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Sustainable Manufacturing: Concepts and Opportunities

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Abstract – As the way we produce and consume has changed in recent years, people are increasingly aware that a new economic model that takes these factors into consideration is required. Public concerns about the effect of industrial operations on the environment and society are growing, which has put increased pressure on the industries themselves to be open and honest in disclosing the consequences of their activities. Accordingly, this article first presents an overview of the main concepts related to sustainable manufacturing, meaning of sustainable manufacturing, need for future, important, opportunities for manufacturing sustainability within industry 4.0, and metrics to evaluate organizations' sustainability performance. However, the positive ecological and economic impacts of sustainable manufacturing seem fairly widespread.

Key Words – Sustainability, Manufacturing Sustainability, Industry 4.0, Enabling Technologies, SM

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1. INTRODUCTION

Sustainability is satisfying today's demands without jeopardizing future generations' capacity to fulfill their needs; (World Commission on Environment and Development, 1987). Three important elements of sustainable development economic, environmental and social have been increasingly recognized in the wide debate and usage of the term.

Figure 1: The three pillars of sustainability in the environment.

Historically, production was related to undesirable side effects, since producers had to convert resources inputs into utilizable outputs (e.g. economic value) with thermodynamic efficiency constraints. In the past four decades, an increasingly significant worldwide problem and a huge challenge to society have emerged from the impact on the environment of industrial activity. The adoption of environmental degradation prevention techniques was encouraged with awareness of the effect of human activities on the global environment. These fields of practice include industrial ecology, green supply chain management, product life-cycle administration, corporate environmental management and design, product services systems, etc. These techniques may be used on a range of labels and areas including industrial ecology.

Many factors, such as growing product and system complexity, environmental concerns, lack of knowledge inclusion, technological advances and simulation techniques play a significant part in defining the requirements of a future generation production pattern. The concept of sustainable production (SM) was recently developed as a pollution control sub-structure under several terms (e.g., environmental conscious production, green production) (P2). SM's primary aim is to reduce the industrial effect on the environment. Environmental activities have been linked to adverse company performance for a long time, however numerous studies have proven this assumption incorrect. The sustainability indicators show the relationships and numerous variables affecting the three elements of sustainability. The relationships, for example, are seen in Fig 3.2:

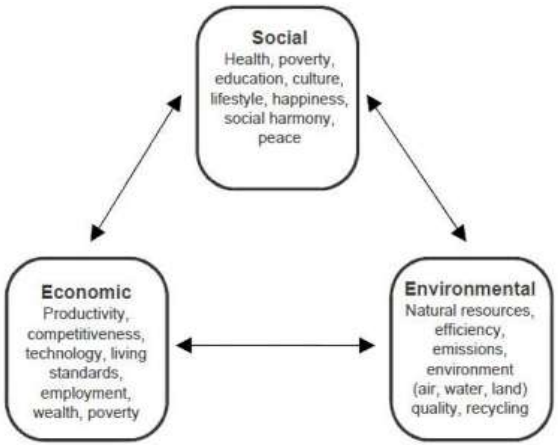

Figure 2: Relationships between social, environmental and economic sustainability and certain variables.

1. The natural resource base supplies manufacturing materials that rely upon employment and earnings;

2. Employment influences the development of wealth, living standards and poverty;

3. Crime, social unrest and instability are related to poverty;

4. Health impacts on resources, air and water quality;

5. Production resources impact profitability

2. SUSTAINABLE MANUFACTURING: AN OVERVIEW

In recent years SM has been recognized as an integrated approach to increase the economic, social and environmental performance of a company with even higher recognition. Appropriate manufacturability has been incorporated into new ideas for management (managed and assessed product cycle, eco affectivity etc.), novel technologies, and innovative design and engineering methods. Research frameworks cover many different areas (enterprise, supply chain, manufacturing cell and operations etc.). Tonelli et al. suggested a sustainable industrial system framework including chain design; sustainability measurement and management performance and organizational changes, by using a system de-sign method. In its approach, Koho et coll. presented a strategy to promote the creation of sustainable manufacturing firms in Finland and underlined measurement as a foundation for improvement using DMAIC (Definition, Measurement, Analysis, Improving, and Control). A framework for development and evaluation of relevant skills throughout the whole supply chain was created by Subic et al.. Zhang et al. sought to combine sustainability assessment with decision-making technique in accordance with LCA and SLCA that would contribute to process planning at production cell level. Masood et al. suggested a method for milling with a view to increasing the life of cutting tools for sustainability in machining operations. Hassine et al. provided a case study using a specially designed multi-target optimization technology on a durable turning operation.

