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Sustainable Supplier Selection in Medical Device Industry: Toward Sustainable Manufacturing

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Abstract

In order to achieve sustainability in manufacturing operations, sustainability needs to be incorporated in all stages of an organization's supply chain. One aspect of sustainable manufacturing includes the manufacturing of sustainable products in which procurement of sustainable components by eligible suppliers plays an important role. Recently, green/sustainable supplier evaluation and selection has achieved a considerable amount of attentions among researchers. Current research narrows the gap in sustainability evaluation of suppliers specifically operating in medical device industry using an efficient Fuzzy Inference System (FIS). Finally, it is concluded that how sustainable procurement can lead a manufacturer to move toward sustainable manufacturing.

Keywords: Sustainability; sustainable product design; sustainable supplier selection; sustainable manufacturing.

1. Introduction

According to the National Council for Advanced Manufacturing [1] in the U.S., sustainable manufacturing includes the manufacturing of "sustainable" products and the sustainable manufacturing of all products. Consequently, the first part of this definition includes manufacturing of renewable energy, energy efficiency, green building, and other green and social equity-related products and the second part focuses on the sustainable manufacturing of all products with consideration of full life cycle stages of product manufactured.

Jayal et al. [2] pointed out that incorporating sustainability in manufacturing not only requires considering sustainability in products and manufacturing processes but also in the entire supply chain. Vinodh and Joy [3] pointed out that manufacturing organizations can survive in the competitive environment by integrating important drivers of sustainable manufacturing (environmental, economic, and social sustainability). Recently, Gunasekaran and Spalanzani [4] investigated that environmentally friendly manufacturing has become an interesting issue among companies around the world. Consequently, manufacturing a more sustainable product can help an organization to move toward sustainable manufacturing. A product consists of many components that all need to be sourced from other manufacturing companies or suppliers. All those sourced components are required to be aligned with the sustainability policies of the buyer company. Hence, the Triple Bottom Line (TBL) concept where all three dimensions of sustainability are considered needs to be incorporated into the supplier selection policies of the buyer company, if the buyer organization seeks to move toward sustainable manufacturing.

The main focus of this paper is to shed light on the process of supplier selection in the medical device manufacturing industry sector where there are limited academic research activities published. One of the main challenges in the medical device sector is the sharing of data across the supply chain echelons due to its high confidentiality. Before introducing some of the main criteria involved in the process of supplier selection in medical device industry, a literature review of previous research activities in the research domain

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of sustainable supplier selection is presented.

Bai and Sarkis [5] utilized grey system and rough set theory with the explicit consideration of sustainability attributes for the supplier selection process. In their study, they presented a comprehensive literature review of the available criteria for supplier selection.

Govindan et al. [6] mentioned that achieving TBL benefits rely on the suppliers' environmental and social collaboration. They developed a fuzzy Multi-Criteria Decision Making MCDM approach for supplier selection decisions with consideration of sustainability criteria. One drawback of their research activity was to introduce a hypothetical illustrative example rather than providing a real world application.

Dai and Blackhurst [7] developed a an integrated analytical approach, combining Analytical Hierarchy Process (AHP) with Quality Function Deployment (QFD), to enable the 'voice' of company stakeholders in the process. Their developed methodology consisted of four hierarchical phases: linking customer requirements with the company's sustainability strategy, determining the sustainable purchasing competitive priority, developing sustainable supplier assessment criteria, and lastly assessing the suppliers.

Buyukozkan and Cifci [8] developed a novel approach based on fuzzy analytic network process within multi-person decision-making schema under incomplete preference relations. The method not only makes sufficient evaluations using the provided preference information, but also maintains the consistency level of the evaluations. The main criteria considered in their study were organization, financial performance, service quality, technology and social responsibility and environmental competencies. Their proposed framework was applied in a Turkish white goods industry.

Amindoust et al. [9] proposed a ranking method on the basis of fuzzy inference system (FIS) in order to evaluate and rank a given set of suppliers. In the evaluation process, decision makers' opinions on the importance of deciding the criteria and sub-criteria, in addition to their preference of the suppliers' performance with respect to sub-criteria are considered in linguistic terms.

