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Planning the route of container ships: A fuzzy genetic approach

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ABSTRACT

Nowadays, liner shipping has become a constant operation model for shipping companies, and scheduling is an important issue for operation. It is well-known that a nice plan for route of container ships will bring long-term profit to companies. In the earlier works, the market demand is assumed to be crisp. However, the market demand could be uncertain in real world. Fuzzy sets theory is frequently used to deal with the uncertainty problem. On the other hand, genetic algorithm owns powerful multi-objective searching capability and it can extensively find optimal solutions through continuous copy, crossover, and mutation. Due to these advantages, in this paper, a fuzzy genetic algorithm for liner shipping planning is proposed. This algorithm not only takes market demand, shipping and berthing time of container ships into account simultaneously but also is capable of finding the most suitable route of container ships.

1. Introduction

The characteristics of liner shipping services for container ships include fixed ports, fixed routes, and fixed time service. Therefore, when planning the route of container ships, one has to assess the market demand, scheduling, and various potential cost for deciding the ship size, quantity, and shipping interval. These considerations aim at enabling shipping companies to provide long-term and stable service in shipping market, help the operator of container deployment to arrange the route, and facilitate the business officers to explicitly define the value of shipping service, such as time of container loading and delivering when spreading business. To stabilize the market share, once the ship set sail, shipping companies will not change the route except for the change of environment or the business model of shipping companies. Therefore, it is necessary and significant for shipping companies to plan the route of container ships.

When shipping companies plan the route of container ships, scheduling problem is an important issue. To achieve the goal of minimizing cost or maximizing profit, the planning and scheduling have to take voyage cost, operation cost, berth charge, and market demand into account. Several articles studied the planning and scheduling of the route of container ships. Lu (2002a) designed the route of container ships assuming that the minimum demand of containers between each port is known and the slot space of container ships can satisfy this demand. His method aims at voyage cost, the sum of berth cost, and minimum of cost of buffering time to find the best routing of container ships by linear programming model. However, this model can not confirm the state of real market because it assumes that the market demand is crisp. Assuming that the market demand is known, the slots of container ships can completely satisfy market demand, the operation scale of fleet can be extended infinitely, and the container ships can berth at the port infinitely. In the research on optimum fleet scale of container ships, Yan, Lin, and Lin (1999) tried to find optimum fleet scale by linear programming model. However, some assumptions in their model seem unreasonable. For example, the loading capacity of container ships is different, the liner companies' investment in certain route is finite, and the space of port is also limited. Lu (2003) also paid attention to the dispatch of empty container when modeling ship's routing and container positioning are concerned. This shows that it is relatively important to consider empty container when one determines the dispatch of container ships and plan of route in liner shipping.

Lu (2002b) constructed liner shipping as a loop by network-illustration. To reduce cost, each voyage only berths one time at each port in this route. Assuming that there is a route composed of five ports, marked A, B, C, D, and E, and the route is modeled as shown in Fig. 1. In Lu (2002b), the schedule of container shipping must take the requirement of shipper, market competitiveness, and the restriction of shipping companies themselves into account; besides, shipping time of container is what the shipper cares about most (Lu, 2002b). According to the route of container

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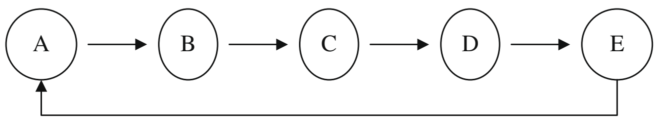

Fig. 1. The former route of container ships.

ships planned in Fig. 1, if there are containers shipped to Port C, the containers must be loaded at Port D. Then, the containers have to be shipped from Port D, E, A, B to Port C. For example, the route of container ships is A → B → C → D → E → C → A... as shown in Fig. 2. If there are containers have to be shipped from Port D to Port C, ships only have to pass Port E. In this way, the shipping time can be reduced significantly, and this model fits in with market planning nowadays. Hence, although cost may increase, the future research will focus on how to increase shipping companies' profit by arranging more ports to berth. In Lu (2002b, 2003), Yan and Lan (2003), and Yan et al. (1999), they all constructed a model to find optimal route of container ships by linear programming. They aimed at minimizing cost subject to some restrictions that the market demand and voyage time between ports are fixed and the loading capacity of container ships is infinite. In this paper, we utilize triangular fuzzy numbers to represent the market demand and a fuzzy genetic algorithm is proposed to find the optimum schedule for the route of container ships.

Nowadays, liner shipping has become a constant operation model for shipping companies, and scheduling is an important plan for operation. To plan a suitable route will bring long-term profit to companies; on the contrary, if the route is a loss, it may lead to negative impact on companies' substance in the future. Therefore, we attempt to find the most suitable shipping schedule by considering market demand, shipping and berthing time of container ships in the proposed fuzzy genetic algorithm. Hopefully, this research can be served as a reference for shipping companies when they decide to engage in developing or revising the route of container ships.

