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Development of sustainable manufacturing performance evaluation expert system for small and medium enterprises

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Abstract

This study proposes a fuzzy rule based expert system for sustainable manufacturing performance assessment in small and medium enterprises (SMEs). The initial set of measures and metrics have been identified from the literature based on the characteristics of SMEs. Sixteen metrics were identified and categorized under four economic, five environmental and three social measures. Considering the involvement of human reasoning in the decision making process of manufacturing SMEs, it is proposed to gather the inputs in terms of linguistic variables. The fuzzy rule-based expert system is proposed to elicit the performances of all the aspects and overall sustainability of the organization based on triple bottom-line framework.

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Keywords: Sustainable manufacturing; Performance assessment; Expert system; Small-and medium-enterprises.

1. Introduction

Sustainable manufacturing focuses on the products and processes which are economically sound, minimize negative environmental impacts, conserve energy and natural resources and safe for employee and community [1]. Sustainable manufacturing can also be adopted as a strategy to increase the competitive advantages and market share through enhancing the overall sustainability performance of the organization. To achieve sustainable development in the manufacturing sector, it is important that sustainable manufacturing strategies being adopted in both large and small and medium enterprises (SMEs).

Over recent decades, larger organizations are adopting various sustainability strategies in their manufacturing operations due to pressures from consumers, regulators and community [2]. In order to achieve better sustainability performance of supply chain, larger enterprises extend these practices to their suppliers. SMEs constitute about 80% of these suppliers [3]. SMEs differ significantly from those for large corporations due to characteristics of SMEs, e.g., personalized management, lack of finances, resource limitations, more flexibility, horizontal structure, small number of customers, access to limited market, and lack of knowledge [4-6]. Based on these characteristics; sustainable manufacturing in SMEs cannot be considered as a miniaturized version of the larger organization [4].

The small and medium enterprises are very instrumental in the growth of any economy [7]. In Malaysia, the contribution of SMEs to gross domestic product (GDP) is 41% and provides employment to 57.4 % of nation's workforce [8]. SMEs are broadly categories into three sectors of the economy; manufacturing, services and agriculture. Manufacturing SMEs accounted for 96.6 % of the organizations in the manufacturing sector of Malaysia [9]. The majority of the manufacturing SMEs are the supplier for multi-national companies in their global supply chain. Therefore, manufacturing SMEs are under the increasing pressure to improve their sustainability performance. For example, larger organizations are adopting sustainable manufacturing practices in their operations as a result of the pressure of directives such as European Union (EU) directives

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on Waste Electrical and Electronic Equipment (WEEE), Restriction of Hazardous Substances (RoHS), and Eco-design for Energy-using products (EuP) [10]. The ripple effects of these directives are extended to suppliers in order to enhance the sustainability performance of these larger manufacturing organizations [3].

Most of the performance measurement approaches for sustainable manufacturing are based on the set of metrics, methods and models which are designed and tested in large manufacturing companies. Although, there are some studies on indicator development for SMEs such as development of environmental indicators to assess the environmental performances of SMEs [11] , but performance assessment perspectives considering all aspects of sustainability about manufacturing SMEs are still missing [12]. Despite the many sets of indices and measures, models and methods has been developed, there is still no focused set of measures and metrics and methods available for sustainability performance evaluation of manufacturing SMEs, particularly from developing economy. This study is an attempt to full-fill these research gaps.

Expert systems are important tools in manufacturing systems. Without expert system, it would consume a huge amount of time and cost to the organizations to collect the decision makers' opinions and suggestions to make final decision [13]. This study proposes an expert system for method for sustainability assessment of manufacturing SMEs using fuzzy concepts. The system was developed to evaluate the sustainability performance based on the measures that are important and applicable to manufacturing based SMEs.

The organization of this paper is as follows. Section 2 contains the literature review. Section 3 describes the research design. Section 4 discusses the development of the web-based expert system. The results are presented in section 5. Finally, some conclusions are presented in section 6.

2. Literature Review

This section aims to review the literature to provide a clear view of sustainable manufacturing practices from SMEs perspectives. As the research aim is to develop the performance assessment expert system, the literature review has also been focused on sustainability performance assessment models and metrics.

