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Production planning of multi-stage multi-option *seru* production systems with sustainable measures

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ABSTRACT

With the concerns over climate change and the escalation in worldwide population, sustainable development attracts more and more attention of academia, policy makers, and businesses in countries. Sustainable manufacturing is an inextricable measure to achieve sustainable development since manufacturing is one of the main energy consumers and greenhouse gas contributors. In the previous researches on production planning of manufacturing systems, environmental factor was rarely considered. This paper investigates the production planning problem under the performance measures of economy and environment with respect to *seru* production systems, a new manufacturing system praised as Double E (ecology and economy) in Japanese manufacturing industries. We propose a mathematical model with two objectives minimizing carbon dioxide emission and makespan for processing all product types by a *seru* production system. To solve this mathematical model, we develop an algorithm based on the non-dominated sorting genetic algorithm II. The computation results and analysis of three numeral examples confirm the effectiveness of our proposed algorithm.

1. Introduction

As material, energy and waste costs rise, environmental efficiency improvements will have greater benefit than ever before. Significant benefits from an environmental focus have been shown (Schönsleben et al., 2010). Companies that improve environmental efficiency will thrive, while the rest will suffer higher costs from waste disposal and non-compliance with punitive legislation (Ball et al., 2009) and high energy consumption. The environmental problems have led to concerns about the sustainable development in countries (Jayal et al., 2010). The need for sustainable development arose as a response to growing concerns over how economic growth often was associated with environmental damage (OECD, 2010).

The concept of sustainable development was originally defined by Brundtland Commission (1987), on behalf of the UN general assembly. World Commission on Environment and Development defined that: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission, 1987). In academic debates and business arenas, hundreds of definitions of "sustainability" and "sustainable development" have been proposed referring to a more humane, more ethical, and more transparent way of doing business (Garetti and Taisch, 2012). For a manufacturing enterprise, effective measures should be taken to achieve synchronous development of environment and economy.

Manufacturing industry, the backbone of industrialized society, is the main energy consumers and greenhouse gas (GHG) contributors in recent times (Jeswiet and Nava, 2009; Jovane et al., 2008). According to the World Energy Outlook in 2008, the industrial production activities contribute over 33% of total carbon dioxide emissions and consume more than 40% of total energy. The influence of low carbon economy on manufacturing enterprises becomes increasingly prominent. Manufacturing enterprises that do not measure and manage carbon emissions in their manufacturing system will place themselves at a disadvantage. Sustainable manufacturing has been actualized as an effective measure due to its contribution to carbon dioxide abatement and economic progress (Ball et al., 2009).

To be more competitive, manufacturing enterprises should consider energy consumption and economy as important factors.

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From this point, many manufacturing enterprises from different countries have began to search for new development paths and take some innovations in many aspects to effectively reduce the energy consumption while keep economic growth. The reported methods include switching to less carbon-intensive fuels, developing and applying renewable energy, adopting advanced production system, renewing their equipment, introducing high efficient process, introducing low carbon technologies, adjusting and improving process and so on. These methods provide the promising opportunities for manufacturing enterprises to produce low-carbon and low-cost products.

The research presented in this paper takes an operational approach to minimize carbon dioxide emission caused by energy consumption and minimize makespan during manufacturing within a *seru* production system. *Seru* production system is an innovation achievement of manufacturing system. It is firstly used at Sony in Japan in 1992, and then has been widely implemented in Japanese manufacturing industries, especially Japanese electronics industry (Iwamuro, 2002; Noguchi, 2003; Kimura and Yoshita, 2004; Kono, 2004; Takeuchi, 2006). Based on excellent performance on economic and environmental aspects, *seru* production has been praised as Double E (ecology and economy) production management mode by some Japanese manufacturing enterprises. Although *seru* production systems have been extensively implemented, the theoretical research on them is insufficient, especially in the field of how to achieve sustainable performance.

The rest of this paper is organized as follows. In Section 2, a literature review is expounded. Then Section 3 is dedicated to the problem description, notation and the formulation of mathematical model for our research problem. A NSGA-II method for solving the proposed mathematical model is developed in Section 4. The numerical experiments for our proposed model and algorithm are discussed in Section 5. Finally, the conclusions are drawn in Section 6.

