Developing a New Scheme for Sustainable Manufacturing

Zohreh Molamohamadi and Napsiah Ismail

***Abstract*—Due to the increasing expenses of energy, industrial contamination, deficiencies of strategic raw materials and natural resources, and ecological disasters, sustainability has become one of the most prominent areas in the recent researches. Having a profound effect on all of the organizational aspects of human life, sustainability related issues maintain a strong mutual relationship with manufacturing, as the main aspect of the modern lifestyle.**

Having considered the previous suggested frameworks for sustainable manufacturing, this paper proposes a new structure where not only do the three major pillars of sustainability have interlink connections, but also two more enablers are introduced to be added to the previous ones to develop the existing frameworks. Moreover, a holistic review of sustainability, its definitions, background and current issues are represented here to offer appropriate options to the manufacturing systems for moving faster and safer toward a sustainable future.

***Index Terms*—Manufacturing sustainability enablers, sustainable manufacturing system, sustainability pillars.**

I. Introduction

It has been a time that the issue of sustainability in manufacturing is under the attention of many researchers and several research projects have been published in this virtually new realm of science.

In 1987, [1] defined sustainable development as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Another definition of sustainability according to [2] is "the level of human consumption and activity, which can continue into the foreseeable future, so that the systems providing goods and services to the humans, persists indefinitely."

However, [3] argued that sustainability definition should include dynamic efficiency, total welfare, and represent consumption of market and non-market goods and services. In fact, sustainability aims at a future in which products are completely recyclable, manufacturing does not have any detrimental effects on the environment, and complete disassembly of the products at the end of its life time is routine.

According to [4] sustainable development and related practices can provide competitive advantages for companies, such as better recruitment and retention of employees, cost savings, and improved corporate reputation and relations with stakeholders and financial returns. Furthermore, sustainable manufacturing can open up a wider market in which to operate and increase sales and revenues. Additionally, it can conserve energy and reduce waste resulting in reduced costs for a company. Finally, at a more general level, sustainability reduces the risk of natural disasters such as climate changes by checking atmospheric emissions [5].

Besides presenting a new scheme for sustainable manufacturing as the main aim, this paper investigates the general view of sustainability in manufacturing and its current issues. The rest of the paper is organized as follows: Section II is about the development of sustainability and its main pillars. In Section III the literature of sustainable manufacturing is reviewed. Section IV describes the relationship between sustainability and manufacturing and discusses the new proposed framework for sustainable manufacturing. Section V is about the current issues of sustainable manufacturing and finally the conclusion is debated in Section VI.

II. Development of Sustainability

Sustainability is a widely accepted idea with little guidance about its practical implementation. Semantically, sustainability is a quality that allows preserving, keeping, or maintaining something. In fact, when something is sustainable, it is able to endure or to be kept. In the past, this term was mostly defined as the quality to sustain the environment and was mainly environmentally oriented. However, in current literature, sustainability is defined with three dimensions: environmental, social and economical. Reference [6] popularized these three dimensions (Fig. 1), which he called the triple bottom line (TBL) principle and also known as the three pillars; profit, planet, and people. However, [7] believes in adding technology as the fourth dimension.

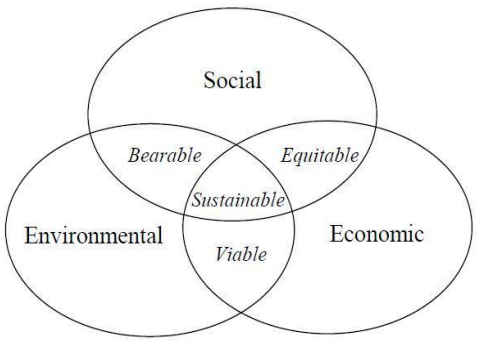

Fig. 1. Three basic pillars of sustainability [6].

Socially looking, the fundamental objective of sustainable development is to meet human needs. From the economic perspective, economic growth is required in areas where the basic needs are not met. As far as environment is concerned,

Manuscript received October 31, 2012; revised January 23, 2013.

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development should not endanger natural systems and consequently life on the Earth. Environmental constraints have to be imposed to preserve the carrying capacity of the Earth, and the use of non-renewable resources should be as efficient as possible.

Reference [8] defined sustainability as creating a proper balance between economic, social and ecological aims. They believe that for businesses, this includes sustaining and expanding economic growth, shareholder value, prestige, corporate reputation, customer relationships, and the quality of products and services. Reference [9] believes that ensuring a sustainable future requires a system approach with interlinked interactions at economic, social, and environmental levels. The reason is that tackling any of these issues in isolation can result in unintended consequences along other dimensions.

III. Reviewing the Literature of Sustainable Manufacturing

Between 1970 and 1990, public concern and awareness about the social and environmental effects of the industrialization failures increased which was mainly the result of the industrial growth and the growing rate of resource consumption [10].

