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Evaluation of environmentally conscious manufacturing programs using a three-hybrid multi-criteria decision analysis method

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ABSTRACT

Environmental management, being an important component in strategies for achieving sustainable development of processes and products, has emerged as a proactive approach in majority of the manufacturing organizations. From the strategic perspective environmentally conscious manufacturing (ECM) programs lead to better environmental management practice. The objective of the current paper is to present an integrated and holistic framework to evaluate ECM programs. This framework combines three multi-criteria decision analysis (MCDA) methods to consider eight major environmentally conscious manufacturing indicators (ECMI) in order to identify the efficiency of each ECM program. First the interdependence relationship among the ECMIs is established using decision-making trail and evaluation laboratory (DEMATEL). Then a range of weightage (i.e. upper and lower bounds) is created for each ECMI using analytic network process (ANP) to include managerial preferences. Finally, this range of weightage for each indicator is applied to perform restricted multiplier data envelopment analysis (RMDEA). Results show that the technical efficiency of the inefficient ECM programs for integrated RMDEA, on average, is calculated as 53.2% whereas traditional input oriented DEA provides the same score as 72.3%. This clearly indicates that integrated RMDEA is better than the input oriented DEA because same level of output could be produced with lesser resources if the ECM programs perform on the frontier. Hence, the advantage of this methodology is that the managerial preferences are successfully implemented through this newly developed hybrid methodology that will help to reduce less resource consumption and lead to better environmental policy.

1. Introduction

The manufacturing sector is a significant contributor to environmental damage and resource use and it may have potential long-term implications if resources are overused. Hence, environment friendly manufacturing has been the focus of considerable attention over the past few decades to prevent global warming and climate change by reducing the carbon footprint (Weiser and Dornfeld, 2009; Allen and Shonnard, 2011; Gaussin et al., 2013). With increasing government regulation and stronger public awareness in environmental protection, firms today simply cannot ignore environmental issues if they want to survive in the global market. Many manufacturers have adjusted their manufacturing philosophies and introduced environmental programs into their organizations. The current focus on environment friendly manufacturing is different from the traditional focus on pollution control. In addition to complying with the environmental regulations for selling products in certain countries, firms need to implement strategies to voluntarily reduce the environmental impacts of their products. Hence, environmentally conscious manufacturing (ECM) practices have been receiving increasing scrutiny from both researchers and practitioners (Lee et al., 2009; Chena et al., 2012; Madu et al., 2002).

A manufacturing system is an input–output system, in which the resources of manufacturing are inputs. In manufacturing processes raw materials are transformed into products or semi-products. Manufacturing systems create great material wealth for mankind by embracing a group of integrated strategies, principles and techniques that work together to achieve one or more objectives (Liu et al., 2002; Deif, 2011). One of the key aspects of ECM is sustainable development to meets the needs of the present without compromising the ability of future generations to meet their own needs. In addition, sustainability is considered attractive proposi-

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tion because of its meeting points among environmental concerns, manufacturing and product design activities in order to achieve economic success, environment cleanness, and social responsibility all together (Ghadimi et al., 2012). ECM programs consider implementation of a range of initiatives at the enterprise level, beginning with the design stage and throughout the product's lifecycle to achieve sustainable development (Gaussin et al., 2013).

Sustainable organizations prevent environmental problems for maintaining clean and green atmosphere. However, the challenge to sustainability is to ensure that industries support economic growth while ensuring environmental protection. On the one hand, integrating environmental concerns into management practices has become increasingly important for firms to gain competitive advantage. On the other hand, integration between environmental management and production strategy is relevant to consider ECM programs so that the impact of organizational activities on the environment can be minimized (Venus, 2011; Jabbour et al., 2012). With today's global awareness of environmental risks as well as the pressing needs to compete through efficiency, manufacturing systems are evolving into a paradigm to employ various environment friendly strategies and techniques to become more eco-efficient. Environmentally conscious manufacturing is an economically driven, system-wide and integrated approach to the reduction and elimination of all waste streams associated with the design, manufacture, use and/or disposal of products and materials. By minimizing waste and recycling, the firm can reduce disposal costs and permit requirements, avoid environmental fines, boost profits, discover new business opportunities, increases employee morale, and improve the state of the environment (Curkovic, 2003).

Due to the rapid economic development and the relatively limited resources, ECM programs not only consider recycling and minimizing wastes, but also focus to minimize energy utilization (Bunse et al., 2011; Zhu and Cote, 2004; Vinodh and Rathod, 2010). It is also important to maximize the usage percentage of resources and minimize the damage to the environment in the early product design stage. ECM programs incorporate the principles of environmental protection and energy conservation into production and service activities to reduce industrial waste, save energy and scarce resource, and minimize pollutions to natural environment, while accomplishing production economy (Zhou et al., 2012; Tseng et al., 2008). Manufacturing organizations require to develop and to implement environment friendly manufacturing tools and techniques to stay competitive in the market and creating new business opportunities (Joung et al., 2012; Marchi, 2012). In this regard, a comprehensive and integrated generic framework is required to evaluate ECM programs.

