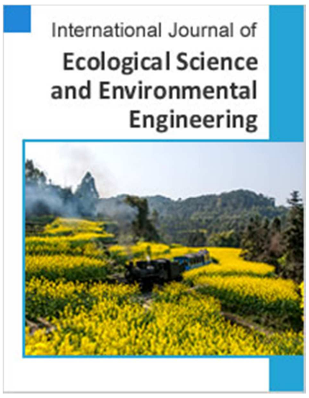
International Journal of Ecological Science and Environmental Engineering
2017; 4(6): 93-99
http://www.aascit.org/journal/ijesee
ISSN: 2375-3854

American Association for Science and Technology



A Systematic Literature Review of Design & Manufacturing for Sustainable Product

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Citation

Luma Adnan Alkindi, Halla Atiya. A Systematic Literature Review of Design & Manufacturing for Sustainable Product. *International Journal of Ecological Science and Environmental Engineering*. Vol. 4, No. 6, 2017, pp. 93-99.

Keywords

Sustainable Manufacturing and Design,
Combined Sustainability Index (CSI),
Model,
Multi-objective

Received: October 23, 2017
Accepted: November 16, 2017
Published: December 7, 2017

Abstract

In the 21st century, manufacturing companies are facing the challenge to remain competitive in global markets by finding a more sustainable approach to product design and manufacturing. This is associated with the main features of companies' competitive landscapes namely, simultaneous cost reduction and quality improvement of the product. It may appear that reaching both these goals together is prohibitively problematic as they are considered by "manufacturing leaders" as opposing objectives. However, much recent research has been done on introducing approaches to delivering low cost, high quality sustainable products based on finding a link between the design or the manufacturing processes and other key elements of sustainability; economic, environmental, and social. Indeed, these approaches often times include limitations such as the lack of integration between the design and manufacturing stages of the product and do not adequately address three key parts of sustainability; economic, environmental, and social. Consequently, these approaches, have a low applicability, and hence few opportunities for success. However, for delivering a sustainable product, the key parts of sustainability, as well as the integration of product design and manufacturing processes must be optimized in terms of one effective measure. This project aims to propose an approach for design and manufacturing sustainability. The combined sustainability index (CSI) is developed as a comprehensive evaluation metric for alternative scenarios of the process and also as a tool that enables decision makers to run optimal processes. The applicability of the CSI has to be tested and verified in a real industrial setting with the aim to improve the sustainability performance by designing a product and the corresponding manufacturing processes for that product. Process optimization is carried out in terms of the highest CSI score achieved.

1. Introduction

The need to implement sustainability concept in designing and manufacturing products has become, more than ever, a matter of crucial importance in today's economy. From the descent of raw materials through to the final use and disposal, sustainable or "green" products outweigh conventional products on their environmental and social intrinsic worth. Manufacturers need to follow activities of production internalize negative environmental externalities while profits maximize and social economic benefits. Most of the manufacturing organizations expend large quantities of resources at the same time generate wastes and pollution. However with recent increase in sustainability issues, organizations should consider taking suitable measures to enhance their sustainability aspects. It has thus become the need of the time for manufacturers to pursue manufacturing activities, which helps in minimizing environmental impacts while maintaining social and economic benefits (Joung et al. 2013) [1]. One of definitions of the sustainability is Brundtland description. It explains sustainability as "meeting the needs of the present generation without compromising the ability of future generations to meet their own needs. The purpose of this paper is to determine the sustainable product and to set major operational parameters to maximize a proposed manufacturing sustainability index.