2.1 Sustainable manufacturing and SMEs

Global or bigger companies have been developing the capability required to achieve the sustainable manufacturing over the recent decade. In 2005, General Electric announced *Ecoimagination* to dramatically increase the company business keeping in mind the environmental aspect. Returning from the verge of bankruptcy in 2008, General Motors adopted sustainability as an important principle in its business practices. The success in sustainability initiative stories of larger companies such as BMW, Dalmer, Coca-Cola and many more are well reported and recognized. But focusing on sustainability reporting it is found that percentage of larger companies publishing CSR is around 95%, whereas only around 48% small and medium scale enterprises (SMEs) publish their CSR (KPMG CRR, 2011).

The lack of sustainability efforts in SMEs is attributed due to characteristics of SMEs. SMEs often lack the awareness, expertise, skills, finance, and human resources to build the required changes for sustainability within the organization [10, 14]. Hillary [6] identified barriers and drivers for the environmental management system for SMEs. These barriers are lack of knowledge, training, implementation cost, transient cost and so on. The drivers for sustainability in SMEs, as identified by Hillary [6], are customers, government, local community, employees, insurers, banks and larger companies. This study concluded that despite these barriers, SMEs do achieve benefits from Environmental Management System (EMS). Lepoutre and Heene [15] reported that firm size and characteristics of SMEs are also recognized as barriers for sustainable practices. However, the effect of these barriers can be nullified by critical analysis and strategy to overcome the constraining barriers.

Now-a-days, SMEs are adopting the green initiatives to enhance their competitiveness to survive in the market [10]. For instance, European Union (EU) directives on Waste Electrical and Electronic Equipment (WEEE), Restriction of Hazardous Substances (RoHS), and Eco-design for energy-using products (EuP) have forced bigger organizations to adopt the sustainable practices in their operations [10]. The ripple effects of these directives are extended to suppliers in order to enhance the sustainability performance of these larger manufacturing organizations. Many of these suppliers are SMEs that represent approximately 80% of global enterprises [3]. Further, SMEs are also under pressure to improve their sustainability performance due to government regulations, local community groups, environmental groups, and investors from financial institutions [6, 15, 16]. Using an empirical study, Williamson, et al. [17] reported that business performance and regulations are drivers for environmental practices of SMEs. They also emphasised that Manufacturing SMEs try to improve business performances because of the pressures placed on them by market-dominated decision-making frames. Using an empirical study in Turkish SMEs, Agan, et al. [18] concluded that most influential driver for sustainability is expected benefits such as cost savings, increased customer satisfaction, new market opportunities, improved corporate image, and higher profits.

2.2 Sustainability assessment methods & metrics

Researchers have applied various tools and techniques for sustainability evaluation. Zamagni [19] presented a life cycle sustainability assessment model which combines LCA, Life Cycle Costing and Social LCA. Jaffar, et al. [20] presented a model based on the weighted sum of the product sustainability components, such as, economic, environmental and social, to assess the sustainability of products. Egilmez, et al. [21] presented an economic input-output LCA and data envelopment analysis (DEA) model for sustainability assessment of manufacturing units in the United States of America. Sustainability evaluation model of a desalination plant based on resources, ecological factors and environment have been proposed by Afghan, et al. [22]. Vinodh, et al. [23] presented a model for environmental impact assessment of an automotive ancillary using the eco-indicator. Bayesian network approach for calculating sustainability of coastal lakes in New South Wales (Australia) has been presented by Ticehurst, et al. [24].

In manufacturing, the assessment methods require inputs based on decision makers' perception towards indicators and measures, which are generally fuzzy. Fuzzy logic based models have been proved very useful for decision making based on human reasoning [25]. The fuzzy logic based methods have been used for the sustainability evaluation in the various areas such as petroleum corporation sustainability [26], land management unit [27] sustainability assessment of nations [28] , sustainability of a chemical industry [29] and sustainability of mining and mineral sectors [30]. Phillis and Davis [31] presented a fuzzy logic model for assessment of corporate sustainability using multi stage fuzzy reasoning model. Using, sensitivity analysis in their model, the authors demonstrated that important indicators affecting corporate sustainability can be identified. Based on the fuzzy logic, the Fuzzy Inference System (FIS) methods have been also applied in manufacturing organizations. For example, modelling of surface roughness in face milling by Kovac, et al. [32], prediction of remaining useful life of cutting tools by Gokulachandran and Mohandas [33], modeling and analysis of packing properties through FIS by Erginel [34], intelligent robotic assembly by Jakovljevic, et al. [35], optimization of machining process by Iqbal, et al. [36] and suppliers' performance evaluation by [37, 38]. Amindoust, et al. [39] proposed a FIS method for supplier selection based on the sustainability performance evaluation. They implemented a three-stage FIS model.