An increasing focus on value creation via sustainable industrial production systems is seen (Sustainable Supply Chains SSCs and Closed Loop Supply Chains CLSCs). The reverse logistics (RL) and the CLSC were stressed by Govindan et al. as an opportunity of income instead of cost-reduction. Schenkel et al. divided value into four kinds of values (economic, environmental, customer and information) and gave insights into maximizing value by coordinating supply chains forward and backward. Ageron et al. have identified the competitive benefit of sustainability problems incorporated in SCM as the desired approach. Gopal Krishnan et al. suggested that sustainable operations should be developed throughout the value chain and 3BL should be addressed in an integrated way. By creating a discrete-event model, Galal et al. investigated sustainability, particularly reducing emissions, across the agri-food supply chain.

SM has to be studied in connection with the broader system-containing subjects from the system viewpoint. Comprising the widespread variety of factor throughout the whole product life cycle and their connection with large systems (the supply chain, the market and ecology), the understanding of external interactions becomes important. By splitting into three kinds of interacting systems (industrial, social, and environment-oriented),Fiksel created a tri-value 3V model in which the complex dynamic links and value flows between them may offer a system modeling architecture. Concerning the principles of complexity theory, Moldova has presented a systemic model, wherein a system not only contributes to its own, in terms of attractors, but also to the sustainability of a huge contained system. Zhang et al. presented the definitions and the evaluation methodology for SM based on ST from an operational perspective. The approach for sustainability evaluation for manufacturing companies developed by Mol-Davska et al. is driven by ST.

3. MEANING OF SUSTAINABLE MANUFACTURING

The concept of sustainable manufacturing, established early in the 1980s to meet the rising understanding and concern about economic growth and global business and trade expansion, is one of larger ideas for sustainable development." Development that meets present need without compromising the ability of future generations to

satisfy their own needs is sustainable growth. It contains two key ideas:

- The idea of the conditions for which priority is to be provided and in particular the basic necessities of the world's poverty;
- The idea that the status of technology and social structure imposes limitations to environmental capabilities.

Sustainable production was presented and accepted as a guiding concept in the creation and achievement of sustainable development at Rio de Janeiro's UNCED summit in 1992. As sustainability becomes a company's anticipated business practice, big and smaller sustainable production businesses and their networks of suppliers and consumers are being established, developed and implemented. A number of definitions need to be considered regarding sustainable production:

US Department of Commerce:

"For the purposes of Commerce's Sustainable Manufacturing Initiative, sustainable manufacturing is defined as the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound".

Lowell Center for Sustainable Production:

"The production of products and services utilizing systems and processes:

- non-polluting
- energy conservation and natural resources Sustainable Production
- Sustainable economically
- Secure and healthy for employees, communities and customers
- Rewarding all working people socially and artistically"

4. CONCEPT OF SUSTAINABLE MANUFACTURING

Environmental management system

Organizations are taking the environmental component more and more into consideration. The most common approach to improve the environmental outcome of a company in the short and medium term is thus EMS. This may be described as an agenda that allows every business to monitor its major environmental effects systematically and to minimize possible pollution hazards by law and with the purpose of continual improvement. In this regard, ISO14001 is the most common International Standard for the development, implementation and maintenance of an EMS. The standard is organizational and does not specify quantitative goals or particular emission measurement techniques for emission levels.

Life cycle assessment

The LCA approach is standardized through the extensive usage of ISO environmental standards for environmental impact assessment (especially ISO 14040). The recognized LIFE definition is 'the environmental and management approach which takes account of all elements of the use of resources and of environmental discharges connected with an industrial system, from cradle to grave.' The following is an accepted definition of LIFE. 54 The LCA may be used to systematically evaluate the effect of various SM solutions on the environment and to determine advantages and trade-offs between choices.

In this regard, in addition to the environmental elements, the LCA concept has developed into the life cycle sustainability assessment (LCSA) to extend the scope of the PLC indicators (Kloepffer 2008). For example, the definition of Zhang and Haapala77 includes the concept of LCSA in addition to the dimensions of the TBL: 'sustainable production can also be interpreted as product production in a form that minimizes the environmental impact and considers that a product employee, community and consumer across PLC has social responsibility in order to obtain an economic profit.

