Journal of Cleaner Production xxx (2015) 1–17

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Electricity monitoring system with fuzzy multi-objective linear programming integrated in carbon footprint labeling system for manufacturing decision making

Earl-Juei Wang [a,*], Chun-Yu Lin [b], Tai-Sheng Su [b]

[a] National Pingtung University of Science and Technology, Department of Industrial Management, 1 Hsueh-Fu Rd., Nei Pu Hsiang, Pingtung, Taiwan 912, Pingtung, Taiwan

[b] Department of Industrial Management, National Pingtung University of Science and Technology, Taiwan

ARTICLE INFO

Article history:
Received 27 September 2014
Received in revised form
31 May 2015
Accepted 15 July 2015
Available online xxx

Keywords:
Electricity monitoring systems
Environmental regulations
Cost-effectiveness
FMOLP
Carbon footprint label

ABSTRACT

In the novel electricity monitoring system designed in this study, manufacturing data with energy consumption are transformed in real time in the communication module and analysis module and then sent to such information devices as notebooks, i-Pads, or i-Phones. A fuzzy multiple objective linear programming (FMOLP) model is formulated to integrate the designed system for making decision associated with about environmental regulations and cost-effectiveness of carbon emissions in manufacturing firms given a carbon footprint label (CFL). Implementation results demonstrate that the proposed system is very effective in terms of CFL, cost-effectiveness, and manufacturing capacity. Importantly, the electric monitoring system can be practically installed in specific equipment to acquire electric consumption in real time and then helped decision makers to achieve a satisfactory solution in which manufacturing costs and CFL are simultaneously considered under restrain of electricity uncertainty.

1. Introduction

Owing to the increasing environmental awareness globally, firms are pursuing means of complying with emerging regulations for reducing carbon emissions. However, the reduction of carbon emissions increases the cost inputs and this impact must be evaluated. Determining the relationship between carbon emissions and energy consumption is essential for enterprises that limited by environmental regulations. Consistent with the global trend toward reduced carbon emissions, products are being given carbon footprint labels (Upham et al., 2011). Manufacturing firms must consider how to maintain profitability ratios, focus carefully on energy consumptions, and minimize equivalent carbon emission by improving operational systems (Kuhtz et al., 2010). Previous investigations have shown that enterprises must clearly identify the competitive advantages that can be gained by applying competitive production strategies (Hafeez et al., 2007; Yang et al., 2007). However, most of these investigations focused on green supply chain systems and fail to link manufacturing alternatives with cost-effectiveness. A workable carbon reduction strategy must consider planning and cost-effectiveness.

The "carbon footprint" is derived from the ecological footprint and is a measure of the total amount of CO_2 emissions that are directly and indirectly generated by an activity or a product over its manufacturing and operating life (Wiedmann and Minx, 2008). Measured carbon emissions in business include direct on-site emissions and internal and indirect off-site, external, upstream and down-stream emissions. Enterprises must consider alternative means of reducing carbon emissions in terms of their carbon footprint label (CFL). Green supply chains have been widely discussed but most discussions focused on either vendor selection or technical improvement, and they lack a systematic analysis in support of effective production decisions (Chen et al., 2012). Since carbon footprints may cause firms to change their on-site or

* Corresponding author.
E-mail addresses: second@mail.npust.edu.tw, tina.wangs@msa.hinet.net (E.-J. Wang), sam771116@hotmail.com (C.-Y. Lin), tyson@mail.npust.edu.tw (T.-S. Su).

http://dx.doi.org/10.1016/j.jclepro.2015.07.086
0959-6526/

internal manufacturing operations, altering the cost structure, a systematic formulation for analyzing cost-effectiveness is therefore needed. A cost-effective analysis system depends on an accurate and meaningful data collection mechanism. Since manufacturing enterprises must respond to the placing of orders and fulfill manufacturing requirements in a short period, a real-time workable response system must integrate data collection into manufacturing decisions (Candell et al., 2009).