The success of evaluation method also depends on the selection of appropriate set of indicators. The indicator should be simple and robust, reproducible and consistent, cost-effective in data collection, complement regulatory requirements and coherence with the organization's vision. Different sets of indicators have been developed to measure the sustainability at the organizational level such as ISO 14000 (including ISO 14020, ISO 14040 and ISO 14064), Dow Jones Sustainability Indexes (DJSI), Global Reporting Initiative (GRI) and sustainable manufacturing Toolkit by Organization for Economic Cooperation and Development (OECD) [40]. Except OECD toolkit, all organizational level set of indicators are general in nature and suitable for larger organizations [41]. Based on the characteristics of SMEs, OECD toolkit provides 18 indicators, which address only the environmental dimension of sustainability. Considering economic, environmental and social dimensions, sustainability evaluation methods and frameworks are still evolving.

3. Research Design

The purpose of this study is to develop a web based expert system that will aid decision makers in the performance assessment of their manufacturing system based on the Triple Bottom-Line (TBL) of sustainability. The TBL framework provides a very comprehensive approach towards the sustainability. The performance assessment system is based on the evaluation framework adopted from [42] as shown in Fig. 1. This framework is developed for Malaysian SMEs and may not applicable to bigger companies or the SMEs from developed countries.

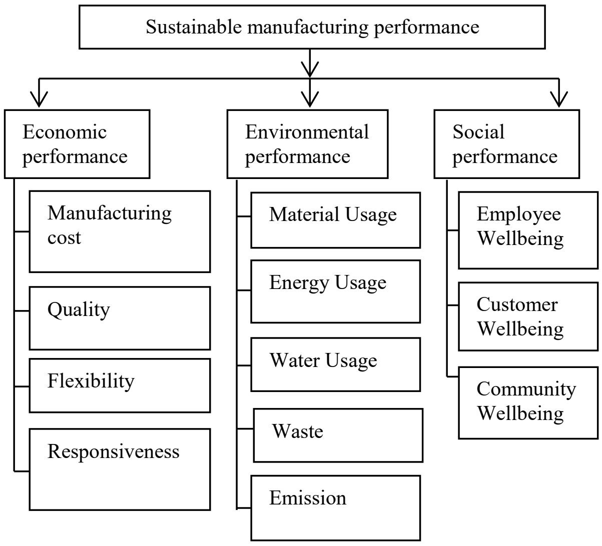

Fig.1. Framework for expert system

Sustainability performance assessment is divided into economic, environmental and social performance assessment. The economic dimension of performance measurement recognizes the metrics effectively measuring relations with customers and suppliers that results in achieving financial goals [43]. The measures for economic performance are manufacturing cost, quality, responsiveness and flexibility. The environmental performance is all about how well an organization manages the environmental aspects of its activities, products, and services. The measures considered for environmental aspect of sustainability are material usage, energy usage, water usage, waste and emission. Social performance assesses how well an organization has translated its social goals into practice. Social performance can be evaluated in terms of the impact of organization's decisions and activities on society that contribute towards sustainable development including health and welfare of society, stakeholder's expectations, compliance with applicable law and integration throughout the organization [44]. In this study, the measures for social performances are employee wellbeing, customer wellbeing and community wellbeing. The measures and their corresponding metrics for sustainability assessment are presented in Table 1. It should be noted that measures and metrics that have been considered for development of this expert system in this study as presented in Table 1 were adopted from [42]. Considering the involvement of human reasoning in manufacturing decision making, the sustainability evaluation module is based on the fuzzy logic concepts. Using a sensitivity analysis, the evaluation module can also identify the most important measures for sustainability improvement. The important measures identified during the evaluation process can be a suitable basis for strategy selection.

