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A recursive operations strategy model for managing sustainable chemical product development and production

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A B S T R A C T

Sustainable consumption and production is a critical issue in the chemical industry due to increasing public concerns on environmental and safety issues. Organizations are urged to improve the quality of chemical products while minimizing the environmental impacts during production. In current practice, chemists and formulators have to determine both the ingredients to be used and the machine parameter settings during product development and production. Without appropriate operations strategies for managing sustainable consumption and production, a significant portion of the ingredients, toxic materials and pollutants are wasted or emitted during the trial-and-error processes when developing chemical products. In addition, inappropriate machine parameter settings, such as blending speed and blending temperature, result in inefficient energy use. Motivated by these issues, this paper describes a recursive operations strategy (ROS) model for achieving sustainable consumption and production in the chemical industry. The ROS model first identifies the business strategy, and then defines operations strategies by assessing the competitive priorities and policies with the use of artificial intelligence, including case-based reasoning and fuzzy logic, so as to manage the operations functions. The effectiveness of the model is verified by means of a case study. The results indicate that the model can provide direct guidelines for the users to develop products based on previously developed products. By so doing, the number of trials for testing various ingredient formulae can be reduced, minimizing the ingredient waste. The proposed model is also capable of achieving continuous improvement and determining the optimal production process conditions for avoiding unnecessary energy consumption.

1. Introduction

In view of improved standards of living, consumers now have higher expectations on products during purchasing. Together with a number of constraints stemming from public concerns, such as environmental, legislative and safety issues (Govindan et al., 2014), there has been a rapid growth in consumer demand for targeted end-use properties (Charpentier, 2009). In particular, chemical-based consumer products, such as soap, shampoo, detergents and cosmetics, have to be more multifunctional, micro-structured, and better engineered than that in the past, so as to meet the consumer requirements. This has posed new challenges to the chemical industry in remaining profitable and in achieving sustainable growth.

Because of the demands of the current industrial environment, a growing awareness of sustainable consumption and production has also been cultivated in the chemical industry. Traditionally, a significant portion of the chemical ingredients is wasted during chemical product development, and the determination of machine parameter settings used in production, such as temperature and speed, relies on human experience. Thus the efficiency of energy use is not monitored or controlled systematically.

In this paper, a recursive operations strategy (ROS) model is proposed to support sustainable consumption and production in the chemical industry. The goal of the model is to improve the sustainability level of the industry with respect to the reduction of waste and energy. Firstly, the overall business strategy of the

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company is defined. Then, operations strategies are designed to manage the operations functions based on specific competitive priorities. Subsequently, policies are designed with the use of artificial intelligence so as to manage the operations functions. The novelty of the proposed ROS model includes the integration of Case-based reasoning (CBR) and fuzzy logic that is applicable for managing sustainability in the chemical industry. CBR has been widely adopted as a knowledge support tool for solving problems in such experience-rich domains as chemical product development. For instance, Craw et al. (1998) presented a CBR approach for tablet formulation in pharmaceutical product development. Avramenko and Kraslawski (2006) used CBR to formulate fat and oil products. However, previous work mainly focused on improving the effectiveness of the chemical product formulation. The trade-off between effectiveness and sustainability was not fully considered. Furthermore, while the parameters used in chemical product development are usually expressed in linguistic terms, the practical adoption of parameters have to be determined quantitatively. Solely using CBR cannot dynamically suggest the appropriate parameters quantitatively. In line with these, the proposed ROS model is considered novel as it is one of the pioneering models focusing on the improvement of sustainability in chemical product development by integrating CBR and the fuzzy set theories. CBR is applied to provide knowledge support for developing new products such that the number of trials, together with the associated chemical disposal, can be reduced. Fuzzy logic is used to determine the appropriate parameter settings to be used in such a way that the energy consumption can be optimized. Continuous improvement can be made because of the learning abilities of CBR and fuzzy logic in policy design.

The contributions of this paper include a novel recursive operations strategy model specifically designed for the chemical industry, an integrated approach to improving the sustainability of chemical product development and production, and a more sophisticated formulation of operation policies supported by the integration of artificial intelligence techniques. In addition, though CBR has been a promising tool in providing knowledge support in experience-rich domains, it does not take the vagueness of human thought and expression into account when determining the quantitative parameters used in product development and production. This research solves this problem by integrating CBR and fuzzy set theories in order to determine the appropriate parameter settings for maintaining sustainability.