2. Literature review

With the growing concern about climate change and environmental issues, ECM programs are gaining popularity with significant potential in theoretical study as well as industrial applications (Gaussin et al., 2013). It has become important for companies to raise their environmental awareness because more and more international customers and buyers now require their suppliers to produce products that do not contain hazardous and toxic substances (Chiou et al., 2011). In recent years, though environmental management has evolved to include boundary-spanning activities such as green purchasing, reverse logistics and product stewardship, however in developing countries most of the adopted green solutions remain to be the traditional command-and-control or "end-of-the-pipe" solutions where a firm tries to eliminate or reduce negative environmental impacts after they are created, rather than adopting a proactive approach to reduce the sources of waste or pollution. Hence, there is a need to develop algorithms, models, heuristics, and software for addressing major environmentally conscious manufacturing indicators (ECMI) like cost (manufacturing cost including environmental expenditure) (I1), raw material consumption (I2), water consumption (I3), energy consumption (I4), reduction in greenhouse gases (GHG) emission (I5), waste reduction (I6), reduction in water-pollutant discharge level (I7) and reduction in stack-dust emission (I8) (Vachona and Klassen, 2008; Eltayeb et al., 2011; Ilgin and Gupta, 2010; Toke et al., 2012).

Branker et al. (2011) propose a microeconomic model to optimize manufacturing and environmental costs. The importance to reduce raw material consumption is also emphasized by the researchers and practitioners (Report of European Commission, 2014). Fantozzi et al. (2014) focus on the need to reduce water and energy consumption. Reducing energy use also may help to solve the problem of GHG emission (Fang et al., 2011; Sundarakani et al., 2010). Energy intensive manufacturing sectors are major sources of GHG emission as mentioned by different researchers (Curkovic, 2003; Branker et al., 2011; Chena et al., 2012). Minimizing solid wastes may be considered as an integrated part of ECM program (Jayal et al., 2010; Uiterkamp et al., 2011). Regarding wastewater, segregation of waste water streams may help in reducing wastewater volume and waste strength (Report of CPCB, 2008). Several reports and researchers highlight to control water-pollutant discharge level and stack-dust emission (Report of IFC, 2007; Devi and Dahiya, 2008).

Considering different ECMIs researchers have applied different mathematical modelling and optimization methods. Nabavi-Pelesaraei et al. (2013) consider artificial neural network (ANN) and multi-objective genetic algorithm to model and optimize energy inputs and GHG emissions. Researchers have also focused on different multi-criteria decision analysis (MCDA) methods to evaluate ECM programs because MCDA explicitly considers multiple criteria in decision-making environments for analyzing complex real problems. Typical MCDA methods involve three steps; namely (i) determining the relevant criteria and alternatives, (ii) attaching numerical measures to the relative importance to the criteria and the impact of the alternatives on these criteria and (iii) processing the numerical values to determine a ranking of each alternative (Pineda-Henson and Culaba, 2004; Sarkis, 1999; Mittal and Sangwan, 2014). Khalili and Duecker (2013) describe the need to apply MCDA for the evaluation of ECM programs.

Govindan et al. (2014a) analyze the drivers of environmentally conscious manufacturing with fuzzy MCDA approach. Govindan et al. (2014b) also evaluate environmentally conscious manufacturing practices using a hybrid MCDA model combining decision making trial and evaluation laboratory, analytic network process (DANP) with PROMETHEE. Pineda-Henson and Culaba (2004) develop a diagnostic model using analytic hierarchy process (AHP) to assess productivity of ECM. Madu and Madu (2002) use AHP to apply environment friendly design in manufacturing. While Sarkis (1999) considers a hybrid method consisting (ANP) and data envelopment analysis (DEA), Wu and Pagell (2011) consider a hybrid method consisting decision making trial and evaluation laboratory (DEMATEL) and ANP. Focusing on technological aspects, Tseng et al. (2013) present the evidence of environmentally conscious innovation practices and implications for operations management research by developing a hybrid method (linguistic preferences and ANP with entropy weights). However, there is a need to enrich these frameworks by integrating more sophisticated methods of MCDA (Sarkis, 1999). Hence, the current paper describes a hybrid method consisting three major methods of MCDA (namely DEMATEL, ANP and restricted multiplier DEA) to evaluate ECM programs.