2. Literature review

With the increasing concerns on energy consumption and environmental impacts, more and more researchers have paid attention to the investigation of sustainable manufacturing, which plays a key role in helping the transition toward sustainable development. Many researchers have shown that environmentally sustainable practices can lead to competitive outcomes in manufacturing industries. Rusinko (2007) surveyed the entire U.S. commercial carpet industry, and indicated that environmentally sustainable manufacturing practices positively associate with manufacturing cost, product quality and so on. Yang et al. (2011) found that the environmental performance has positive impacts on financial and market performance. Gimenez et al. (2012) analyzed the impact of environmental and social programmes of firms on environmental, social, and economic performance, and indicated that there is a positive relationship among them.

Many sets of key performance indicators for sustainability have been reported in the literature. Most studies on sustainability in operations management usually take energy consumption and/or carbon footprint as the important factors. Sundarakani et al. (2010) examined the carbon footprint across supply chains. Pekala et al. (2010) described a general modeling approach for optimal planning of energy systems subject to carbon and land footprint constraints. Hua et al. (2011) investigated how firms manage carbon footprints in inventory management under carbon dioxide emission trading mechanism. Zhang et al. (2012) proposed an easier way of calculating carbon footprints of products by focusing on the connection characteristics between components, and a novel method for identifying connection units with high greenhouse gas emissions. Heddeghem et al. (2012) provided a mathematical model for calculating carbon footprint, and proposed manufacturing footprint and geographical region parameter as two critical factors for evaluating carbon footprint. Dormer et al. (2013) investigated the carbon footprint associated with plastic trays used as packaging for foodstuffs.

In the literature, many works are devoted to investigating the methods to achieve sustainability. Zhang (2011) built a low carbon operation model of manufacturing enterprise, and divided the production management into low carbon procurement, low carbon production, low carbon marketing and low carbon product handling. Smith and Ball (2012) developed guidelines for material, energy and waste process flow modeling to pursuit zero carbon manufacturing and sustainable manufacturing. In the literature, two approaches that are helpful for reducing greenhouse gas emissions were provided (Fang et al., 2011; He et al., 2012; Mouzou et al., 2007). One is to reduce the amount of electrical energy used. The other is to use energy with low carbon dioxide emission. Pusavec et al. (2010) proposed methods to reduce resource consumption and create less waste on a machining technology level for achieving production sustainability. In this paper, we focus on the first method to reduce GHG so as to reduce carbon footprint.

For the methods to achieve sustainability, many researchers paid attention to the methods about machine tools. Vijayaraghavan and Dornfeld (2010) correlated energy usage with operations in the manufacturing system. They proposed a method to reduce energy consumption by monitoring and analyzing of energy consumption of machine tools in manufacturing system. Mori et al. (2011) measured power consumption of machining center in various conditions, and indicated that the modification of cutting conditions can reduce energy consumption. Branker et al. (2011) proposed a microeconomic machining model that can optimize machining parameters and include all energy and environmental costs with respect to carbon emissions and cost sensitivity. Cao et al. (2012) proposed a carbon efficiency approach to characterize the life-cycle carbon emissions of machine tools, and proposed strategies of reducing varied carbon emissions by improving energy efficiency and making the best match of production tasks with equipment.

Several approaches to evaluate carbon dioxide emission have been developed in the literature. Jeswiet and Kara (2008) proposed a carbon dioxide emission signature method to calculate the total carbon dioxide emission caused by electrical energy consumption in manufacturing process for producing a complete product. Seow and Rahimifard (2011) adopted a novel approach to model energy flows within a manufacturing system based on product viewpoint and enhance the transparency of energy consumption across manufacturing processes. Götze et al. (2012) proposed an integrated approach for the energy-oriented evaluation of machine tools consisting of the measurement of energy consumption, modeling of energy flows and simulative analysis of the energy saving potentials.

Several studies also concentrated on the operational decision-making with the consideration of environmental performance. Mouzon et al. (2007) proposed a multi-objective mathematical programming model to minimize the energy consumption and total completion time, the results can facilitate the production manager to determine the most efficient production sequence which can minimize energy consumption and total completion time simultaneously. Mouzon and Yildirim (2008) proposed a framework to solve a multi-objective optimization problem that minimizes total energy consumption and total tardiness. He and Liu (2010) explored a systematic methodology to incorporate energy consumption and environmental impact into scheduling activity and production operation for machining processes. He et al. (2012)