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Application of a mixed fuzzy decision making and optimization programming model to the empty container allocation

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ABSTRACT

Containerization transportation has been growing fast in the past few decades. International trades have been growing fast since the globalization of world economies intensified in the early 1990s. However, these international trades are typically imbalanced in terms of the numbers of import and export containers. As a result, the relocation of empty containers has become one of the important problems faced by liner shipping companies. In this paper, we consider the empty container allocation problem where we need to determine the optimal volume of empty containers at a port and to reposition empty containers between ports to meet exporters' demand over time. We formulate this empty container allocation problem as a two-stage model: in stage one, we propose a fuzzy backorder quantity inventory decision making model for determining the optimal quantity of empty container at a port; whereas in stage two, an optimization mathematical programming network model is proposed for determining the optimal number of empty containers to be allocated between ports. The parameters such as the cost of loading container, cost of unloading container, leasing cost of empty container, cost of storing container, supplies, demands and ship capacities for empty containers are considered in this model. By taking advantages of the fuzzy decision making and the network structure, we show how a mixed fuzzy decision making and optimization programming model can be applied to solve the empty container allocation problem. The utilization of the proposed model is demonstrated with a case of trans-Pacific liner route in the real world. Six major container ports on the trans-Pacific route are considered in the case study, including the Port of Kaohsiung, the Port of Hong Kong, the Port of Keelung, the Port of Kobe, the Port of Yokohama and the Port of Los Angles. The results show that the proposed mixed fuzzy decision making and optimization programming model can be used to solve the empty container allocation problem well.

1. Introduction

Containerization transportation has been growing fast since the participation of container ships in the early 1970s. Over 75% of the vessels in the liner international trade are container ships. The growth of international trade has also increased the size of the liner shipping companies significantly. For example, one major liner shipping company who provides round-the-world service now serves more than 40 ports, owns close to 90 containerships, and handles over one million containers annually. Given the breadth of a major liner shipping company's activities, ad hoc decision making is highly inadequate.

Cheung and Chen [1] indicated that most liner international trades are typically imbalanced in terms of the numbers of import and export containers, because of the different economic needs in different regions. Thus, liner shipping companies often need to reposition their empty containers or to lease empty containers from vendors to meet exporters' demands. However, the availability of container is subject to a lot of uncertain factors, including the demands at ports, the returning time of containers from consignees and the ship capacities available for empty containers. Faced with these uncertainties, liner shipping companies tend to operate conservatively. For example, a liner shipping company who offers a 10-day grace period for consignees to return empty containers (beyond which time, consignees need to pay a penalty) routinely estimates the returning time as 10 days even though the returning times range from 4 to 10 days.

Li et al. [2] discussed that since a shipping line pays substantial operational expenses to maintain its container fleet, it is important that shipping carriers plan and schedule efficiently the inventory quantity of both company-owned containers and leased-containers. Owing to an imbalance of international trade, the shipping line accumulates a number of empty containers at some container ports, while other ports are often faced with a shortage of empty containers. It is therefore essential that any unnecessary empty containers are transferred from surplus ports

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to shortage ports. But how many empty containers at any one container port are necessary or unnecessary? How many empty containers are owned or leased?

Although there are many approaches and models proposed in the past for solving the empty container allocation problem, most of these approaches and models were established either by the inventory model or by mathematical programming. Few researchers proposed model for solving the empty container allocation problem by combining both the inventory model and mathematical programming. Thus this paper proposes a mixed fuzzy inventory decision making and mathematical programming model for solving the empty container allocation problem.

In stage one this paper proposes a fuzzy backorder quantity inventory model for determining the optimal quantity of empty containers at a port. This model focuses on the decision making of optimal quantity of empty containers at a container port with stochastic import and export at the same time. In this fuzzy backorder inventory model, quantities and costs are uncertain. These uncertain quantities and costs are expressed in fuzzy numbers. Furthermore, in order to find the optimal backordering quantity for this fuzzy backorder inventory model, this paper uses the Extension Principle, Graded Mean Integration Representation method and Kuhn-Tucker conditions to manipulate the fuzzy arithmetical operations and find the optimal fuzzy quantities for the fuzzy inventory model.

In stage two, an optimization mathematical programming network model is proposed for determining the optimal number of empty containers to be allocated between ports. Based on the results for the fuzzy backorder quantity inventory model in stage one, we can further obtain the optimal number of empty containers to be allocated from surplus ports to shortage ports by using the optimization mathematical programming network model. Finally, the utilization of the proposed model is demonstrated with a case of trans-Pacific liner route in the real world.