Table 1. Performance measures and metrics for sustainable manufacturing

Aspects/ Measures	Metrics
Economic performance	
Manufacturing Cost	Reduction in material cost, cost associated with labour, decrease in energy cost, decrease in delivery cost, increased in recycling cost, reduction in waste disposal cost, increase in environment protection cost
Quality	Increase in delivery reliability, percentage decrease in level of scrap, percentage decrease in level of rework
Responsiveness	Decrease in order lead time, decrease in manufacturing lead time, decrease in product development time
Flexibility	Increase in demand flexibility, increase in delivery flexibility, increase in production flexibility
Environmental performance	
Material Usage	Decrease in material intensity, percentage decrease in virgin material usage, increase in recycled/ remanufactured/ reused material usage, percentage decrease in hazardous material usage
Energy Usage	Decrease in total energy consumption, percentage increase in renewable energy usage, percentage increase in energy saving
Water Usage	Decrease in water total consumption, percentage increase in recycled water usage
Waste	Decrease in total waste generated, increase in level of recyclable/remanufacture/ reusable waste, percentage decrease in landfill, percentage decrease in hazardous material in waste, percentage decrease in waste water
Emission	Decrease in CO_2 emission, decrease in BFCs emission.
Social performance	
Employee Wellbeing	Average number of training hour, decrease in turnover ratio, decrease in number of accidents, increase in job satisfaction, improvement in working conditions, level of employee participation in decision making
Customers Wellbeing	Increase in customers' satisfaction, disclosure of product & service information, level of health and safety assessment of product, availability of take back / warranty
Community Wellbeing	Number of community projects, decrease in number of non-compliance, availability of child labour policy, composition of work force, salary compared to local minimum wages, community involvement in decision making

4. The Expert System

The evaluation method in the expert system is based on the hierarchal fuzzy inference system. In each fuzzy inference system, a set of rules is used to draw the conclusion. In a fuzzy rule-based system, every combination of variables requires a different rule, thus increasing the linguistic variable results into the rule explosion. The linguistic variables used for performance ratings are poor, fair and good, and for importance weights of measures are low, moderate and high.

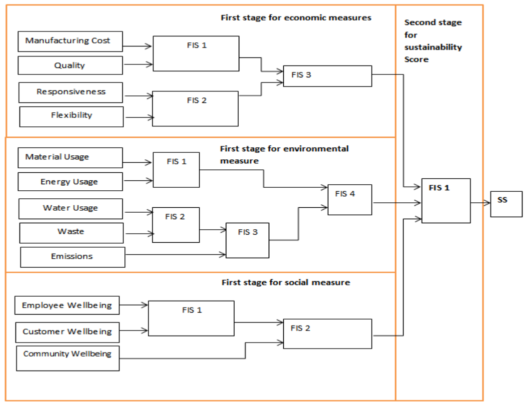

Fig.2 Hierarchal structure of fuzzy assessment system

To obtain the final sustainability performance score, the system is divided into two stages as shown in the Figure 2. At the first stage, there are three categories of hierarchal fuzzy systems to compute the performances of the three aspects (i.e. Economic performance, environmental performance and social performance). To avoid the rule explosion, it is proposed to use two inputs and three membership functions for each fuzzy system at this stage. The weighted performance of the organization with respect to each measure is considered as input to the fuzzy systems at this stage. The weighted performance values and importance weights of the measures are determined on the basis of performance ratings and importance weights of corresponding indicators. To determine the weighted performance ratings of measures, following formula has been used in this study.

$$\text{Weighted performance rating of measure} = \frac{\sum_{i=1}^{n} p_i \times w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

$$\text{And importance weight of measure} = \frac{1}{n}\sum_{i=1}^{n} w_i \quad (2)$$

Where p_i is the performance rating of corresponding i[th] indicator and w_i is the importance weightage of corresponding i[th] indicator, respectively. The performance ratings and importance weights of the indicators will be input by the users when they are using the fuzzy rule-based system to evaluate their sustainability performance.

In the rule-based system, the terms following the IF statements of the rule are called the premises, while the THEN part of the rule is called the conclusion. The fuzzy AND operator is applied to combine the premise variables. The resulting degree of membership of the logically combined premises is called the adaptability of the premises to the conclusion of the rule [45]. The conclusion part of each rule is a fuzzy singleton, expressed as a word that is associated with a distinct numerical value. The influence of the premise on the conclusion is given by the implication functions. The next step involved the establishing the full sets of 'If and Then' rules for each system. The fuzzy rule bases for fuzzy systems at first and second stages are presented in Table 2 & Table 3. A group of experts in the field of sustainable manufacturing were contacted to lend their opinion on conclusion of the rules.