Azadnia et al. [10] proposed an integrated approach of Fuzzy Analytical Hierarchy Process (FANP) and fuzzy logic in order to solve the sustainable supplier selection problem. In their research, greenhouse effect, pollution and environmental protection were considered as environmental elements. Cost and service were categorized as economic elements with risk and social reputation were included in social sustainability.

Recently, Govindan et al. [11] published a review paper in the area of green supplier evaluation considering three points for analyzing the papers: (i) which selection approaches are commonly applied?, (ii) what environmental and other selection criteria for green supplier management are popular?, (iii) and what limitations exist?. They concluded that "environmental management systems" is the most common criterion in the literature. Brandenburg et al. [12] also published a more recent review paper on mathematical models that focus on environmental or social factors in forward supply chains.

In this paper, the most important criteria of supplier selection in medical device industry is gathered and categorized that can be considered as the main contribution of the paper. A short description of some of these criteria (exclusively being used in medical device sector) is provided in this paper to give a better understanding to the readers. An efficient Fuzzy Inference System (FIS) is utilized in order to quantify the data and information regarding each of the sub criteria. The rest of this paper continues with section 2 that gives a description of the methodology. Section 3 presents the main parts of this paper that is about addressing the problem in medical device industry and implementation of the methodology together with results and discussion. Finally, some remarks were concluded in Section 4.

2. Methodology

The utilized methodology in current research activity is based on previously conducted research activity by Ghadimi et al. [13] in assessing the sustainability of a typical product design. The core approach of that methodology is modified in order to evaluate the suppliers with regards to TBL attributes. The flow diagram of the methodology is shown in Fig. 1.

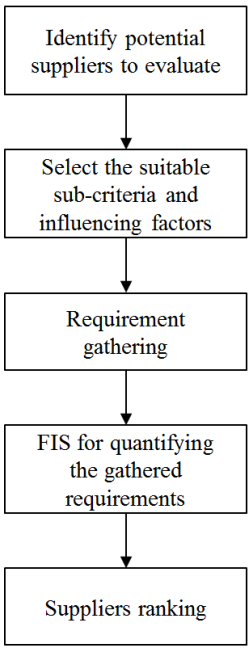

Fig. 1. Methodology steps

3. Real world application

The main focus of this research activity is to highlight the process of supplier selection in Medical device industry as it is almost neglected in the current supplier selection literature. Company XYZ is a manufacturer of medical devices for hospitals and health care organizations. It is located in Shannon, Ireland. The company currently employs 16 people. XYZ added a new section to its family of departments in 2006 that has specialized competence in miniature spring components for the medical device industry. As such XYZ is ISO13485 (specifies requirements for a quality management

system for organisations required to demonstrate its ability to provide medical devices that consistently meet client and regulatory requirements) compliant and manufactures under guidelines set out by the US Food and Drug Administration (FDA) in relation to medical device development and production. As a Small and Medium Enterprise (SME) manufacturing firm, they are strive to maintain their and exceed their current position in the market. Acting as suppliers for other bigger organizations in the medical device industry, the manager and CEO of the company foresees that one of the key factors for his company to stay in the business is to transfer all of the manufacturing and supply chain operations into sustainable supply chain and sustainable manufacturing. He mentioned that their end customers are either bigger companies or hospitals and health care organizations willing to pay for products that are more aligned with EU environmental and sustainable directives and legislations. In order to commence this transformation, the XYZ Company contacted our research centre (Enterprise Research Center) to initiate the process.

After many meetings with the manager and other representatives of the company, it was decided to start the process with selecting their suppliers with regards to TBL attributes. It was justified for the decision makers inside the company that one of the important steps in supplier evaluation is to come up with appropriate selection criteria. It was mentioned that there are many evaluation criteria in the literature that can help them to identify the proper criteria but they were informed that these already existing criteria in the literature might not be 100% suitable for selecting suppliers in the medical devices sector.