The labeling of on-site/internal products with their carbon footprints is normally based on manufacturing to enable rapid response to change in environmental regulations (Kannan et al., 2012). Factors of interest include materials, production capacity, types of machines used, and the technology used. Batch-order production firms face, problems when estimating carbon emissions in advance of production, as they must consider larger variations in manufacturing from associated with order changeover as well as manufacturing planning and operations (He et al., 2012). Since data based on prior manufacturing experiences may be unavailable, decision-makers require a fuzzy method of evaluating associated with internal manufacturing planning and outsourcing enterprises can meet their manufacturing goals with carbon footprint labels (Shaw et al., 2012). For instance, an order for a stamped auto part may require 1 month to complete with the specified carbon footprint emissions associated with ten manufacturing procedures since downstream manufacturers must estimate their carbon emissions just as the upstream manufacturers do. Carbon footprint labels on products may vary among orders or vendors, and firms that can rapidly manufacture products within the carbon emission limits imposed by buyers may increase their competitiveness (Upham et al., 2011). However, uncertainties include the machine used, yield rates and carbon emissions in various production stages. Factors that affect yield rates and cost-effectiveness include technology, skill of workers, equipment, material, and manufacturing parameters that are related to order specifications and scheduling. Varying yield rates further complicate the control of carbon emissions (Mantripragada and Rubin, 2013).

This study focuses on cost-effectiveness with CFL for manufacturing firms. An optimal model is systematically formulated to analyze manufacturing strategies given varying cost components. The proposed optimization model with fuzzy multiple goals evaluates manufacturing options. Alternatives considered in the proposed models are in-house manufacturing costs, make/outsourcing decisions, and energy sources and operations limitations. The model considers capacity planning and carbon emission requirements with multi-stage planning in terms of connecting relationships to CFL as a basis of model formulation.

This work presents an electric monitoring system that collects manufacturing data and evaluates production efficiency given relevant costs using fuzzy multiple goal models. The specific objectives are as follows:

1. To devise an electricity monitoring system for collecting manufacturing data;
2. to develop a fuzzy multiple goal model that incorporates costs and carbon footprint objects in manufacturing, and
3. to construct a cost-effective integrated manufacturing system that supports carbon footprint labeling.

This paper is organized as follows. Section 2 reviews relevant literature. Section 3 presents the integrated manufacturing system and the fuzzy multiple goal model. Section 4 tests the applicability of the proposed methodology to a case study of a manufacturing firm. Finally, Section 5 draws conclusions and recommends future research.

2. Literature review

Many factors must be considered when designing production systems that minimize costs. Compared to other environmental issues, carbon reduction in manufacturing operations has not been studied extensively. This section reviews the literature on green production, carbon footprint labeling, and carbon inventory as well as related mathematical methods and applications.

2.1. Green production

A manufacturing strategy that satisfies environmental regulations is often referred to as “green production”. Given the trend toward environmentally-friendly products, Jayal et al. (2010) investigated products that are exported from developing countries to industrial countries and are environmentally harmful. They found that firms are currently investigating potential methods of mitigating carbon emissions. Environmental regulations may determine the materials acquired, the process of manufacturing, and recycling. In fact, the concept of green products was developed two decades ago with a focus on the green products concept originally applied to develop efficient manufacturing strategies (Florida, 1996). Since green production affects manufacturing and supply chains, researchers have studied the relationship between environmental management and factory performance (Klassen and McLaughlin, 1996) and the operational aspects of environmental management technologies (Klassen and Whybark, 1999). Studies of green production are numerous and diverse (Jimenez and Lorente, 2001; King and Lenox, 2001; Sroufe, 2003). The United Nations Framework Convention on Climate Change (UNFCCC) has recently provided guidelines for global mitigation of the greenhouse effect. As firms pursue different methods of satisfying international regulations to reduce carbon emissions, their challenge is effectively balancing environmental, economical, and societal concerns with operational performance (Verghese and Lewis, 2007). Yang et al. (2007) discussed the interaction among lean production, environmental practices and environmental performance and analyzed their effects on just-in-time flow, quality management, employee participation, marketing performance, and financial performance. Although green manufacturing is an important issue in both the literature and in industrial practice, a clear definition of sustainable manufacturing has not been established (Jayal et al., 2010). Therefore, the meaning of green manufacturing and its effects on manufacturing guidelines, procedures, and systems warrant further study (Deif, 2011). Considering whole green production, De Silva et al. (2009) emphasized that an evaluation process must begin in the first stage of product design, and Badurdeen et al. (2010) further argued that it should account for the total life cycle of the product.

To satisfy international regulations concerning green production, Sarkis (2003) devised an integrated analytical model that considered the environment, product life cycle, green production, and ISO 14000 standards. Regarding supply chains, green production must include a means of evaluating factors that affect the environment in the material selection, component acquisition, and manufacturing phrases (Enarsson, 1998). Since the environmental impact report must consider the purchasing phase, firms must select suppliers that use manufacturing processes consistent with green production. Min and Galle (1997) presented a purchasing strategy that considered the interaction among green production factors. A supplier evaluation/selection model developed for the high-tech industry by Lee et al. (2009) included manufacturing quality, technological capability, cost of product over its total life cycle, green image of product, pollution control, environmental