Table 2. Fuzzy rule base matrix for first stage

First Input Second Input	Poor	Fair	Good
Poor	Poor	Poor	Fair
Fair	Poor	Fair	Fair
Good	Fair	Fair	Good

Table 3. Fuzzy rule base matrix at second stage

First Input	Second Input	Third Input	Output
Poor	Poor	Poor	Poor
Poor	Poor	Fair	Poor
Poor	Poor	Good	Poor
Poor	Fair	Poor	Poor
Poor	Fair	Fair	Fair
Poor	Fair	Good	Fair
Poor	Good	Poor	Poor
Poor	Good	Fair	Fair
Poor	Good	Good	Fair
Fair	Poor	Poor	Poor
Fair	Poor	Fair	Fair
Fair	Poor	Good	Fair
Fair	Fair	Poor	Fair
Fair	Fair	Fair	Fair
Fair	Fair	Good	Fair
Fair	Good	Poor	Fair
Fair	Good	Fair	Fair
Fair	Good	Good	Fair
Good	Poor	Poor	Poor
Good	Poor	Fair	Fair
Good	Poor	Good	Fair
Good	Fair	Poor	Fair
Good	Fair	Fair	Fair
Good	Fair	Good	Fair
Good	Good	Poor	Fair
Good	Good	Fair	Fair
Good	Good	Good	Good

The approach adopted to obtain the conclusion part of the rules involved in the application of fuzzy methodology. The methodology used the weighted performance ratings of the measures to obtain the 'conclusion' for each rule. The first step was to represent the weighted performance ratings of the measures with triangular fuzzy numbers as shown in Table 4. The input variables for assessment of sustainability manufacturing usually have a lot of ambiguity [46]. Thus, use of triangular or (and) trapezoidal membership functions are recommended. Finally, a defuzzification was carried out to obtain a crisp value of the conclusion for each rule.

Table 4. Fuzzy numbers for estimating linguistic variable values

Performance Ratings	
Linguistic variable	Triangular Fuzzy number
Poor	(1, 1, 4)
Fair	(2,4,6)
Good	(4,7,7)

It should be noted that after selecting two by two inputs, if one input variable remains, it would be considered as an output variable of a fuzzy system in that category as shown in Figure 2. The first stage is continued until all input variables are accommodated and number of outputs for each category is reduced to one. There are three output variables at first stage, which are considered as input variables at the second stage. At the second stage, the three input variables represent economic, environmental and social aspects. Thus, it is proposed to use three inputs and three membership functions for a fuzzy system at this stage. The output of the second stage of the fuzzy system provides the overall sustainability score (SS) of the performance of the organization.

5. Illustrative Example

The example of the screenshots of the sustainability evaluation system is presented in Fig.3. It is seen that system is user friendly and applicable in sustainability evaluation and then suitable for strategy selection. The users were required to input the values of importance weights and performance ratings in linguistic terms using radio buttons. The results of sustainability evaluation can be obtained from this expert system in easily manner.

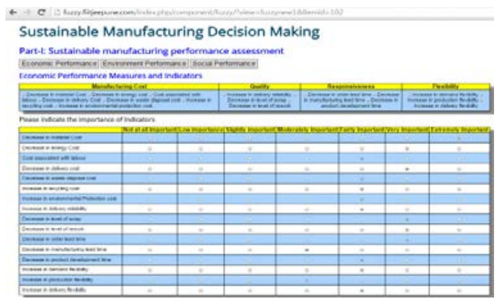

Fig.3. Screenshot of economic performance indicators (Importance rating)

6. Conclusion

This study presents an expert system for sustainability evaluation of manufacturing SMEs. To date, there are very few studies on sustainability evaluation of manufacturing SMEs. In this study, the indicators for sustainability performance evaluations identified from literature considering the characteristics of manufacturing based SMEs were applied. The varied importance of indicators is considered in this study that is very often in the decision making in manufacturing organization. Due to the vagueness in manufacturing decision making, the decision makers expressed their opinions in linguistic terms instead of crisp values. Therefore, fuzzy logic based expert system was developed to deal with subjectivity involved in performance evaluation of manufacturing SMEs.

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