2. Sustainability

Discussions about sustainability are moved by the basic notion that a company's performance must be measured not only by the profit, but also by the amount of damages/improvements to the environment and social systems (Schneider, Meins 2012) [2]. A sustainable company is the one that, at the end of the accounting period, was able to main an intact biosphere (Elkington, 2012) [3]. Sustainability has been defined in many ways, but the most frequently used definition for it is "as meeting the needs of the present generation without compromising the ability of future generations to meet their own needs." (WCED, 1987) [4], the definition puts focus on two aspects, first the needs and consumption, and secondly our environment's and planet's ability to meet and fulfill the needs of today and in the future. Sustainability is typically further divided into three pillars, economic, social and environmental as in Figure 1. These are also referred to as "the triple bottom line or the "3P" planet, people, and profit (e.g. WCED, 1987; Martins et al., 2007; Elkington, 2007) [3], [4]. The aspect of economical sustainability focuses on securing economic viability in short and long range. Social sustainability can be achieved as people feel that they can have a fair share of wealth, safety and influence (Jovane et al., 2008) [5]. Environmental sustainability, "seeks to improve human welfare by protecting the sources of raw material used for human needs and ensuring that the sink for human wastes are not exceeded, in order to prevent any harm caused to human beings" (Goodland, 1995) [6].