Recently, the XYZ company is initiating a new production line for manufacturing a new type of product. They are involved in all of the operations required for manufacture of the new product. It was decided to select this newly lunched product as the subject of the current research activity. For sourcing one component of this product, three suppliers were identified by the production team of the company. All of these three suppliers are operating under FDA guidelines. The most important and time consuming part of this research was to identify the appropriate evaluation criteria that was done after many meetings and discussions that are reported in the following sections.

3.1. Sub criteria and influencing factors identification

The evaluation sub criteria and their influencing factors were identified based on the three dimensions of sustainability that are environmental, economic and social. Fig. 2 shows the sub criteria and influencing factors related to the environmental sustainability dimension. Green image, pollution control and green competencies sub criteria were recognized to be the most important ones based on the decision makers opinion inside the company. One of the important influencing factors for green image sub criteria is market reputation which considers the reputation of the supplier company regarding environmental issues considerations in their operations. Solid waste deals with quantifying the amount of environmental threatening wastes being produced per manufactured unit of the product. For this particular product, the amount of metal waste was measured.

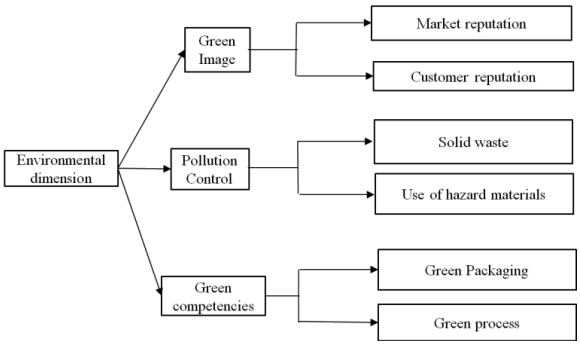

Fig. 2. Environmental sustainability sub criteria and influencing factors.

Fig. 3 illustrates the identified sub criteria and influencing factors for economic sustainability dimension. Cost, quality, delivery/service and technical capability are the four sub criteria involved in economic sustainability dimension based on the decision makers opinion inside the company. For better understanding, a short description of some of these influencing factors that are exclusively related to the medical device industry is provided in the following:

Document control procedure: the purpose of this procedure is to define the methods by which document changes are made and approved at XYZ Company, and the controls necessary to ensure compliance with the regulatory requirements of ISO 13485.

Requirement MDD: the supplier company's ability to define the routes, procedures and tasks to be conducted to ensure that XYZ and its medical devices will comply with the requirements of the Medical Device Directive (MDD 93/42/EEC) is considered.

Medical device vigilance: the supplier company's ability to define responsibilities; functions and activities associated with reporting adverse and near adverse incidents to a Notified Body/Competent Authority as required by the MDD 93/42 EEC is evaluated.

Handling and preservation of product: the supplier company's ability to formalize the handling, storage and preservation of components shipped by the supplier to the XYZ Company is evaluated. Products/raw materials stored on spool racks or in the cabinet are used in the manufacture of finished medical product or are the finished product that requires to be treated with care.

Product identification and traceability: the supplier company's ability to ensure that their product can be identified and tracked at all stages from raw material, to manufacture, sterilization, transporting and delivery to the XYZ is considered.

Post market surveillance: the supplier company's ability to establish and maintain a documented market feedback system is considered.

Failure Mode Effects & Critical Analysis (FMECA): The purpose of the FMECA is to outline the overall framework for performing Process FMECA in the XYZ which applies to all new process development conducted in the XYZ.

Regarding the social sustainability dimension, recently,

academia and industrial practitioners are debating about the new emergence of applications of Corporate Social Responsibility (CSR) (and also sustainability) concepts in supply chain. This means that addressing the supplier selection problem solely from the view point of green issues cannot be considered a comprehensive assessment of suppliers [14]. In current research, two main sub criteria were identified that are health and safety and employment practices. The CEO of the XYZ mentioned that they are looking for companies that consider social sustainability practices in a fair manner. He believes that this is very important in medical device industry to educate and train the workers and staff regarding new standards and guidelines for paying attention to their health and safety as any fatal incident during manufacturing of products can affect the company's reputation in a bad manner. Having a bad reputation in medical device sector can lead to fewer sales as this issue is very critical for end customers.