The rest of this paper is organized as follows. Section 2 is the literature review. The methodology is introduced in Section 3. In Section 4, the proposed mixed fuzzy decision making and optimization programming model is tested by a case of one Taiwanese shipping company in the real world. Finally, conclusions are given in Section 5.

2. Literature review

2.1. The inventory model

In practice, as far as each port is concerned, decision makers encounter the stochastic nature of supply and demand as well as uncertainty in travel and unloading times. The model for such a port can be simplified as a random arrival and a random departure inventory problem. For a port, Park and Noh [3] and Sheikh et al. [4] present a port simulation model as a planning and analysis tool for port operation. The research is concentrated on the analysis of a port. For fixed arrival and departure rates, the inventory model has a special feature compared with the general models. The model needs to consider the replenishment not only from ordering empty containers, but also from the containers full of imports with one period delay. The model also needs to consider the case in which the decision maker provides empty containers to satisfy some orders by other ports, which means to export empty containers to somewhere. This kind of model is called a model with negative demand. Li et al. [2] consider the empty container allocation problem to be a nonstandard inventory problem with positive and negative demands at the same time under a general holding-penalty cost function and one-time period delay availability for full containers just arriving at the port. They develop an inventory model for solving the empty container inventory problem at a port.

On the other hand, in the classical inventory model, all costs and quantities are considered as real numbers. Park [5] used fuzzy set concept to treat the inventory problems with fuzzy inventory costs under arithmetical operations of Extension Principle. Chen et al. [6] considered a fuzzy inventory model with fuzzy yearly demand, fuzzy ordering costs, fuzzy inventory costs and fuzzy backordering cost. They used Function Principle [7] as operations on the total cost, and used the median rule to find the optimal economic order quantity and the optimal backorder quantity. Yao and Lee [8] developed a fuzzy inventory model with fuzzy backordering quantity. They applied the Extension Principle to find the optimal fuzzy ordering quantity. Chang [9] discussed how to obtain the economic order quantity when the demand quantity is uncertain. Chen and Hsieh [10] discussed the fuzzy backorder inventory models. The Second Function Principle [11] is used to the fuzzy arithmetical operations on generalized trapezoidal fuzzy numbers in the fuzzy total cost function. Chen et al. [12] considered fuzzy economic production quantity model with fuzzy costs, fuzzy quantity and imperfect production. They used Function Principle, Graded Mean Integration Representation method and Kuhn-Tucker conditions to find the optimal fuzzy economic production quantity for the fuzzy production inventory model. Chou [13] proposed a fuzzy backorder inventory model with fuzzy costs and fuzzy quantity. The Kuhn-Tucker conditions are applied to find the optimal backorder quantity for the fuzzy inventory model. The model is applied to a simple example of the decision making of empty container inventory.

In fact, the optimal quantity of empty containers at a port is vague in the real world. Thus this paper proposes a fuzzy backorder quantity inventory model for solving the decision making problems of optimal quantity of empty containers at one port. In this model, costs and quantities are expressed in trapezoidal fuzzy numbers. Moreover, in order to find the optimal order quantity for this fuzzy backorder inventory model, this paper uses the Extension Principle, Graded Mean Integration Representation method and Kuhn-Tucker conditions to manipulate the fuzzy arithmetical operations and to find the optimal fuzzy quantities.

2.2. The empty container allocation problem

Early description of using network models for empty container allocation can be found in [14]. Florez [15] formulates the DCA as a deterministic network flow problem that can be solved by standard network algorithm. Crainic et al. [16] propose both deterministic and stochastic network models for the inland transportation of empty containers. Crainic et al. [17] further develop a multicommodity network model for assigning depots to customers in the inland transportation network where empty containers can be transported among depots to minimize the total inland transportation costs (between depots and customers and between depots). Chen and Chen [18] consider the movements of both loaded and empty containers, and develop a multicommodity dynamic network model. Chen and Ma [19] further extend this model into a stochastic setting, which is similar to the one proposed by Crainic et al. [16].

Powell [20] considers the problem as being soluble by dynamically allocating resources to tasks. Dynamic and stochastic network formulations have been extensively studied and many similar practice problems have been investigated. For example, one has to allocate empty vehicles to the appropriate terminals, motive power to services, crews to movements or services, customer loads to driver-truck combinations, empty containers from depots to customers and returning container from customers to depots, etc. Many approaches and corresponding results can be used to solve containerization problems [1,21–23].