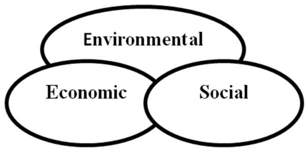

Figure 1. *Interaction of three parts of sustainability.*

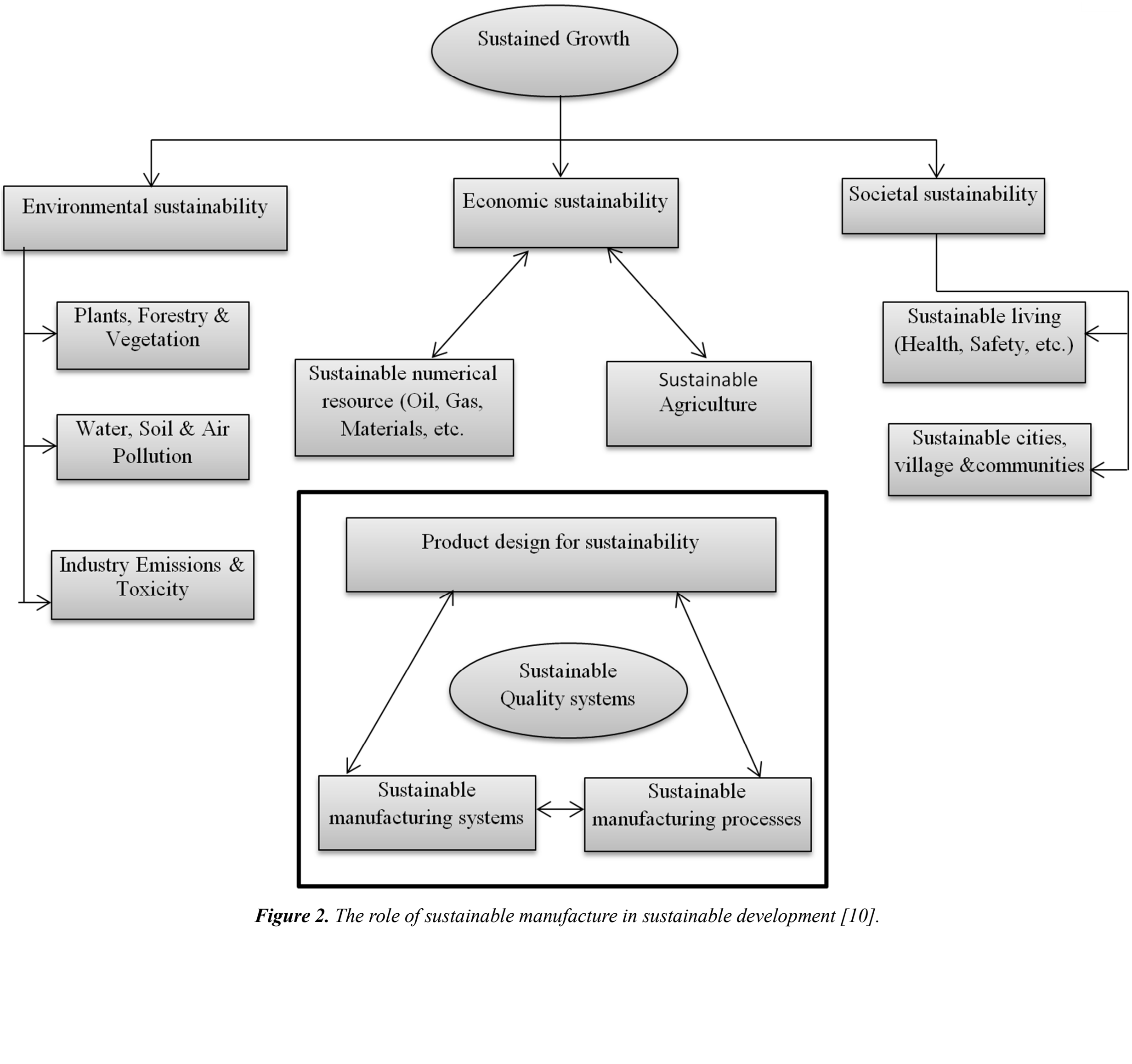

Figure 2. *The role of sustainable manufacture in sustainable development [10].*

Sustainability is equity and harmony extended into the future, a careful journey without an endpoint, a continuous striving for the harmonious co-evolution of environmental, economic and socio-cultural goals (Mega and Pedersen 1998) [7]. The common aim [of sustainable development] must be to expand resources and improve the quality of life for as many people as heedless population growth forces upon the Earth, and do it with minimal prosthetic dependence (Wilson 1998) [8]. Although sustainability planning often focuses on environmental goals, such as emission reductions and habitat preservation, a municipal government survey found that their sustainability policies are also based on economic goals such as infrastructure cost savings and economic development (Binghamton University 2016).

Since implementing sustainability principles in designing and manufacturing products has become a priority for researchers and corporations, the need to build new models to quantify all the aspects of sustainability, has become a major issue. One such model was proposed by Jawahir and Wanigarathne at the University of Kentucky, figure 2 showing the essential role of sustainable manufacture in overall sustainable development by illustrating how sustainable manufacture are inter-related to environment, economy and society [9].

According to Jawahir et al [10], the quantification of product sustainability becomes essential in understanding the" sustainability content" in a manufactured product. Even if there are many measurable methods to assess the environmental aspect of sustainability such as Life Cycle Assessment (LCA) method, in which the full environmental consequences of a product system is evaluated, there is no universally accepted method to quantify all the aspects of product sustainability [11]. The desire to assess all major aspects of sustainability, has pushed product designers to find new methods and tools to improve the existing standards and measurable factors in order to reduce the need for virgin raw materials, choose the right eco-friendly sources of energy, minimize wastes, and maximize the product end-of-life value.

3. Sustainable Development Indicators

Sustainable development consists of three dimensions: economic, social, environmental, summarizes by Almstrom et al., (2011) [11]. Each of the pillars is evaluated be asset of sub-indicators. Azapagic & Perdan (2000) [12], proposed indicators of sustainability as a framework for industry based also on the three components of sustainable development as shown in table 1 below. Table 1. Shows that the first category of indicators is environmental indicators that based on a life cycle approach, which considers the supply chain of materials and energy that illustrate a whole picture of interactions between human activities and environment. These indicators have three main categories: (1) environmental impacts that some of them affects environmental locally while some others affect environmental globally; (2) environmental efficiency illustrates how smaller is more sustainable since material and energy intensity determine the total amount of materials and energy used to produce a product; and (3) voluntary actions that are related to a proactive response of business to environmental problems.