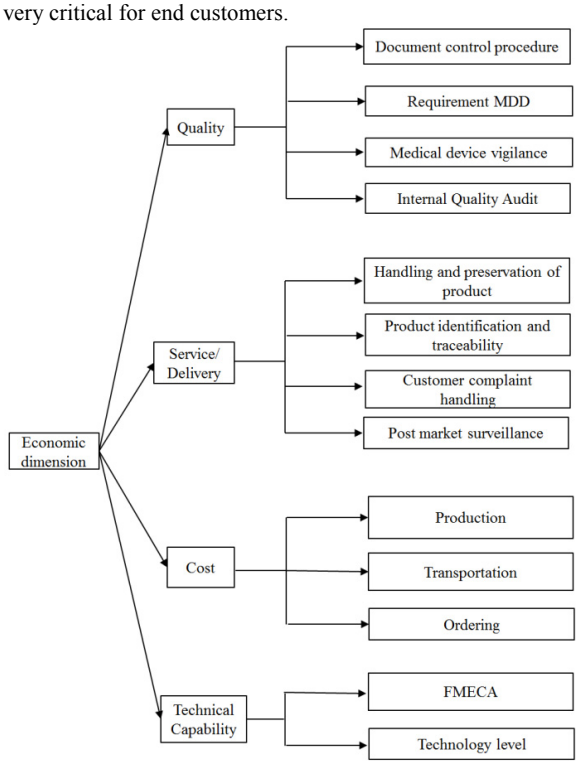

Fig. 3. Economic sustainability sub criteria and influencing factors.

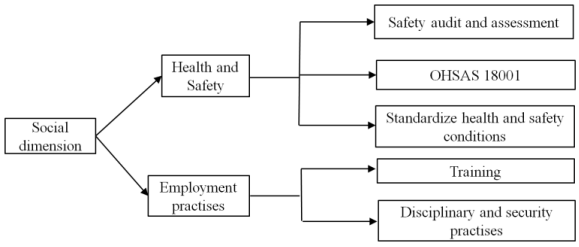

Fig. 4. Social sustainability sub criteria and influencing factors.

3.2. Implementation

After identifying the related sub criteria and their influencing factors, some of the required data were gathered based on the manufacturer's previous audits history record and discussions with the manufacturer's CEO and owner as access to the suppliers information was limited at the time of conducting this research.

The next step after requirement gathering acts as the main part of the methodology. All crisp data that are gathered in the requirement gathering step are transformed into grades of membership for linguistic terms of fuzzy sets. After determining the grades of membership, the target range or reference value is to be set for each input variable. This value indicates the minimum and maximum values of the input variable. The selection of reference values is usually based on the national and local policy or may be set by the organization or manufacturer to meet their objectives. Constructing the input variables' membership function is based on these reference values. Then, the linguistic value of zero to one (0 to 1) is selected as a reference value for constructing the output membership function. After constructing the membership functions for input and output variables, fuzzy rule base system will be constructed based on the decision makers' knowledge inside the organization. These decision makers can be the company owner, chief executive officer, general manager, system manager or a combination of these. Fuzzy inference comes after constructing the rules. In this part, the result of each rule is generated as fuzzified inputs and goes through the inference system. The output of the fuzzy inference system is the input for defuzzification process. In order to perform the fuzzy evaluation the MATLAB software was utilized. Ultimately, scores of all sub criteria will be calculated [10, 13]

3.3. Results and discussion

Table 1 tabulates the evaluation results of the three suppliers. The scores for each of the sustainability dimension sub criteria are reported separately. Using these scores, the suppliers' performance in each of the sub criteria can be monitored and obtained. For instance, supplier 3 holds the best score in cost sub criterion among the three suppliers which means that this supplier has better policies regarding minimizing its cost influencing factors that are production, transportation and ordering costs.