Reference [11] presented a review of the research development in Environmentally Conscious Manufacturing and Product Recovery (ECMPRO) and provided a survey of published work. Not only does ECMPRO involve integrating environmental thinking into new product development such as design, material selection, manufacturing processes, and delivery of the product to the consumers, but also it covers the end-of-life management of the product after its useful life. Reference [12] remarked the characteristics of a sustainable production system and discussed that organizations moving towards environmentally friendly and sustainable processes will recover costs quickly. Based on a sustainable manufacturing paradigm, [13] described a new approach to product development which integrates the environmental requirements in every very stage of product's life cycle.

In the area of manufacturing systems design, [14] discussed the concept of design for environment (DfE). By assessing 25 manufacturing systems in the printed board industry, it concluded that using less resource and generating less waste and emissions along with measuring and managing the environmental balance with information technology will assist in making a sustainable and intelligent system. Having surveyed the members of the U.S. commercial carpet industry, [15] addressed the effects of incorporating environmental sustainability in manufacturing systems on their competitive outcomes such as manufacturing cost and product quality. References [16]-[19] focused on the application of green or sustainable practices in small and medium enterprises (SMEs). The substantial upfront greening cost is one of the major challenges with which such business enterprises are confronted in relation to adoption of sustainability in the supply chain. The statistical results of a meditational regression model represented in [20] demonstrate the greater tendency of firms with closer supplier partnerships and continuous improvement toward developing a proactive environmental management program. This will enrich competitive advantage through cost savings, quality improvement, and process or product innovation. By using data from over 4000 manufacturing facilities in seven OECD (Organization for Economic Co-operation and Development) countries, [21] evaluated the determinants and effects of green supply chain management (GSCM) on environmental and business performance. Reference [22] focused on modeling and optimization aspects and provided an overview of some recent trends and challenges in achieving sustainability at the product, process and system levels. Reference [23] presented a review of a set of indicators and a categorization of quantifiable indicators- based on environmental stewardship, economic growth, social well-being, technological advancement, and performance management- for measuring sustainability. It is also explained how these indicators can be used in assessing a company's manufacturing operations. Besides adding technology and education as the two enablers of sustainability in manufacturing, [24] built a wide picture of the research challenges in the area of sustainable manufacturing based on the IMS2020 project.

IV. Evolution of Sustainable Manufacturing Framework

Manufacturing provides primarily important goods and services to support the quality of human life and mainly contributes to the world economy. It is actually something beyond production and includes all industrial activities from the customer to the factory and back to the customer. In other words, manufacturing lies at the core of industrial economies and contains all the different kinds of services that are connected to the manufacturing chain.

Many studies have evaluated the economical and social importance of manufacturing for the various regions of the world. For instance, Manufuture project (2004) highlighted up to 22% manufacturing contributions to Europe's GDP, and mentioned that 70% of jobs in Europe depend on manufacturing. Thus, there would be no doubt about the significance of manufacturing on the society and economy. Moreover, the huge impact of manufacturing on the environment by consuming raw materials and energy, and harmful gas emission implies the necessity for including the environment as the third factor being affected by manufacturing.

Apart from society, economy, and environment, nowadays manufacturing is strictly based on technology, so the evident role of technology on sustainability cannot be neglected. Recently, some researches have been conducted on whether technology can solve the catastrophic environmental and social threats. Reference [25] underlined that though technology is related to both problem and solution for environmental harms, it is a crucial factor in environmental preservation. Some other researches ([26]-[28]) considered technology as a standalone dimension in sustainability development. Technology can assist in providing a positive relation between social and economical aspects and environmental constrains. For instance, information and

communication technologies (ICTs) can contribute to achieving a more sustainable way of work and life, design, manufacturing and product use. Thus, technology must be considered as a vital component of the sustainability model, by considering its primary role in supporting actions toward a more sustainable society. Furthermore, based on this concept and with regarding to education and knowledge as the indispensable components of technological development, [24] represented a framework for sustainable manufacturing, where technology and education are assumed as the two critical enablers of the sustainability pillars (Fig. 2).

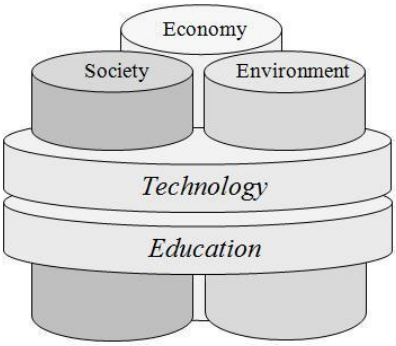

Fig. 2. Technology and education as sustainability enablers for sustainable manufacturing [24].