Table 1. *Sustainable development indicators [13].*

Environmental indictors	Economic indictors	Social indictors
Environmental impacts	Finical indictors	Ethic indictors
Resource use	Value add	Preservation of culture values
Global warning	Contribution to GDP	Stakeholder inclusion
Ozone depletion Solid waste	Expenditure on environment protection	Involvement in community projects
Acidification	Ethical investment	International standard of conducts
Eutrophication	Human capital indictors	Business dealings
Photochemical smog	Employment contribution	Child labor
Human toxicity	Staff turnover	Fair prices
Eco toxicity	Expenditure on health and safety	Collaboration with corrupt regimes Intergenerational equity
	Investment in staff development	
Environmental efficiency		Welfare indictors
Material and energy intensity		Income distribution
Material recyclability		Work satisfaction
Product durability		Satisfaction of social needs
Service intensity		
Value actions		
Environmental management system		
Environmental improvements		
Above the compliance levels		
Assessment of suppliers		

4. Literature Review

Today's Trends Three current trends in this engineering specialty include lowering energy consumption, minimizing environmental impact, and a greater focus on reducing cost. Lowering energy consumption is important to every type of business and almost every individual as the costs of energy continue to rise. Industrial engineers look for ways to allow systems to reduce the energy wasted by operating at certain times of the day. Minimizing environmental impact, While reducing energy can also be considered a way of reducing environmental impact, this is such an important trend that it deserves attention in its own right. Finally, reducing manufacturing cost. These trends toward "greener" living and reducing our environmental footprint can be seen in many areas of our lives today, and industrial engineering is no different. However, one thing we know for sure is that the future will continue to usher in changes and engineers will seek better ways to adapt. So there are many reaserachers propsed methodolgy for acheiving sustainable product "green product" [1], [13]-[23].

Siddhartha Kushwaha (2005), proposed index term as "A Comprehensive Sustainability Index (CSI) Balanced Social, Economic & Environmental Approach" to measure sustainability of countries based on the triangular tradeoff among environment, economy and society. The comprehensive sustainability index (CSI) is based on genuine saving, ESI, EPI and HDI. Collected hierarchal clustering method is used to group 101 countries with their peers into two groups: (1) More Sustainable Nations (63 countries) and (2) Less Sustainable Nations (38 countries). The low standard deviation in CSI represents the clustering of nations about mean CSI value. The clustering is an indicator of mediocre sustainability of nations. Hence severe measures are needed to be taken by governments, policy makers, industry and residents to increase the sustainable environment [13].

Schmidt and Butt (2006), developed method term as product sustainability index (PSI), was based on LCA impact assessment categories. It includes eight key environmental indictors across three major aspects of the product sustainability. The economic indicators are from Life-cycle Costing (LCC) assessment method. The societal indicators are aimed at evaluating the safety and mobile capability of a product. This methodology was further applied to two of their vehicle models [14].

de Silva et al. (2009), Ungureanu et al. (2007), eveloped sustainability scoring method to quantitatively assess the potential benefits of using aluminum alloys for manufacturing of an auto body. This method involves six major elements of the Design for Sustainability (DfS): environmental impact, functionality, manufacturability, recyclability and re-manufacturability, resource utilization/economy and societal impact. Each of these elements was sub-divided into several corresponding sub-elements. Different levels of influencing factors were categorized based on their significance to the product. The level of importance of each sub-element was assigned with high, medium, or low weights. Finally, sustainability scores of two different materials (steel alloy and aluminum alloy) were computed and their levels of sustainability performance were compared [15] [16].

Nomeda Dobrovolskiiené and Rima Tamošiūnienė (2015), proposed a tool term as composite sustainability index of a project (CSIP) which to measure the sustainability of a business project in the construction industry, take 15 criteria (four economic, six environmental and five social criteria) of construction sustainability selected, then group of professionals had to rank the importance of each criterion from 1 to 15, where the highest score was 15 points and the lowest 1 point. The next step is normalization by applying a distance to a reference method, the normalized value is calculated as the ratio between the indicator and an external benchmark (or target value). The final step is aggregation. At this stage, an aggregate index, called a composite sustainability index of a project is developed. The most common form of aggregation is the summing-up of the weighted and normalized individual indicators [17].