2. Fuzzy sets theory

Fuzzy sets theory, proposed by Zadeh (1978), is frequently utilized to deal with the uncertainty problem. The membership function is employed to describe the uncertainty and imprecise information. Because of its simplicity and similarity to human reasoning, it has been successfully applied to a good many fields such as manufacturing, engineering, management science, economics and military science.

Let U be an universe set with all possible element x. A fuzzy set A in U is represented by a membership function $\mu_A(x)$ which is associated with each point in U a real number in the interval $[0, 1]$. The membership function $\mu_A(x)$ stands for the degree of membership of x in A. The *support* of a fuzzy set A is defined as the crisp set of all elements in X such that $\mu_A(x)$ is greater than zero. In particular, a fuzzy number A is a convex subset of the real line $\boldsymbol{R}$ with a normalized membership function and it can be represented as (Zadeh, 1978).

$$\mu_A(x) = \left\{ \begin{array}{ll} \mu_{AL}(x), & a \leqslant x \leqslant b \\ 1, & b \leqslant x \leqslant c \\ \mu_{AR}(x), & c \leqslant x \leqslant d \\ 0, & otherwise \end{array} \right\}, \tag{1}$$

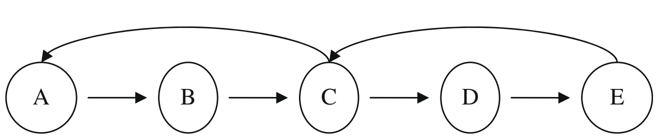

Fig. 2. The discussed route of container ships in this paper.

where $a, b, c, d \in \boldsymbol{R}$, μ_{AL}: $[a, b] \to [0, 1]$ is continuous and strictly increasing and μ_{AR}:$[c, d] \to [0, 1]$ is continuous and strictly decreasing.

A triangular fuzzy number A can be denoted by $A = (a, b, c)$, where $a < b < c$ (Fig. 3). The middle point b represents the variable value with the maximal grade of membership value, i.e. $\mu_A(b) = 1$; a and c are the lower and upper bounds of the available area. They are used to reflect the fuzziness of the data.

Formally, for any $x \in U$, its membership value is evaluated as follows:

$$\mu_A(x) = \begin{cases} \frac{(x-a)}{(b-a)}, & a \leqslant x \leqslant b \\ \frac{(x-c)}{(b-c)}, & b \leqslant x \leqslant c \cdot \\ 0, & otherwise \end{cases} \tag{2}$$

Triangular fuzzy numbers can represent the estimated cost or time naturally. For example, if the investment cost is represented by the triangular fuzzy number $A = (3, 5, 10)$ (unit: \$ × million), then it implies that the investor optimistically thinks the investment cost only needs 3–5 million. On the other hand, he also pessimistically thinks the investment cost maybe needs 5–10 million. The most possible investment cost he thinks is equal to 5 million.

There are a variety of fuzzy set operations. Among them, two operations related to the proposed algorithm are *addition* and *subtraction*. Let $A_1 = (a_1, b_1, c_1)$ and $A_2 = (a_2, b_2, c_2)$ be two triangular fuzzy numbers. The definitions of these fuzzy set operations are presented as follows (Kaufmann & Gupta, 1984):

(i) The *addition* of fuzzy numbers A_1 and A_2 is denoted by $A_1 + A_2$ and given by

$$A_1 + A_2 = (a_1 + a_2, b_1 + b_2, c_1 + c_2). \tag{3}$$

(ii) The *subtraction* of fuzzy numbers A_1 and A_2 is denoted by $A_1 - A_2$ and given by

$$A_1 - A_2 = (a_1 - c_2, b_1 - b_2, c_1 - a_2). \tag{4}$$

3. Genetic algorithm

The genetic algorithm learning model was initially developed by Holland (1975) and is based on the Darwinian principle of natural selection. Genetic programming has been successfully applied to problems that are difficult to solve using traditional methods. Common areas of application include scheduling problems, such as the traveling salesperson problem, network routing problem for circuit-switched networks, and problems in the area of financial

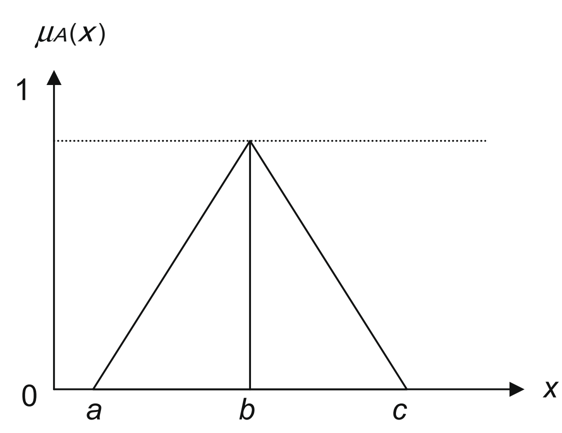

Fig. 3. Triangular fuzzy membership function.