The PLC

Not only during the manufacturing or use phase should the sustainability of the produced goods be taken into consideration, because the management of the "end of life" is in most instances more important after it is no longer utilized? Thus, from a lifelong viewpoint, the examination of sustainability brings us to the broad notion of PLC. Process design, planning of production, manufacture, assembly, consumer use, final reuse, recycling and reprocessing are the key stages of the PLC. SM is feasible only if organizations, as Zarte et al., take the entire PLC into account. Furthermore, the following after usage of the product led to the idea of numerous life cycles, due to the final stages of the PLC. A crucial aspect in guaranteeing that the various life cycles will get us to a closed loop flow is the 6R idea – Reduce, Reuse, Recycling, Recover, Redesign and Re-manufacture. The idea of a closed circuits and a circular economy (CE) was frequently linked with SM in recent years. Closed loop production methods aim efficiency in material, component and water flows throughout

the product's subsequent lives in various use phases by promoting reuse or reproduction, if not feasible.

Triple bottom line

The TBL created by Elkington is another common name in this area. The TBL expand the scope of sustainability (also known as pillars) include social, environmental and economic considerations. The TBL method includes the expansion of the organization's duties, which often focus on manufacturing monetary issues and achieve advantages in compliance with legalities and norms. But the TBL method integrates these environmental and social obligations to the economic outlook via new performance metrics.

The economic component, which is usually emphasized, is the easiest to grasp. Within the strictly financial viewpoint, the management provides an organizational perspective analyzing a series of actions that enhance the value or service of goods, labor and other resources to become products or services at acceptable costs. This means that only the economic perspectives are more prevalent in the area of SM.

The social component appears harder to absorb and grasp, since it is more complex for organizations, particularly small and medium-sized businesses, to evaluate their effects and social responsibility. The notion of corporate social responsibility (CSR) covers social dimension activities but, depending on context and interpretation, may take up many meanings. Carroll's most popular definition is

What presents, as a pyramid, four types of corporate social responsibility: 'The economic, legal, ethical and charitable obligations that society has for companies at any moment are part of corporate social responsibility'. Figure 3.3The link between most specified ideas appears to a large extent.

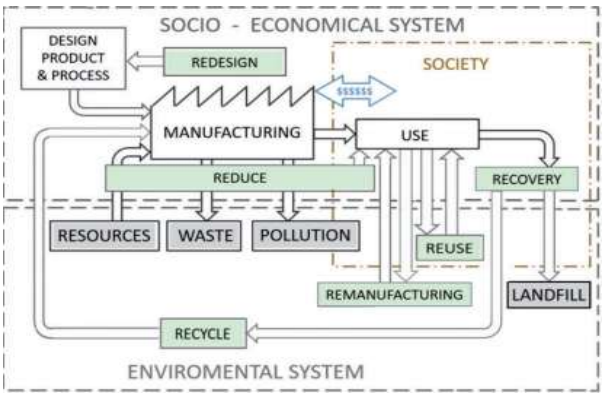

Figure 3: 6R and TBL dimensions SM procedure sequence.

Frameworks and metrics

It is important to evaluate performance and to verify that the goals are complied with to make suitable strategic and operational choices in order to effectively manage the businesses. The production is a mature function of the company such that businesses systematically evaluate economic success by accounting for resources used and for value created throughout the production process. Furthermore, the whole supply chain may cover this accounting. Measuring the effect of productive activity on sustainability is still a complicated job, taking into consideration materials, components, energy and other resources used during manufacturing processes. Moreover, it is also possible to input waste and emissions into various industrial and natural recycling systems which must be assessed and have environmental, social and economic impacts.

The performance has to be assessed using qualitative and quantitative metrics84 in order to effectively manage production systems or even whole supply chains from a sustainable viewpoint. This facilitates the discovery of linkages and interactions amongst three sustainable aspects. These indicators for SM facilitate decision-making when product, process and system design is optimized.

The necessity for a range of indicators for each element of the SM is generally agreed. The indicators will include managerial control and decision making, as well as stakeholder information, in the internal reporting of the business, for example. The selection and practical use of sustainability indicators in decision-making is a problem for organizational leaders. Moreover, even though the quantification of economic indicators is obvious, managers find it difficult to measure environmental and social indicators as specified. On the other hand, the relative weightings of indicators may change greatly based on the production type or the phase of the PLC being considered and therefore the weightings and outcomes of the sustainability reports should be assessed to see whether they differ depending on the weighting.