The remainder of the paper is organized as follows: Section 2 reviews the literature related to this study. Section 3 introduces the proposed decision support model. Section 4 presents a case study for demonstrating the feasibility of the model. Section 5 gives the results and discussion. Finally, Section 6 gives conclusions of this study.

2. Literature review

Considering the continued deterioration of the global environment due to global warming and scarcity of resources (Dadhich et al., 2015), the unsustainable pattern of consumption and production in the industrialized countries is viewed as the main culprit. According to Barber (2007), sustainable consumption and production is generally constructed as two parts: sustainable consumption and sustainable production. Sustainable consumption pays attention to the awareness of changing customer behavior, values and their motivation. On the other hand, sustainable production considers not only the quantity of goods or services, but also its production process, the extraction of raw material and the waste and pollution generated from the production cycle (Pusavec et al., 2010). With the increasing environmental concerns, a consensus is growing that a certain level of commitment to sustainability practices should be adopted (Hassini et al., 2012), and attention has been paid to minimizing the environmental impacts of process design and development (Nikolopouulou and Ierapetritou, 2012). For a successful enterprise, sustainable consumption and production helps to build a good image for the firm by producing customer-driven products with high quality. Prominent research areas include minimization of waste generated (Hilaly and Sikdar, 1995; Chang and Hwang, 1996; Dantus and High, 1996; Kheawhom and Hirao, 2004) and reduction of energy consumption (Gadalla et al., 2006; Karuppiah et al., 2008; Sun et al., 2015).

In general, the focus on minimization of waste should not only on the manufacturing processes, but also on the product life cycle, from product development to final disposition (Freeman et al., 1992; Nazzal et al., 2013). Nuner et al. (2016) investigated the strategic environmental decisions of a luxury car manufacturer to reduce the overall emission during the production process. In chemical product development, most products are developed through experimental trial-and-error approaches (Wibowo and Ng, 2004; Cheng et al., 2009; Hill, 2009; Conte et al., 2011). As a consequence, an appreciable amount of chemical substances are disposed of after experimentation before a product with the desired properties can be formulated successfully.

In order to minimize harmful chemical waste during the manufacturing stage, an enterprise should start from reviewing their business strategy and operation strategy so as to develop a long term sustainable business goal (Gunasekaran and Spalanzani, 2012). Business strategy clearly defines the business goal and mission of a company on how to achieve competitive advantage, while operation strategy is aligned with the organization's overall business strategy considering the competitive priorities, objectives and activities of operation for effective resources allocation (Adamides, 2015; Slack and Lewis, 2011; Teece, 2010). To achieve the business goal in sustainable production, environmental consideration is defined as a core direction to link strategies to operations (Simpson and Samson, 2010). Schoenherr (2012) studied the relationship between sustainable business strategy development on manufacturing plant operations considering environmental concerns. Leonidou et al. (2015) suggested that the implementation of environmental friendly business strategies facilitated the achievement of competitive advantage on product differentiation. By defining appropriate business strategies related to sustainable production, companies can hence formulate operations strategies to minimize waste during the production process. Shavarini et al. (2013) suggested that the business and operations strategies should be aligned to improve the business performance. Kim et al. (2014) proposed an operation strategy model to link business strategy with production strategy by considering the tradeoffs between competitive priorities, and setting the performance targets and action plans. Brown and Blackmon (2005) discussed the importance of aligning manufacturing and competitive strategies during operations. Kristal et al. (2010) studied the influence of operations strategy on competitive capabilities in terms of cost, time, quality and flexibility, on business performance. Oltra and Flor (2010) suggested that cost and quality had positive impacts on the business strategies in the relationship between operation strategies and business results while negative impacts were found on time and flexibility through an empirical study. In addition to the above four competitive capabilities, Nand et al. (2013) proposed an integrated operations strategy model by also considering the asset and operating frontiers. Longoni and Cagliano (2015) examined the environmental and social sustainability concerns when designing the operations strategy. To summarize, it is found that most of past studies mainly focused on investigating the influence of competitive capabilities, operations