Table 1. Sub criteria scores

	Supplier 1	Supplier 2	Supplier 3
Environmental sustainability			
Green image	0.25	0.75	0.75
Pollution control	0.521	0.408	0.765
Green competencies	0.5	0.75	0.75
Economic sustainability			
Quality	0.69	0.75	0.56
Delivery/Service	0.75	0.25	0.5
Cost	0.5	0.25	0.75
Technical capability	0.5	0.5	0.75

Social sustainability			
Health and safety	0.5	0.75	0.756
Employment practises	0.426	0.654	0.683

Table 2 reports the sustainability dimensions scores for the three suppliers. It can be perceived from the results that supplier 3 is obviously the best supplier in all aspects of the sustainability. Supplier 1 is not performing very well regarding environmental and social sustainability comparing to supplier 2 and 3. But, it seems that their organization is doing well regarding economic sustainability. The managerial implication that can be drawn out of this result is that supplier 2 are doing very well in minimizing their operations cost and expenses but with the cost of having lower environmental and social sustainability score. For instance, they don't hold an appropriate green image in the market and that is because the managers of this company are not paying attention to the customer reputation influencing factor. On the contrary, supplier 2 is not doing well regarding economic sustainability as they hold the lowest score among the three suppliers. But, their environmental and social sustainability scores are quite high and reliable if in any case the CEO of the XYZ company wants to do business with a vendor with good environmental reputation in the market. One important result that needs to be highlighted here is consideration of social sustainability practises by supplier 2 and 3 which in most of the time requires government or other regulatory bodies' obligations.

Final supplier performance index of each supplier were obtained by calculating the average of the three sustainability dimensions' scores. Supplier 3 is ranked as the first preferred supplier. Supplier 2 comes after supplier 2 as the second preferred supplier with supplier performance index of 0.592. Finally, the least preferred supplier is supplier 1 with 0.499.

Table 2. Sustainability dimension scores

	Supplier 1	Supplier 2	Supplier 3
Environmental sustainability	0.424	0.636	0.755
Economic sustainability	0.61	0.437	0.64
Social sustainability	0.463	0.702	0.719
Supplier performance index	0.499	0.592	0.705

4. Conclusion and future work

The supplier selection problem is proven to be one of the most important and popular problems in the research domain of supply chain management. The number of research papers published in the area of traditional supplier selection where all the attentions were paid to consider the most important criteria such as price, quality, service and ranking the suppliers based on an assessment method. These approaches demonstrated to be competitive and practical until the emergence of the sustainability issues which has drawn the attention of mangers and CEOs of companies to incorporate sustainability vision in all aspects of their manufacturing and supply chain activities. Therefore, research directions in the supplier selection problem have been attracted to address and eradicate these challenges as much as possible.

Manufacturing of sustainable products is argued to be one of the most important steps towards incorporating sustainability into manufacturing operations of an organization. However, manufacturing a sustainable product cannot be accomplished by considering sustainability issues just in the manufacturing organization itself. It requires sourcing of sustainable components for manufacturing the final product. In order to achieve this goal, the manufacturing organization needs to be work with suppliers that consider the TBL concept in their manufacturing environment. This matter was the motivation of the current research activity. The sustainable supplier selection problem was considered in medical device industry with the aim of elaborating more on evaluation.

Equal weighting is considered in current research activity for the criteria and sub criteria based on experts' opinion in the case company. However, lack of these weighting can have negative effects on precision of the assessment results. Integrating fuzzy evaluation with weighted criteria and sub criteria and as a result, inclusive involvement with expert knowledge can make the proposed method more precise which is considered to be the subject of the future work.

Current work is a sub section of a five-phase framework for capturing uncertainty in the process of supplier selection and order allocation using a Multi-Agent System (MAS) approach. The rationality of business decisions concerning order allocation, demand forecasting, pricing and workforce and plant investment, all functions with a time dimension, thus centrally fall within the scope of MAS modeling. This aspect of the research is also being considered within our future publications. Integrating the MAS approach with the supplier evaluation and selection process is an emerging research avenue among researchers conducting research activities in industrial engineering, supply chain management and computer science.

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