5. MANUFACTURING SUSTAINABILITY: NEED FOR FUTURE

Production industries play an important role in the world's resource use and trash production. Globally, energy in the industrial sectors increased by 61% between 1971 and 2004, accounting for over a third of the worldwide energy use of today. Likewise, 36% of global carbon (CO2) emissions are accountable for (IEA, 2007).

The industrial sector is nonetheless in a position to become a motor for a sustainable society. They may design, implement and develop products and services leading to better environmental performance. This requires a change in the perspective and understanding of industrial

production and the use of a more integrated business strategy (Maxwell et al., 2006).

The environmental effects of industrial production have historically been addressed by pollutants that spread less or less harmfully (UNEP and UNIDO, 2004). The sector has employed many control and treatment actions to decrease emissions and effluent emissions driven in part by tighter environmental rules. More recently, their attempts to enhance mental performance have shifted to think about the life cycles, integrated environmental plans and management systems and, across all of their value chains, businesses have also started to take on increased environmental obligations.

The adoption of more integrated and systemic techniques to increase sustainability has laid the foundation for new business models or delivery methods that may potentially lead to significant environmental benefits. Economic and environmental synergy among previously unaffiliated industrial producers may be exploited in the form of closed-loop circular systems, which have concentrated in particular on revitalizing discarded product in new manufacturing resource areas.

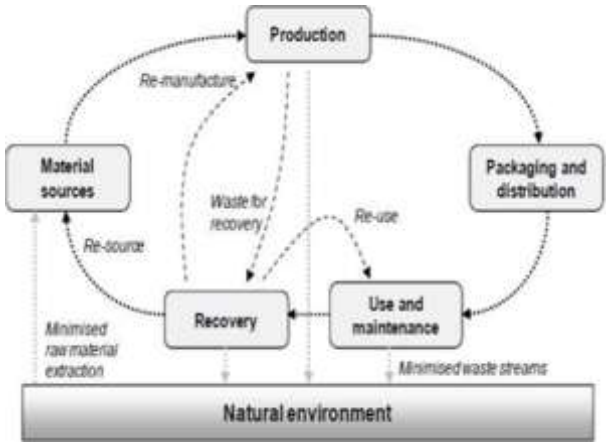

Figure 4: Production method for closed loops

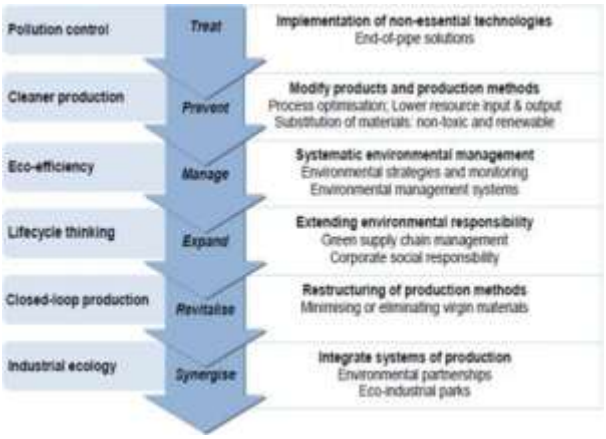

Figure 5: Development of ideas and methods for sustainable production

How does it differ from other ideas, like green, environmentally friendly production?

Sustainable manufacturing, by dealing with all three components of sustainable development: the environment, the economics and society, is more complete and systematic than green. Although it includes all the environmental concerns such as pollution, toxicity of materials and GHG emissions, it is not confined to these problems and does not form part of an environmental management system. Sustainable production uses technically and non-technologically sound methods from the selection of materials and production processes through to organization, structure and reporting. The focus is turned towards waste disposal, purification, recovery, accountability from end-of-pipeline solutions to beginning, to a new opportunity approach at the product or production stage.

Why is it important

There are many major factors in the company's strategic efforts for the adoption of sustainable production:

1. The present global crisis has shown that traditional business models, targeted at maximum economic development, are fragile and, in many instances, not viable without evaluating and reducing the adverse effect of over corporate limits.

2. The reality, its anthropological roots, and the necessity of modifying its trajectory before the consequences of human habitats are too serious; 2.

