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An application of a fuzzy knowledge system for air cargo overbooking under uncertain capacity

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ABSTRACT

Overbooking is a yield management policy of to air cargo to sell more cargo than the available capacity to minimize oversale and spoilage cost. In a yield management system of air cargo, roughly 40% of air carrier profit is obtained from overbooking. Thus overbooking is very important for air cargo yield management. However, the work becomes more complicated to evaluate overbooking capacity under uncertain environment. In this paper, an air cargo overbooking method is presented under uncertain environment to determine overbooking capacity. By the method, we are involved in the development of a fuzzy knowledge system based on fuzzy reasoning to solve the air cargo overbooking problem. Finally, a numerical example is illustrated to describe the fuzzy knowledge system.

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1. Introduction

Yield management, or called revenue management, can be defined to integrate investment factors to enhance profitability. In the real world, about 5% additional revenue comes from a good yield management system [13]. From 1988 to 1990, the implementation of a passenger yield management(PYM) system at USA Airlines has generated $1.4 billion in revenue [6]. In a yield management system, approximately 40% of total benefits are generated from overbooking. These benefits have taken place in airlines, hotels and rental car companies. There are many overbooking approaches shown as below.

An airline or hotel overbooking problem was expressed on a non-homogeneous markovian sequential decision process by Rothstein [9,10], and he utilized dynamic programming to solve the overbooking problem. To determine the overbooking level, Shlifer and Vardi [12] proposed a model with three different criteria under certain capacity. The three criteria were to determine the spoilage incurred by rejecting a passenger relative to the profile of carrying one, ensure the oversale probability, and ensure the expected oversale level that does not exceed an allowable maximum. Liberman and Yechialli [7] solved a hotel overbooking problem based on considering the uncertainty of customer cancelation behavior. Rothstein [11] presented an application survey of airline overbooking, then he analyzed and discussed the overbooking issues for air carriers. Alstrup et al. [1] considered two classes of passenger to propose a methodology for formulating a flight booking policy. Smith et al. [13] presented the development and implementation of a yield management system of American Airlines, and the revenue impact. Oakley et al. [8] was involved in developing a cargo overbooking model to address the complexities of overbooking. A general decision rule of overbooking was proposed by Bodily and Pfeifer [2]. They expressed specific models on random survival process. For the development and implementation of a cargo-overbooking model, Kasilingam and Hendricks [5] proposed a belief discussion of American Airlines. Curry [4] developed a couple of models to solve

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overbooking problems. Chatwin [3] provided a rigorous treatment on a multi-period overbooking problem, which is related to a single flight leg with certain capacity and single service class. The model presented a continuous time version with stationary fares.

According to the above overbooking research, most of them assume that available capacity is under certain environment. Thus Kasilingam [6] developed a generalized cost model of air cargo overbooking under uncertain capacity. Commonly, uncertainty of available capacity arises because of a variety of reasons of air cargo. Especially, uncertain situations will increase overbooking complexity. Nevertheless, overbooking becomes more and more important than ever, these days. A tremendous growth was predicted in air cargo demand recently [6]. As the growth of worldwide cargo volume was estimated to triple during two decades, it was very important to effectively manage available capacity. Therefore, an overbooking method of air cargo is essential under uncertain environment. In this paper, we apply a fuzzy knowledge system to solve air cargo overbooking problems under uncertain environment. Processing of the fuzzy knowledge system has three steps: the first step is to determine the air cargo overbooking level, the second step is to estimate the capacity available, and the final step is to integrate overbooking level and capacity available to evaluate the overbooking capacity. The details of these steps will be described as follows.

Usually, air cargo overbooking capacity under uncertain environment is hardly ever estimated. To estimate the air cargo overbooking capacity, we have to determine the overbooking level, and evaluate available capacity. Available capacity is obtained from shipments booked. On the other hand, the overbooking level is determined by three factors, including show-up rate, oversale cost and spoilage cost. Show-up rate should consider cancelations, no-shows, and variable tender behavior. Combining cancelations, no-shows with variable tendering, show-up rate is a composite index. Besides show-up rate, oversale cost and spoilage cost are critical in an overbooking problem as well. Oversale cost is the cost of being unable to provide the promised capacity for the customer. Spoilage cost is the cost which does not use the available capacity.

After determining the critical factors of the overbooking level, we have to aggregate these factors. One fuzzy reasoning method can aggregate show-up rate, oversale cost and spoilage cost to determine the overbooking level. Fuzzy reasoning is constructed on a set of fuzzy decision rules to present the relationship of show-up rate, oversale cost, spoilage cost and overbooking level. These fuzzy decision rules can be merged into a single knowledge base to determine the overbooking level on a given condition. Then, the overbooking capacity can be evaluated by comparing overbooking level with available capacity.

For the sake of clarity, fuzzy sets theory [15] is presented in Section 2. The development of a fuzzy knowledge system to estimate the overbooking level, and determine the overbooking capacity is expressed in Section 3. Finally, one numerical example of applying a fuzzy knowledge system to solve the overbooking problem is illustrated in Section 4.

2. Preliminaries

We review some basic notions of fuzzy sets [15] presented as follows.

Definition 2.1. Let U be a universe set. A fuzzy set X of U is defined by a membership function $\mu_X(x) \to [0, 1]$, where $\mu_X(x)$, $\forall x \in U$, indicates the degree of x in X.

Definition 2.2. Let X be a fuzzy set of U, where U is a real line. X is normal, if and only if $\sup_{x\in U} \mu_X(x) = 1$.

Definition 2.3. Let X be a fuzzy set of U, where U is a real line. X is convex, if and only if $\mu_X(\lambda x+(1-\lambda)y) \geq (\mu_X(x)\wedge\mu_X(y))$, $\forall x, y \in U$, $\forall \lambda \in [0, 1]$, where the symbol $\wedge$ denotes the minimum operator, i.e.

$$\mu_X(x) \wedge \mu_X(y) = \min(\mu_X(x), \mu_X(y)). \tag{1}$$

Definition 2.4. Let X be a normal and convex fuzzy set of U with a piecewise continuous membership function $\mu_X(x)$. The support of X is the crisp set defined by $S_X(0) = \{x \,|\mu_X(x) > 0\}$.

Definition 2.5. Let X be a normal and convex fuzzy set of U with a piecewise continuous membership function $\mu_X(x)$. The level α set of X is the crisp set defined by $S_X(\alpha) = \{x \,|\mu_X(x) \geq \alpha\}$ for any $\alpha \geq 0$.

Definition 2.6. Let X be a normal and convex fuzzy set of U with a piecewise continuous membership function $\mu_X(x)$. X is bounded, if and only if $S_X(\alpha)$ is bounded for all $\alpha \geq 0$

Definition 2.7. A fuzzy number X is a fuzzy set that is both normal and convex in the universe U.

Definition 2.8. A triangular fuzzy number X can be defined by (a, b, c) as shown in Fig. 1. The membership function $\mu_X(x)$ is presented as below [15,17]:

$$\mu_X(x) = \begin{cases} (x-a)/(b-a), & a \leq x < b, \\ 1, & x = b, \\ (c-x)/(c-b), & b < x \leq c, \\ 0, & \text{otherwise.} \end{cases} \tag{2}$$

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