product must be in tune with the fashion trend to be popular in the market because [new on product] reports a high probability for most technically sustainable product not to be popular in the market. [14] Argued that styles and trends have influence on the market in many ways. The trend of today encourages acquisition of only modern things, which are in fashion. Therefore, it is imperative to always consider how the product can be designed in a more sustainable way and that can rhyme with the current trends and style.

7.5 Sustainable production with environmental management system and standards

The environmental management system systems (EMS) have recorded a wide acceptance within many different companies across the world as they take effort towards environmental issues. EMSs is an independent coordination that provide direction to mitigate environmental impacts and establishes programs to meet, lead, and exceed in sustainability through energy efficiency. EMSs is a management instrument that can be used to guide and organize manufacturing forces by emphasizing the necessity of integrating environmental sustainability and stewardship into the planning stages of work, and by providing specific plans and procedures that take into account the environment. Therefore, any company that has employed actions towards environmental harmony truly has implemented an EMS [13]. EMS can simply be defined as ‘‘the part of the overall management system that includes the organizational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, achieving, reviewing and maintaining the environmental policy’’ [14].

8 Discussion

Sustainability assessment of a certain product starts from the raw material processing, the manufacturing process and the product manufacturing system. Therefore, achieving sustainable manufacturing begins with design of a new product where suitable materials and manufacturing processes can be used. This is because new innovations and more sustainable production approaches will be required into manufacturing system. As raw materials are depleting, advance materials studies demands for more articulated researches and training of engineers and scientist.

Understanding the market, giving special recognition to the trends of fashion, cultural and traditional norms and beliefs of the target consumers, in cooperating ICT in maximizing sustainability of product and educating or enlightening the populace about the inevitability for sustainable living in society are all needed inputs for sustainable manufacturing. Therefore, a holistic approach of product design and development including total life cycle analysis will possibly ensure sustainable manufacturing.

9 Conclusion

Creating a sustainable society where manufacturing, utilization and disposal of product are sensitive to the ecological system required a holistic and collaborative contribution from all stakeholders. Knowledge among people on sustainability and the value of living in a sustainable manner is a task to achieve through education, dissemination of knowledge in workshop, seminars and exhibitions. The populace must be sensitized on the need to be preserving the world for the future generations. The path to achieving this must have political control and support, to formulate laws that will encourage sustainable manufacturing in companies and discourage generation of waste and green house gas emission. Educational research in the relationship of scarce materials and resources of energy, development of modern and fashionable products as well as spreading information of more sustainable products can strongly advance improvements in sustainable manufacturing.

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