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Simulation-based heuristic method for container supply chain network optimization ☆

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ABSTRACT

With the emerging of free trade zones (FTZs) in the world, the service level of container supply chain plays an important role in the efficiency, quality and cost of the world trade. The performance of container supply chain network directly impacts its service level. Therefore, it is imperative to seek an appropriate method to optimize the container supply chain network architecture. This paper deals with the modeling and optimization problem of multi-echelon container supply chain network (MCSCN). The problem is formulated as a mixed integer programming model (MIP), where the objective is subject to the minimization of the total supply chain service cost. Since the problem is well known to be NP-hard, a novel simulation-based heuristic method is proposed to solving it, where the heuristic is used for searching near-optimal solutions, and the simulation is used for evaluating solutions and repairing unfeasible solutions. The heuristic algorithm integrates genetic algorithm (GA) and particle swarm optimization (PSO) algorithm, where the GA is used for global search and the PSO is used for local search. Finally, computational experiments are conducted to validate the performance of the proposed method and give some managerial implications.

1. Introduction

Container supply chain is an integrated system including transportation, packing, container storage, container loading, container transshipment, container unloading and unpacking. Container supply chain is essentially logistics service supply chain, which has characteristic features of service supply chain. However, there are some differences between them. (1) The structure of the container supply chain is more complex than that of logistics service supply chain. The container supply chain is made up of all the activities required to deliver containers to customers, such as inventory, transportation, loading/unloading, distribution, cargo and shipping agency, and customer service. However, the structure of logistics service supply chain is functional logistic service provider-logistics service integrator – manufacturers or retailers. (2) In the cost structure fold, container supply chain is also more complex, which refers shortage cost, transportation cost, handling cost, storage cost overstock cost. The logistics service supply chain generally only considers service cost. In all the activities, container supply chain is a network for satisfying value increment of the entire chain. The integration and collaboration of the container supply chain management processes and systems are more evident and become more necessary. The most necessary condition for maximizing economical, security and social benefits of the entire supply chain is the coordination of all nodes in container supply chain. With the mushroom development of the service economy in the world, the optimization and coordination of container supply chain network have become the mainstream in this research area.

With the emerging of free trade zones (FTZs) in the world, many manufacturing, service, logistics, port and shipping enterprises gather in FTZs, which does not only bring about huge logistics, but also bring about diversified product supply chain and service supply chain, such as container supply chain. FTZs have further requirements for higher efficiency and lower cost of global supply chain. Thus, the service level of container supply chain plays an important role in the efficiency, quality and cost of the world trade. The performance of container supply chain network directly impacts its service level.

In order to reduce costs, minimize inventories and of course, improve profits, effectively integrating the information flow, logistics, commerce flow and cash flow within the demand and supply process plays a very key role. For most node enterprises of

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container supply chain, such as inland yards, container terminals and shipping lines, two major and very interdependent issues must be simultaneously addressed. The first issue is delivering containers with very short lead times at a customer-acceptable cost. The second issue is sharing the effective, high-quality and timely information. Regardless of anyone in container supply chain, more effective supply chain network will be a prerequisite to win–win cooperation. In fact, effective container supply chain management must become an integral part of competitive and survival strategy. Therefore, we must seek appropriate method to optimize the network architecture of container supply chain from the entire chain perspective.

This rest of the paper is organized as follows. In the next section, relevant literatures are reviewed. In Section 3, mathematical models are formulated for our problem. Section 4 proposes a simulation-based heuristic for resolving our problem. Numerical experiments for evaluating the proposed model and heuristic are performed in Section 6, and some concluding remarks and future research are given in the last section.

2. Literature review

To date, there are numerous studies on supply chain management [1]. Most of these studies have been devoted to product supply chain or service supply chain management. However, container supply chain management is rarely addressed. Although container supply chain close to logistics service supply chain, but these studies on logistics service supply chain only considered two or three echelons. The models and methods for logistics service supply chain are not entirely suited to our problem. Moreover, although container supply chain network optimization is imperative, most significant researches have focused on the empirical study. Since container supply chain is tightly related to logistics and port, only a brief review of studies highly related to service supply chain, logistics service supply chain and shipping supply chain are provided in this section.