Peihao Li and Mingjia Liu (2015), develop a mathematical model term as Comprehensive Sustainability Index (CSI) that can be used to comprehensively evaluate and clearly define a country's sustainability based on factor analysis. Sustainability index was determined by a linear combination of a set of indicators. They selected 10 representative indicators coming from three aspects: social development, economic development and environmental protection. They used factor analysis to convert observations of correlated variables into values of linearly uncorrelated variables called factors thus determining the weights of indicators. In the evaluation section, they select 15 countries to form the;'/sample, 5 least developed countries, 5 developing countries and 5 developed countries. By calculating the value of CSI of each country, they found out that there are clear differences among the CSIs of the three kinds of countries. And based on such differences, they reached classification of CSI [18].

Zhang et al. (2013), Presenting methodology involving the use of total life-cycle approach, including the life-cycle assessment (LCA) method, for improving the product sustainability performance of metallic automotive components sustainability aspects (economic, environmental and social) [19].

C. Vilaa, J. V. Abellán-Nebota, J. C. Albiñanaa and G. Hernándezb, proposed framework developed the key stages for a sustainable product lifecycle strategy. Proposed model establishes all the processes carried out through the product lifecycle and indicates the application and interaction of specific methodologies, tools and knowledge at each stage that will help to achieve sustainability. The processes applied are controlled by means of the ecodesign and sustainable manufacturing approach throughout the lifecycle of the product. This makes it possible to increase the efficiency in product development and sustainable lifecycle management. [20]

Chen et al., conducted a literature review to assess a set of twelve sustainability tools used at the factory level. The investigated tools were evaluated against four criteria: rapid assessment, application at the factory level, generic applicability and holistic view of sustainability. They concluded that the existing tools fail to satisfy all four criteria simultaneously, and hence, no tool efficiently aids facility planners in developing sustainable factories [21].

Joung et al., conducted a review on indicators for sustainable manufacturing encompassing a set of 11 indicators. They presented a classification scheme of the NIST covering five dimensions of sustainability: environmental stewardship, economic growth, social well-being, technological advancement and performance management [1].

Samuel and Hashim, applied the framework developed by the Lowell Center for Sustainable Production (LASP) and the Global Reporting Initiative (GRI) to assess the sustainability of petrochemical industry in Malaysia. Chen et al. developed a sustainability measure for small and medium-sized enterprises (SMEs) in [15]. The developed tool relies on a database and a survey of 133 questions to cover all three dimensions of sustainability. Results of the different indicators are weighted and normalized and aggregated to a single score. The tool could help decision makers in identifying potential areas of improvement [23].

The contribution of this paper is to determine the sustainable product capturing the totality of sustainability aspects (economic, environmental and social). The current work differs from previous work in that it offers a mathematical model considering the totality of aspects of sustainability, not only environmental, to help systematically plan and improve sustainable manufacturing activities.

5. Mathematical Model Development

5.1. Problem Definition

Manufacturing companies aims to increase profits by reducing manufacturing cost of product, but given to the increase in taxes paid versus each amount of carbon dioxide emitted through manufacturing of product. Therefore the world towards to manufacture "green product". Consider a manufacturing system, such as that described in Figure 3, producing a variety of products. The system transforms a set of natural resources with the aid of labor, technology and financial resources to outputs. These outputs are the required products to be sold in the market in addition to scrap resulting from inefficiencies in the transformation process and some recyclable material. The operation of this manufacturing system has economic, environmental, as well as social impacts on its surrounding environment. Most of researchers introducing approaches to reducing manufacturing cost and others introducing approaches reducing carbon dioxide emission, often include limitations such as the lack of integration between the design and manufacturing stages of the product and three key parts of sustainability; economic, environmental, social. Quantity and variety decisions have to be made that shape the efficiency of the manufacturing operation. These decisions are Production process method, Skill levels of workers, number of workers, Number of machine, and type of material. These decisions heavily affect the economic, environmental and social aspects of the facility and, thus, determine the manufacturing sustainability. The target is to arrive at decisions concerning the sustainable product and the aforementioned operating parameters, so as to maximize system sustainability.