The sustainable manufacturing framework can be further improved by creating interconnection relationships between the three major pillars and adding two more enablers, ethic and accountability, to the proposed framework by [24]. We believe that without ethical and accountability concerns, no responsibility would exist for social, economic, and environmental progress and sustainability efforts would be defeated. Thus, we propose Fig. 3 as the new framework for sustainable manufacturing development.

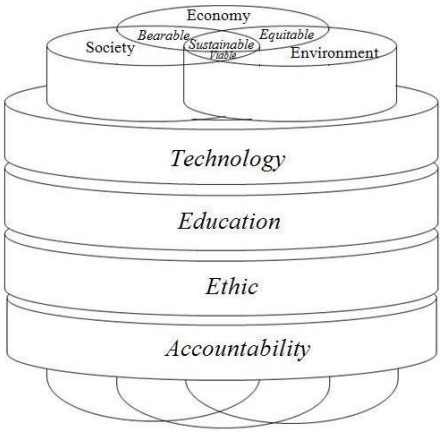

Fig. 3. The new proposed framework for sustainable manufacturing.

In this view, sustainable manufacturing can be defined as providing goods and services for satisfying the customers' needs in a society while accelerating economic growth and decelerating the environmental damage. These goals would not be achieved unless through applying technology by highly educated people with strict code of ethics and accountability.

Technology here is interrelated with the economy by proposing new and more productive solutions, with the environment by saving the nature, and with the society, by improving the quality of human life. On the other hand, education is an imperative requirement for perfectly addressing the sustainability objectives through the appropriate use of products and technology. Actually, without experts and erudite employees, the destructive effects of applying and developing technology would far outweigh its productive influences. Moreover, ethics and accountability which were not considered in the previous structures are the two other vital prerequisites without the existence of which no strong commitment would be demonstrated to the society, economy, environment, and the needs of the next generations. The relationships between these two new enablers and the three major pillars are specifically stated below.

Ethical and economic issues are connected intimately; Economic ethics or so-called ethical economy analyzes the justification and the conditions of implementation for ethical norms in the economy. The relationship between environment and ethics in manufacturing can be defined as a type of relationship that businesses establish with the living and non-living creatures of the Earth. As a matter of fact, environmental ethic is how the manufacturing systems interact with and value the natural environmental assets. Social ethic is the systematic reflection of manufacturing and running businesses on the moral dimensions of social systems and communities. It further includes analyzing the possible options for addressing the social problems caused by business activities and making great efforts for resolving them.

Accountability can act as a powerful stimulus for achieving economic, environmental, and social growth. Economic accountability in the area of producing goods and services implies taking the full responsibility for the effects of financial and economic related decision makings and actions on the potential stakeholders, including employees, customers, governmental and nongovernmental organizations, owners and community as a whole. Manufacturing companies and enterprises are expected to be environmentally accountable and bear the burden of deteriorating the natural environment and devote conscious effort to compensate it. Moreover, manufacturing social accountability is the measure of an enterprise's state of being attentive to the emerging social concerns of its stakeholders.

V. Current Issues in Sustainable Manufacturing

In order to make manufacturing more sustainable, issues at all relevant levels involving product, process, and system, and not just one or more of them in isolation, must be considered [22]. At the product level 3R concept which refers to reduce, reuse, and recycle must be extended to a more recent methodology, called 6R, to form the infrastructure for sustainable manufacturing through reducing, reusing, recovering, redesigning, remanufacturing, and recycling [29]. Moreover, a rapid convenient sustainability evaluation procedure must be developed without notably compromising the aims of life cycle assessment (LCA).

According to [30], at the process level there is a need to achieve optimized technological improvements and process

planning for reducing energy and resource consumptions, toxic wastes, occupational hazards, etc., and for improving product life by manipulating process-induced surface integrity. In other words, at the process level, sustainable manufacturing research addresses issues related to planning, analysis, improvement, and the development of processes.

Reference [31] mentions that all aspects of the entire supply chain, and all the major life-cycle stages, including pre-manufacturing, manufacturing, use and post-use, over multiple life-cycles must be taken into account at the system level. It is at this level that challenges relating to supply chain design, facility design and operations, and production planning would be addressed.

VI. Conclusion

The introduction of sustainability into the product and process development, regarding environment, economy, and society, has compelled the manufacturing companies to move instantly toward producing long-life sustainable products. This, in turn, requires improved models, frameworks, metrics, and optimization techniques to be taken into consideration. Although many researchers have addressed these prerequisites recently, they have still great need to be enhanced to facilitate the industries' improvement in the area of sustainability. This paper presents a general overview of sustainable manufacturing and proposes a new scheme for it. The main pillars in the new framework are considered to have interlinked relationships as each affect and would be affected by the others. Besides, two more decisive enablers, required to stimulate and accelerate the process of manufacturing sustainability, are added to the proposed framework. In fact, incorporating ethic and accountability along with technology and education can strongly expedite the industries' improvement in sustainability area.

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