Knowledge-Based Systems 70 (2014) 88–96

Contents lists available at ScienceDirect

Knowledge-Based Systems

journal homepage: www.elsevier.com/locate/knosys

# Fuzzy rule-based demand forecasting for dynamic pricing of a maritime company

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ARTICLE INFO

*Article history:*
Available online 13 May 2014

*Keywords:*
Dynamic pricing
Dynamic programming
Fuzzy IF-THEN rules
Transportation
Demand forecasting

ABSTRACT

In this study, the pricing problem of a transportation service provider company is considered. Our goal is to find optimal prices by using probabilistic dynamic programming. A fuzzy IF-THEN-rule based system is used to identify the demand levels under different prices and other characteristics of the journey. The results obtained by optimal price policies show that the revenue increases by applying dynamic pricing policy instead of fixed pricing. Thus, the diversification of pricing policies under different conditions is beneficial for the company.



## 1. Introduction

Dynamic pricing, often referred to as individual-level price discrimination, has become much more common with the increased usage of internet sales [21]. Internet provides a media for companies to offer different pricing strategies in which prices vary over time, consumers, and/or circumstances. Companies try to maximize their profits using these strategies. This attempt is often called as revenue management.

The bulk of the literature deals with the revenue management and dynamic pricing problems of especially airlines, freight, and tourism markets. To the best of our knowledge, there has been no study conducted for maritime public transportation industry. In the transportation market, the demand fluctuates based on weather conditions, price, time of day and day of week. Based on these conditions, passengers decide on whether to travel or not. In other words, passengers' demand/price elasticity may change depending on the weekdays or weekend, early or late hours of a day as well as the weather conditions. Considering this fact, the strength of fuzzy logic in capturing the ambiguity and exploiting imprecise data created a motivation for us to use fuzzy logic in demand forecasting. Fuzzy IF-THEN rules are generated in order to retrieve the price/demand elasticity of passengers. Using these findings, a dynamic pricing model is formulated in order to find the optimal policies under different conditions. Then the policies obtained by dynamic pricing are compared with the fixed pricing policy.

The paper includes seven sections. Literature review follows this section. In Section 3, problem description is given. Then dynamic pricing model is described in Section 4 while Section 5 presents the fuzzy rule based demand forecasting system. In Section 6, the case study is given and finally, conclusion and future research are discussed in Section 7.

## 2. Literature review

Revenue management literature related to the transportation industry is reviewed below in order to reveal the contribution of this study. For a more detailed review of pricing models used in revenue management, the interested readers can refer to Bitran and Caldentey [5] or Talluri and van Ryzin [40], and for a survey of the literature that considers both pricing and inventory decisions, see Elmaghraby and Keskinocak [11,18].

In the revenue management literature, dynamic pricing problems for a fixed stock of a single item sold in finite selling horizon have attracted considerable attention. Gallego and van Ryzin [15] formulate an intensity control model of the dynamic pricing problem and derive several structural properties. Zhao and Zheng [51] consider a similar problem with non-homogeneous demand and show that dynamic pricing policies may have a significant impact on revenue when demand is non-homogeneous. Zhang and Cooper [50] develop a Markov decision process formulation of a dynamic pricing problem for multiple substitutable flights between the same origin and destination, taking into account customer choice

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http://dx.doi.org/10.1016/j.knosys.2014.04.015
0950-7051/

among the flights. Kuyumcu and Garcia-Diaz [26] develop a new analytical procedure for joint pricing and seat allocation problem, which considers demand forecasts, number of fare classes, and aircraft capacities. They use polyhedral graph theoretical approach for optimization and show that it achieves significant computer time saving when compared to a general-purpose integer programming commercial software. A part of the existing literature considers the case of competition for the problem of dynamic pricing in transportation industry. Competition models consider that customers can choose the supplier, in this case, the supplier has to decide how to control the inventory level. However, in our study the market is monopolistic similar to the most of the research on dynamic pricing such as Gallego and van Ryzin [15], Chatwin [7], Feng and Xiao [13], Zhao and Zheng [51] and so on.

The previous literature on revenue management in the transport industry deals especially with the airline industry (some examples are: [26,50,28,19,18]. However, Maddah et al. [29] develop a discrete-time dynamic capacity control model for a cruise ship, being the first study developed for cruise ships. Another example is the study of Bharill and Rangaraj [4]. They consider the case of Indian Railways with an application of the principles of revenue management. The strategy of overbooking is interpreted in terms of waitlist management by the railway company and cancelation action of customers; finally revenue management through differential pricing is suggested as a means to increase revenue on average. To the best of our knowledge, our study is the first attempt that models dynamic pricing for a maritime public transportation company.

