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Multi-objective optimization for sustainable supply chain network design considering multiple distribution channels

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ABSTRACT

The emergence of Omni-channel has affected the practical design of the supply chain network (SCN) with the purpose of providing better products and services for customers. In contrast to the conventional SCN, a new strategic model for designing SCN with multiple distribution channels (MDCSCN) is introduced in this research. The MDCSCN model benefits customers by providing direct products and services from available facilities instead of the conventional flow of products and services. Sustainable objectives, i.e., reducing economic cost, enlarging customer coverage and weakening environmental influences, are involved in designing the MDCSN. A modified multi-objective artificial bee colony (MOABC) algorithm is introduced to solve the MDCSCN model, which integrates the priority-based encoding mechanism, the Pareto optimality and the swarm intelligence of the bee colony. The effect of the MDCSCN model are examined and validated through numerical experiment. The MDCSCN model is innovative and pioneering as it meets the latest requirements and outperforms the conventional SCN. More importantly, it builds the foundation for an intelligent customer order assignment system. The effectiveness and efficiency of the MOABC algorithm is evaluated in comparison with the other popular multi-objective meta-heuristic algorithm with promising results.

1. Introduction

Along with the development of Omni-channel, supply chain enterprises are facing new challenges. On one hand, an increasing number of customers tend to purchase their products online rather than shopping in the conventional brick-and-mortar stores (Brynjolfsson, Hu, & Rahman, 2013). Meanwhile, customers are expecting more flexible delivery service than ever before, such as fast delivery and on time delivery. On the other hand, the market competition is also forcing the supply chain enterprises either to provide novel value-added services or to optimize the existing operations to fulfill the customer requirements (Chan, He, & Wang, 2012). To ensure a flexible delivery, a number of central or regional warehouses have to be built in specific areas to shorten the distance from customers. Adequate product allocation for different warehouses is realized by considering the preferences of customers in particular regions. Two other aspects which confront the development of supply chain enterprises are the environmental influence and social concerns. Energy and resource consumption, governmental legislation and customer awareness are all forcing supply chain enterprises to conduct practical initiatives so as to keep a good environmental image and shoulder the social responsibility. The economic measurement, environmental influence and social concerns constitute the triple bottom line for the development of sustainable supply chain (Linton, Klassen, & Jayaraman, 2007).

Aiming to overcome these challenges, supply chain enterprises undertook a variety of operations and activities, among which the design of an efficient supply chain network (SCN) is the most important and fundamental initiative (Sachan & Datta, 2005). A well designed SCN could be treated as a flexible and scalable system platform, which supports further operations and activities. The operational process of the conventional SCN platform is rather strict. For instance, customer orders can only be delivered from regional distribution centers (DC) and the inventory of regional DC is supplied by the central DC. However, such a strict flow can cause severe waste in terms of manpower and facility. In this research, we propose a novel strategic design of SCN with multiple distribution channels (MDCSCN). In contrast with the conventional SCN, in which the products have to flow through a strict sequence of facilities, the design of MDCSCN presents a much more flexible network platform, especially for customers. Customer orders can be served from any available facility in the MDCSCN. For instance, a customer order can be fulfilled by manufacturers, central distribution centers

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(DC) or regional distribution centers. The determination of serving facilities for customers in the MDCSCN is affected by multiple considerations such as operating cost, transportation cost, customer service level and environmental influence, which are designed to initiate sustainable development for supply chain. With the support of the MDCSCN, a new supply chain system can be designed, which can intelligently analyze customer orders and determine the optimal facility to serve customers.

The design of the MDCSCN pertains to the category of the facility location problem (FLP), in which the location of a number of facilities and the allocation of customers to particular facilities need to be determined. The MDCSCN model is of high complexity due to the multiple echelon settings, the large number of facilities in each echelon and the multiple distribution channels, which lead to a large scale problem and it is not feasible to be solved by exact algorithms. Therefore, meta-heuristic algorithms become the only appropriate choice. In this research, swarm intelligence is employed as the major approach to solve the MDCSCN model. Swarm intelligence is a new branch of meta-heuristics in contrast with the evolutionary computational methods, such as genetic algorithm (GA). Swarm intelligence is inspired by the collective behavior of insect colonies and animal societies (Blum & Merkle, 2008). One of the typical examples of swarm intelligence is the foraging behavior of bee colonies, which drives the introduction of the artificial bee colony (ABC) algorithm. The operation of bee colony possesses two features, self-organization and labor division. Three types of bees exist in a bee colony and each bee controls its own behavior individually. The collective behavior of bee colony demonstrates high intelligence during the searching process towards best food source (Karaboga & Basturk, 2008). Since the introduction of the ABC algorithm, it has attracted much attention from researchers due to its balanced search ability and easy implementation. The original ABC algorithm was designed to solve numerical optimization problems with single objectives. However, the MDCSCN is modeled as a practical industrial optimization problem with complicated constraints and multiple objectives. Therefore, in this research, a multi-objective artificial bee colony (MOABC) algorithm is designed for solving the MDCSCN model, which comprises the priority-based encoding mechanism for solution representation, the concept of Pareto optimality for handling multiple objectives, and the swarm intelligence of the bee colony. The performance of the MOABC algorithm is measured using numerical experiments and the results indicate that it outperforms the multi-objective genetic algorithm (MOGA).