3. All the kinds of parties: customers, investors, employees, suppliers, competitors, local and national authorities, international regulatory authorities, NGOs

4. Scarcity of key operational resources: energy, commodities, water and price volatility, due in part to increasing competition, and higher extraction costs for the depletion of native and non-renewable minerals.

6. OPPORTUNITIES FOR MANU-FACTURING SUSTAINABILITY WITHIN INDUSTRY 4.0

We have seen a rising competitive strain in global marketplaces over the last decades which has created obsessive concern for better quality, cheap prices and shorter delivery times within the manufacturing sectors Increasing living standards, particularly in industrialized nations, however, demands businesses to go beyond management philosophies that are just efficient. Core problems

that managers should address while creating their strategy include environmental difficulties and the sustainability concern. Clearly, today's customer, concerned by its environmental impact, has forced companies to move to new, environmentally efficient manufacturing patterns to maximize the economic effectiveness and sustainability of processes, and the creation of an atmosphere in which new technology may be the impetus for change.

The industrial sector has always faced major trade-offs between economic development and ecological improvements.

In fact, the desire for a more sustainable development – that meets the demands of the present and does not compromise future needs' – only started to emerge in 1987, according to the Brundland report. The study and the subsequent climate change treaties raised awareness of the environment in countries, consumers started to seek environmentally-friendly goods and businesses began to see new economic opportunities. 103 Many academics and practitioners have also suggested in this context that 'Industry 4.0' may provide answers to resolve this issue of Eco efficiency.

In the context of the 2011 Hanover Fair, Industry 4.0 is a multi-field concept which symbolized the commencement of the fourth industrial revolution.

Industry 4.0 stresses the continuous digitization and connection in an interoperable environment for all manufacturing units. Thus, Industry 4.0 is founded on a variety of fields of technology: the inclusion of horizontal and vertical systems, IoT, cyber security and additive manufacturing (AM) and the analysis of big information. However, the important element of the environmental approach is undoubtedly the ability, provided by the intelligent factory, to monitor and analyze the life cycle of every product, both outside and inside the production area, in a transparent and integrated manner.

In reality, in this context, the notion of 'circular economy' is having a huge effect, closing the 'loop' or economic and ecological flows of resources. The primary focus is to reduce the access to virgin resources (e.g. water) as well as waste and pollution production.

The growing economic system, which has been taking on limitless resources and raw materials, has been linear since the Industrial Revolution. It is an economic model which follows three fundamental principles: "obtaining, using and dismissing." Due to contemporary environmental concerns, however, new eco-efficient production methods are being pushed that incorporate sustainability at the center of their operations.

In addition, CE is the logical alternative to the standard linear model in these circumstances. It also underlines the fact that the digitization and connectivity of the whole production area provided by Industry4.0. clearly increases the sustainability and 'circularity of business' For the first step in the transformation of any existing production environment into a smart factory, vertical and horizontal integration within the company is required, which means integrating all the relevant areas of production, but also, in turn, connecting with distributors via ICT platforms and apps

At the same time, transforming all this data into usable information is the key to decision-making, especially from an environmental and sustainability viewpoint. The advent of Industry 4.0 may thus be viewed as a major enabler for the efficiency and optimization of industrial operations. It thus appears reasonable to assume that Industry 4.0 may assist achieve TBL's sustainable goals in the areas of the manufacturing industry, the economy, and the ecology.

7. CONCLUSION

SM is a broad idea that is growing in both popularity and relevancy in the academic community, and has crossed over into the corporate sector to acquire wide recognition. A new paradigm that is often referred to as "Industry 4.0" has developed in the past decade in relation to the SM that places emphasis on industrial value generation. This new trend provides considerable opportunity for SM to be realised via the application of information and communications technology (ICT), IoT, big data, new manufacturing technologies, human-machine and machine-to-machine interaction. This essay attempts to contribute to the elucidation of the SM ideas addressed in Industry 4.0. Mindful attention is given to the far-reaching implications, both in terms of production systems and management, the economy, the environment, and society. There are many theoretical and empirical frameworks for SM metrics. Empirical studies indicate that productive businesses may be categorised based on 20 distinct indicators, with approximately two-thirds of them concentrating on the economic, and the remaining third centering on the social and environmental. By demonstrating the wide ranging agreement and disagreement found in the research community linked to the definitions of SM and Industry 4.0, we emphasise the uniformity and heterogeneity found in the community's thinking on the social aspects of Industry 4.0.

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