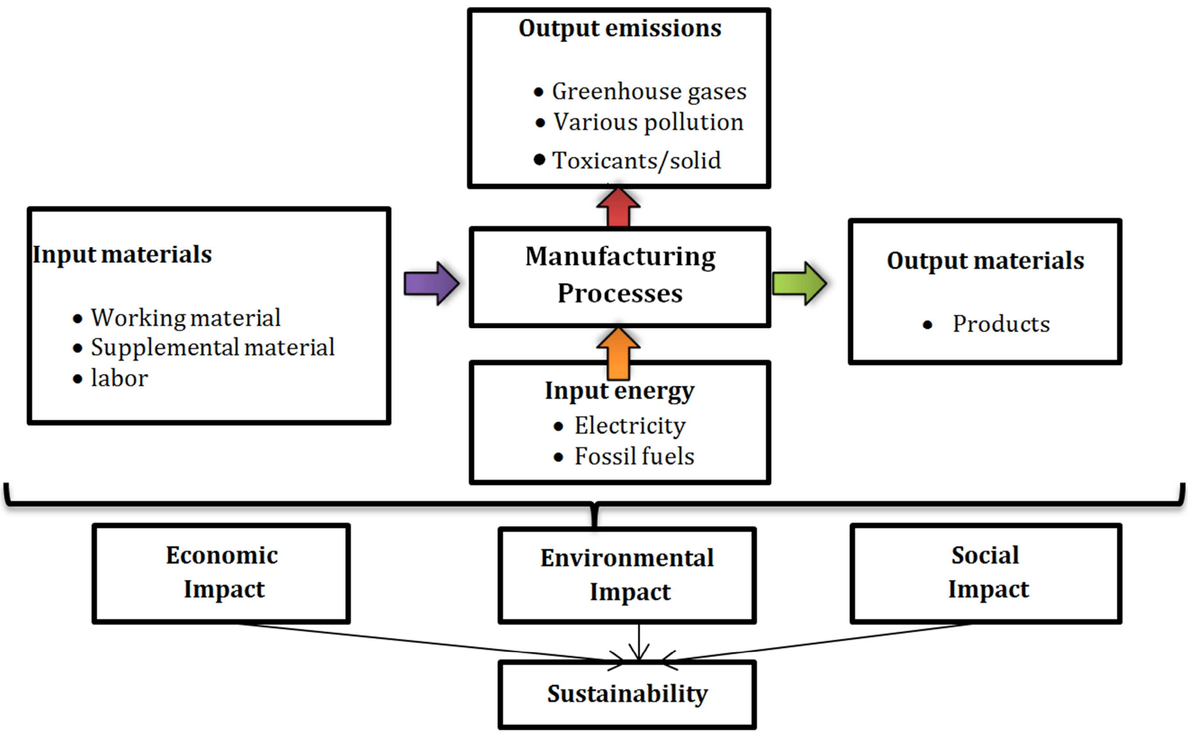

Figure 3. *Elements of a manufacturing system affecting its sustainability [24].*

5.2. Overview of the Approach

The approach developed to assess product design and manufacturing and optimisation and links economic and environment considerations as well as illustrating all the main data and decisions involved in the procedure. The proposed procedure consists of three different sections: the input data, decision variables, and integrated procedure. The approach aims to:

1. Provide a systematic approach to support the manufacturer during the whole project design.
2. Describe all connections between input variables and set design objectives using the block diagram in Figure 4.