The remainder of this paper is organized as follows. After a brief review of the existing literature for sustainable supply chain networks and swarm intelligence, we formulate the MDCSCN model with multiple objectives in Section 3. Section 4 presents the multi-objective optimization approach with swarm intelligence to solve the problem stated in Section 3. The designed experiment and discussion of results are presented in Section 5. The final section concludes this research.

2. Literature review

2.1. Sustainable supply chain network design

The design of the SCN has been drawing ever-growing attention from academic researchers and industrial practitioners as it provides fundamental and underlying support for other supply chain operations and activities. There are a number of publications concerning the SCN design from different perspectives. One of the popular trends is the design using reverse logistics, which emphasizes the collection and process of end-of-life or end-of-use products. For example, Wang and Yang (2007) designed a reverse logistics network for recycling electronic waste. Reynaldo and Jürgen (2009) designed a reverse logistics network for collection of end-of-life vehicles. The closed-loop supply chain is another research topic, in which the forward logistics and reverse logistics are integrated. For instance, Kusumastuti, Piplani, and Hian Lim (2008) designed a closed-loop service network emphasizing the post-sale service. Easwaran and Üster (2010) designed a closed-loop SCN with integrated forward and reverse channels. The integration of the SCN design with other supply chain components is also a promising research area. For example, Hugo and Pistikopoulos (2005) incorporated the life cycle assessment criteria as part of the strategic investment decisions into the SCN design. Amin and Zhang (2012) integrated the closed-loop supply chain configuration with the supplier selection model. Tancrez, Lange, and Semal (2012) presented a location-inventory model for large three-level SCN. Govindan, Jafarian, Khodaverdi, and Devika (2014) introduced a multiple-vehicle location-routing model for the design of SCN for perishable food.

The concept of sustainability could be used to integrate the multifarious objectives for designing SCN (Linton et al., 2007). The measurement of the sustainability of the SCN could be categorized into three aspects, i.e., economic consideration, environmental influence and societal concerns (Piplani, Pujawan, & Ray, 2008). The economic consideration is the most common measurement metric when designing any SCNs, which is frequently measured in terms of either minimizing cost (Fledelius & Mayoh, 2008) or maximizing profit (Shen, 2006). The environmental influence is frequently measured in terms of the carbon emissions, which are associated with the various activities in the supply chain (Sundarakani, de Souza, Goh, Wagner, & Manikandan, 2010). The sustainable development for designing SCN becomes a popular trend. For instance, Frota Neto, Bloemhof-Ruwaard, van Nunen, and van Heck (2008) developed a framework for the design and evaluation of sustainable logistics networks, which balanced the economic profitability and environmental impacts. Karaboga (2005b) planned a sustainable reverse logistics system balancing costs with environmental and social concerns, in which the economic objective, environmental objective and social objective are represented as the collection variable costs, carbon emission and working hours respectively. Eskandarpour, Zegordi, and Nikbakhsh (2013) designed a sustainable post-sales network with multiple objectives, among which the first objective consists of fixed and variable cost; the second objective is to measure customer tardiness and the third objective is to compute the number of disposed components. More research concerning the sustainability and supply chain can be found in the literature (Hassini, Surti, & Searcy, 2012; Seuring & Müller, 2008).

2.2. Swarm intelligence

Swarm intelligence is inspired by the collective behavior of social insects or animal societies, which forms a new branch of the meta-heuristic approaches in contrast with evolutionary computation (Blum & Li, 2008). Swarm intelligence possesses three inherent features, i.e., decentralization, self-organization and collective behavior (Bonabeau, Dorigo, & Theraulaz, 1999). Decentralization means that no central mechanism exists for controlling or managing the behavior of each individual. Self-organization indicates that each individual determines its own behavior. An individual may interact with the other individuals or the environment so as to determine its next move. Such an interaction might follow some simple rules. The behavior of an individual might be non-deterministic or even random. However, the collective behavior of the entire population turns out to be intelligent in regard to achieving certain goals. Ever since the introduction of the concept of swarm intelligence by Beni and Wang (1993), a number of swarm intelligent algorithms have been proposed, such as the Ant System inspired by the operations of ant colonies (Dorigo, Maniezzo, & Colorni, 1996) and the Artificial Bee Colony algorithm inspired by