Applied Mathematical Modelling 39 (2015) 3784–3813

Contents lists available at ScienceDirect

Applied Mathematical Modelling

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

Determining strategy of pricing for a web service with different QoS levels and reservation level constraint

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ARTICLE INFO

Article history:
Received 29 April 2013
Received in revised form 20 July 2014
Accepted 20 November 2014
Available online 16 December 2014

Keywords:
Web service
Dynamic pricing
Optimum control
Nonlinear optimization

ABSTRACT

This paper develops a continuous time optimal control model for identifying price strategies for a web service in order to maximize provider's profit. In real world, web service providers normally change their prices dynamically and provide a web service with different levels of quality of service (QoS) (i.e. web service classes) to satisfy their customers with different requirements. Furthermore, the providers may sell the web service prior to consumption period through a reservation system and customers have the right to cancel their orders. The primary assumption of this paper is that the maximum reservation level for each class of the web service is specified in advance. In addition, the total capacity of the web service is shared among all the service classes. In this paper a novel model is presented in which the demand for each service class is a linear function of price, the unit web service cost and capacity are constant for each class of web service, the total allocated capacity, maximum reservation level for each service class and all the other coefficients (such as maximal demand, price sensitivity, etc.) are time dependent. An algorithm is proposed, which calculates the optimal pricing strategy as a function of time. Additionally, numerical analyses are utilized to evaluate the effect of some important parameters on the control and state variables, total revenue and objective function. Furthermore, the proposed algorithm is compared with some existing approaches.

1. Introduction

During the past two decades, people began to perform their commercial activities through the Internet. Electronic data exchange has been developed as a standard for moving the data between two enterprises in business trades. However, during the recent years, to cope with the complexity of emerging business markets, web services have become more popular and they have provided great developments in integration of various applications. Web services normally simplify cross-organizational communications and outsourcing of software components to third parties. Web service is a system of software developed to provide machine to machine interactions across some networks. Three XML-based standards have been introduced so far to employ the web services: WSDL, SOAP and UDDI. A service provider often implements WSDL to explain how the web service can be invoked, what input parameters are required, and what output data are returned. However, SOAP outlines a communication protocol for the web services. UDDI presents a registry service, which permits advertisement and discovery of the web services [1–10].

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http://dx.doi.org/10.1016/j.apm.2014.11.054

In terms of business practice, dynamic pricing in which the price normally changes over the time is the most natural mechanism for an effective revenue management. The advantages of dynamic pricing methods have long been determined in various businesses, such as airlines, electric utilities and hotels, where the capacity is constant in short-term. Availability of demand data, simplicity of varying prices, and convenience of using decision support systems for assessing the demand data in e-commerce act as a motivation to apply dynamic pricing as an effective technique to determine price of the web services [11–16].

This paper applies continuous time optimal control theory as the main tool to understand the price behaviour of a web service over the time horizon. A continuous time method has the advantage of presenting the exact solution for the real-world applications. The Refs. [17,18] consider the optimal control for analyzing the system behavior useful and recommend it in matters such as dynamic pricing, production and inventory control, finance, marketing, natural resources and economic which have a dynamic essence and change over time. The reason is that in discrete time models adopting proper time points for designating decision variable in them is so difficult and complex. In such models, the decision-maker should identify the decision variables in so many points in order to overcome this limitation. The problem here is that when the time horizon is fairly large, the number of the variables and the constraints of the model increases considerably. This may in turn increase the effort needed to solve the problem. Nevertheless, if optimal control is adopted for solving similar problems, optimal decision variable will be a function of time and the decision-maker will be able to easily find the decision variable in every time by substituting the time in that function. Also, in the dynamic pricing proposed in this article, the provider will first solve the problem once, and if needed, he\she can easily calculate the optimal price in every time in the time horizon. Another application of this technique may be in facilitating the analysis of the price, reservation level, sales revenue, cancellation revenue, total sales revenue and profit behavior over the time horizon. Optimal control theory is built as a branch of mathematics to provide optimal methods for controlling a dynamic system [18–23]. There have been tremendous attempts in the field of optimal control to find the optimum solution for the linear continuous time models [24–28]. One important type of the optimal control theory which is used to examine the proposed model are nonlinear optimal control models. The nonlinear optimal control models are especially helpful for dynamic pricing and other applications of management science. For instance, Holt et al. [29] proposed a dynamic production model in which they considered production costs as well as inventory holding costs over the time. They employed calculus of variations to address the optimum solution for the suggested continuous-time model. Thompson and Sethi [30] considered a producer of a single homogeneous good using the optimal control theory with an infinite time horizon. Pekelman [31] dealt with the problem of identifying the price and production plan of a firm over a limited time period, where the input parameters are time-dependent. Fluid queuing systems were tackled by Fleischer and Sethuraman [32], where they presented a heuristic to determine the optimal control for their problem. Framstad et al. [33] provided a verification theorem to a general jump diffusion setting and explained the connections of adjoint variables to the dynamic programming. In addition, they described that their paper could be applied to the financial optimization problems. Shi and Wu [34] provided sufficient as well as necessary maximum principles for optimal controlling of a system with random jumps comprised of forward and backward state variables. Moreover, the obtained results were employed to a mean–variance portfolio selection problem. Adida and Perakis [17] studied a model based on optimal control theory to investigate the dynamic pricing and inventory control problem for a manufacturing system. They also proposed an algorithm, which detects the optimal production and pricing strategy in terms of the time on a planned time period. Fruchter and Sigué [35] proposed a general dynamic pricing model for subscription services which contain several activation combinations, subscription, and cancellation penalties. They used the optimal control approach to formulate the problem and proved some conditions in which all of the considered pricing schemes can be optimal. Further, they found appropriate conditions in which the optimal cancellation penalties and activation follow a skimming strategy and penetration strategy, respectively. Helmes et al. [36] determined optimal pricing and advertising policies of a class of general new-product adoption models. They provided generalizations of the model in [37], took arbitrary saturation and adoption impacts into account, and solved finite and infinite horizon discounted variations of the related control models.

In the field of e-commerce, one of the most interesting problems is to identify pricing strategy for a web service. Web service providers usually change their prices dynamically and provide different classes of the web service to cover the customers with different requirements. A QoS for the web service is usually evaluated using various criteria, such as reliability, availability, response time, and etc. When users intend to purchase, they consider not only the price but also the quality of that web service [1–4]. Furthermore, since the providers may sell the web service prior to the consumption period, the customers get this opportunity to cancel their orders. In many real-world situations, the providers might be exposed to some limitations on the total capacity and the reservation level for each class of the web service over the time horizon. This assumption motivates the provider to manage capacity of the web service more effectively to get the maximum profit from the available capacity. Tang and Cheng [38] took into account an intermediary of web service who wants to provide the optimal pricing and location policy of a web service. First, they obtained the optimal solution in a linear city framework and then expanded their investigation for the case of unit circle model. They reported that the optimal strategy could depend on delay cost, combination cost, and prices of the component web services. They also reported that the optimal web service intermediary could appear between the web service providers. Esmaeilsabzali and Day [39] surveyed the web service providers with a limited capacity. They implemented an online algorithm for choosing the customers and for detecting the efficient pricing strategies. Wu [40] provided a technique for computing price of web services based on web service functionality, web service QoS, and user knowledge. He reported that the proposed pricing model could provide an even more realistic and accurate price for the web service. Zhang et al. [41] investigated the price competition in data communication services with a QoS