Up to now, tremendous attentions have been appealed towards the research work on logistics service supply chain in achieving competitive advantage, such as logistics service supply chain network design and optimizing, selection of logistics service providers, supply chain integration and coordination with revenue-sharing contracts [2]. Zhen [3] proposed an optimal decision model for designing Service-Oriented Manufacturing supply chain strategy. Persson and Virum [4] developed a set of hypotheses concerning logistics service providers and their roles in supply chain alliances, and proposed a matrix categorizing the players and their strategic position. Choy et al. [5] proposed an integrated logistics management information system to integrate business processes and increase information transparency in the logistics supply chain for reducing uncertainty. Liu et al. [6] thought that a logistics service supply chain consists of one logistics service integrator and many functional logistics service providers, developed a two-echelon order allocation mode1 to establish a subjective utility function of each functional logistics service provider based on the cumulative prospect theory in two-period order allocation. Furthermore, Liu et al. [7] proposed a deterministic approach to the fairest revenue-sharing coefficient when the logistics service integrator and the functional logistics service provider implement revenue-sharing contract under stochastic demand condition. Jayaram and Tan [8] employed the support of extant theory to supply chain integration with third-party logistics providers. Liao and Kao [9] proposed an effective approach integrating quality function development, fuzzy extended analytic hierarchy process and multi-segment goal programming for logistics customer service management. Celebi et al. [10] used analytical network process for logistics management to increase the operational efficiency by facilitating greater collaboration and coordination with business partners.

Container supply chain is one part of shipping supply chain, which has drawn more attention from researchers in recent years. Talley [11] investigated the effects of carrier, port and shipper choice effects in shipping supply chain. Bichou and Gray [12] proposed relevant framework of port performance through conceptualizing ports from a logistics and supply chain management approach. Lam [13] proposed a tool to analyze patterns of ports and routes and shipping lines that are embedded within the shipping supply chain. Gibbs et al. [14] investigated the role of ports in helping to mitigate the emissions associated with the shipping supply chain. Barnes and Oloruntoba [15] highlighted the need for enhanced crisis management capabilities s and across supply networks. Moreover, Yang [16] used a loss exposure matrix and a bowtie diagram to evaluate the impact of risk factors on the shipping supply chain in Taiwan. Lam and Yap [17] investigated the calling patterns of container shipping services to understand the dynamics of liner shipping network and port connectivity in the supply chains and suggested a new classification scheme for mapping vulnerability within ports. Zhen and Chang [18] and Zhen [19] addressed the resource scheduling problems of port node in container supply chain.

As an effective approach for solving manufacturing systems, supply chain systems, financial management systems, transportation systems and logistics systems, simulation-based optimization method has drawn more attention from researchers in recent years. Arango et al. [20] constructed a simulation optimization framework for optimizing the port berth allocation planning problems. Jung et al. [21] used simulation based optimization approach to determine the safety stock level to use to meet a desired level of customer satisfaction. Schwartz et al. [22] proposed a simulation-based optimization framework for inventory management in supply chains under supply and demand uncertainty. Mourani et al. [23] proposed a bi-section search algorithm based on simulation and sample gradients for minimizing the long-run average inventory holding and backlogging cost of a single-stage single-product manufacturing system. Zeng and Yang [24] proposed a simulation-based optimization approach to solve an integrated handling equipment scheduling problem for loading operations. Lee et al. [25] proposed a simulation optimization method for robust flight scheduling. Legato et al. [26] proposed a simulation-based heuristic to generate and evaluate the container yard handling equipment assignment policy. Chang et al. [27] proposed a simulation optimization method for solving the combined berth allocation with quay cranes assignment, where the simulation was used to simulate the handling operations as the ships arrived and evaluate the performance of each schedules. He et al. [28] presented a simulation optimization method to solve the problem of sharing internal trucks among multiple container terminals in a large port with multiple adjacent terminals, where the GA was used for guiding the search process and the simulation was used for evaluating and adjusting schedules. Korytkowski et al. [29] proposed evolutionary simulation-based heuristics to construct near-optimal solutions for dispatching rule allocation. Zhen et al. [30] proposed a simulation optimization framework for ambulance deployment and relocation problems.

Therefore, it can be seen that most significant researches have only concerned with the evaluation of shipping supply chain. However, to our best knowledge, no paper has specially investigated the container supply chain, not to speak of modeling and optimizing the problem of the multi-echelon container supply chain network (MCSCN).

The literature survey also indicates that the simulation optimization is found to be quite powerful by various researchers to find the near-optimal solutions of combinatorial optimization problem such as supply chain systems optimization. Thus, different variations of simulation-based heuristic method are proposed for solving the MCSCN problem with the objective of minimizing total supply chain service cost.

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