Characterization of demand is required in order to model the dynamic pricing problem. Gamma, Normal shapes and Poisson function have been proposed to characterize demand distributions in the previous studies [26,47,28,50]. Some of the existing studies use various assumptions for modeling demand under different price levels based on previous data [47,14,29,28], some other studies use price elasticity functions derived from previous data [4,18]. Price elasticity, which characterizes consumer demand, has also been derived by market research using techniques such as conjoint analysis in order to design optimal pricing schemes [43]. Another approach in the literature is to forecast the demand using econometric models [22,16] and time series methods [22,49]. Recently, intelligent methods have been used to model the complexities of demand forecasting such as artificial neural networks [37,23].

In this study, we consider the problem of finding the optimal pricing policy of a maritime public transportation company. The market is monopolistic and the price has been fixed up to this time. Therefore there is no previous data, which shows the relation between different prices and demand levels. Due to the lack of previous data, it is not possible to employ most of the models used commonly in the literature. Moreover demand is also related to various criteria, such as weather, day of week, time of day as well as price. Due to this fact, the demand cannot be expected to be constant over time. Therefore, the fuzzy set theory proposed by Zadeh [48] and fuzzy-rule based system (FRBS) may be useful for incorporating the imprecision of the criteria (i.e. weather, etc.) in demand modeling. The contribution of this study is to estimate the demand via FRBS and to find optimal price policies for the maritime public transportation. Fuzzy sets enable modeling of imprecise and qualitative knowledge, as well as the transmission and handling of uncertainty at various stages [44]. Fuzzy logic allows us to emulate the human reasoning process and make decisions based on vague or imprecise data. Moreover linguistic terms represent the knowledge, experience, and subjective viewpoint of decision makers in a more intuitive way [20]. Fuzzy rule based systems have been one of the most popular methods to capture and represent fuzzy, vague, imprecise and uncertain domain knowledge in the literature. The fuzzy rule based systems use fuzzy IF-THEN rules to generate a mapping from fuzzy sets in the input universe of discourse to fuzzy sets in the output universe of discourse based on fuzzy logic principles [44]. In recent years, much research has been proposed to develop FRBSs for many objectives such as modeling traffic flow behavior [35], analyzing stock prices [12], economic analysis of RFID investments [44], assessing supply chain performance [33], and predicting weather events [1].

## 3. Problem definition

This study deals with the dynamic pricing problem of a ferry line of the maritime public transportation company, which serves between Istanbul and Bandırma, Turkey. There exists only one service provider offering the ferry transportation in Istanbul. Thus, the market is monopolistic, which means that the formulated dynamic pricing model does not include competition. The service provider, which was a non-profit governmental establishment used to apply fixed pricing in order to serve for public welfare. However, the corporation has been privatized recently and considers applying dynamic pricing in order to increase the revenue. The realized demand in the past years show that the demand varies significantly based on the weather, days of the week and times of the day. Fuzzy IF-THEN rules are generated in order to retrieve the price/demand elasticity of passengers since there is no previous data about the relation between the demand and the price. Finally, using the outputs of the FRBS, a dynamic pricing model is built in order to see the optimal policies under different conditions. We employ a probabilistic dynamic programming method to find the optimal pricing policies. The diversification of optimal policies under different conditions results in revenue increase.

## 4. Dynamic pricing model

In this study, a dynamic pricing optimization problem faced by the maritime public transportation company is considered. The aim is to find the optimal prices of each journey that change by the day, time of trip and weather conditions. These are among the factors, which affect the level of demand. For instance, passengers usually make leisure-travels in the weekends or warm days. However, it is expected that the weather condition being warm does not influence the work-travels of the passengers. Furthermore, while price may be significant for leisure-travels, it may not be significant for work-travels. The important attributes for work-travels may be the time of the trip and seat availability.

The system state $S_t$ is defined with number of seats at time $t$. The actions $a_t$ are the prices and the optimal decision $a_t^*$ at time $t$ will be given according to these actions that will be evaluated at time $t$. In this case the possible price action set $A(S_t)$ of the $S_t$ state is as in (1) if there are $k$ prices observed.

$$A(S_t) = \{a_{1t}, a_{2t}, \ldots, a_{kt}\} \quad (1)$$

Then, the policy $\pi$ is the set of decisions given for each period for each state $S_t, \pi_{S_t} = \{pr_1^*, pr_2^*, \ldots, pr_T^*\}$ where $pr_t^*$ is the optimal price action at time $t$ for state $S_t$. Demand is estimated under different prices together with some other criteria such as day, time of trip and weather condition through fuzzy rule based systems. In this model, demand is "lost" if not fulfilled in the same time period and does not have a cost. However, if there are empty seats, a cost, opportunity cost, is incurred. Therefore, the total demand for each journey at time $t$ is simply the number of seats sold. When demand $D_t$ is appeared, the system state,$S_t$, which is the number of seats changes into $S_{t+1} = \max(0, S_t - D_t)$.

We use probabilistic Dynamic Programming (DP) to solve the problem. DP is useful in multistage decision processes where the optimal policy can be determined recursively. The aim of this