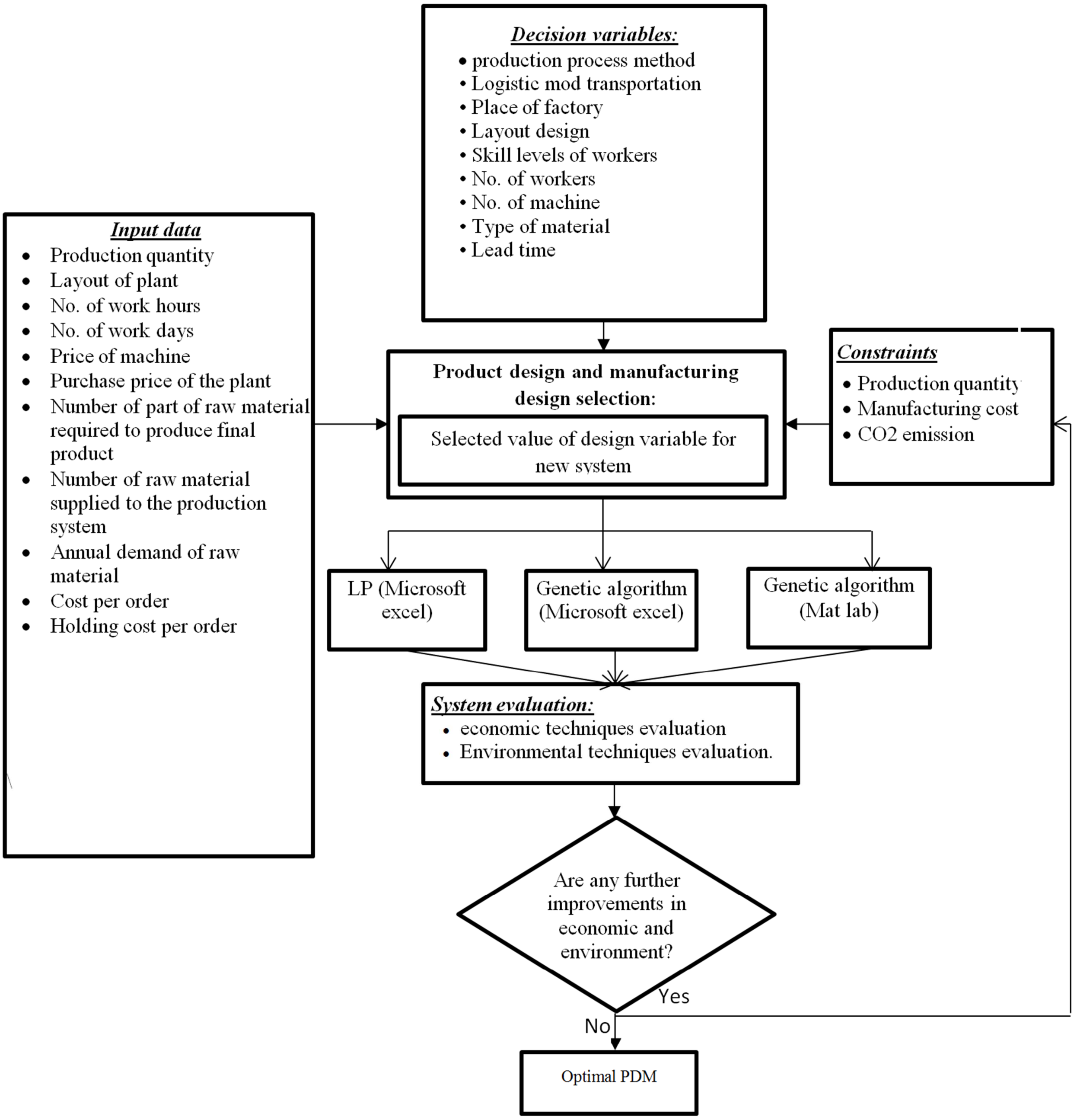

Figure 4. *Systematic approach to achieve CSI scoring.*

6. Conclusion

Manufacturing companies aims to increase profits by reducing manufacturing cost of product, but given to the increase in taxes paid versus each amount of carbon dioxide emitted through manufacturing of product. Therefore the world towards to manufacture "green product". Most of researchers introducing approaches to reducing manufacturing cost and others introducing approaches reducing carbon dioxide emission, often include limitations such as the lack of integration between the design and manufacturing stages of the product and three key parts of sustainability; economic, environmental, social. The contribution of the proposed formulation is its ability to addresses manufacturing cost and carbon dioxide emission.

Acknowledgements

We would like to show our gratitude to the unknown persons for their comments have helped get better the quality of this manuscript.

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