Applied Mathematical Modelling 39 (2015) 2332–2344

Contents lists available at ScienceDirect

Applied Mathematical Modelling

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

Dynamic pricing in a production system with multiple demand classes

Mehdi Ahmadi, Hassan Shavandi *

Department of Industrial Engineering, Sharif University of Technology, 11365-8639 Tehran, Iran

ARTICLE INFO

Article history:
Received 11 May 2013
Received in revised form 24 July 2014
Accepted 23 October 2014
Available online 13 November 2014

Keywords:
Revenue management
Production system
Dynamic pricing
Several demand classes
Markov decision process (MDP)
Rationing

ABSTRACT

This paper considers dynamic pricing in a production system with a single product which is demanded by several customer classes. We seek the structure of the optimal policy assuming m available prices and n demand classes that differ based on the lost sales cost they impose on the system. The assumption of different available prices leads to dynamic pricing structure and the assumption of several demand classes leads to rationing which is proposed in the literature of revenue management. We found that an optimal policy structure exists for this combined problem. The optimal policy has a threshold form which lower thresholds are related to the rationing decision and upper thresholds are related to pricing decision.

1. Introduction

The use of revenue management strategies has increased in operations management practices in recent years. Revenue management (RM) is a field of practice and study that seeks the maximum revenue from limited inventory by focusing on demand management. Classical examples of revenue management problems are allocation of hotel rooms and airline seats on different customer classes. There are two main approaches in revenue management: quantity-based RM and price-based RM.

The primary issues that affect the RM problems are different customer classes and different available prices. In capacity allocation problems, the solution is rationing capacity among customer classes. In pricing problems the solution is differentiating prices among different customer classes.

As an example of different customer classes, Ha [1] says: "component commonality is a strategy that uses one common component for two or more end products. End products that share the common component may have different values to the firm, say, different profit margins".

Papers discussing inventory rationing show that when a manufacturing system has different customer classes, stock rationing is the optimal policy for minimizing the total cost of the system. Stock rationing is defined as reserving a portion of stock to satisfy the demand of more important customers while backordering the demand of less important customers. On the other hand, different possible prices in inventory-production systems are studied in the literature in the category of dynamic pricing. Dynamic pricing is defined as changing the price dynamically with respect to the inventory level.

* Corresponding author. Tel.: +98 21 66165711.
E-mail addresses: m_ahmadi@ie.sharif.edu (M. Ahmadi), Shavandi@sharif.edu (H. Shavandi).

http://dx.doi.org/10.1016/j.apm.2014.10.041

When it is possible to change the price in an unbounded set of possible prices, the price-based approach works better than quantity-based approach. The reason is that we can make the demand near to zero by setting the price high enough. It is clear that, in this case, we can receive more revenue relative to the case of making the demand zero by rationing. The integration of pricing and rationing is useful when the set of possible prices is bounded and there are constraints in decreasing the demand by price changes. Possible reasons for this constraint include brand image in customer's mind and governmental regulations. In this paper, we assume the scenario where companies have a bounded set of possible prices and apply the rationing mechanism in case of limited inventory.

As an example of a practical problem based on the previous assumptions, consider the after sales system of an automobile manufacturer. The demand for spare parts from the dealers to the manufacturer can be ordered via normal or urgent mechanism. The normal order is to charge the inventory and the dealer receives the order in a specific lead time. An urgent order occurs if a car has stopped in the workshop of the dealer for repairing and some of the required spare parts are out of stock in the dealer's warehouse. In this case, the dealer sends an urgent order to minimize the stopping duration of failed car in its workshop and receives the order in a shorter lead time. These two categories of orders can be assumed to be different customer classes with different shortage costs in the manufacturer's stock. The manufacturer can use a pricing and rationing policy to manage its stock in order to response the normal and urgent orders with a profit maximization objective.

To the best of our knowledge based on the literature review in the next section, this article differs with the literature due to considering production environment. The motivation for this article is finding the optimal structure and the relation between rationing and pricing decisions in a common production environment.

We formulate the problem under two pricing conditions. In the first case, we assume all customer classes have the same price at the same time. The reason for this assumption is that the manufacturer cannot differentiate the customers while simultaneously announcing different prices. In the other case, we assume that the manufacturer can differentiate the customer classes by the class name while announcing different prices for different classes. The main contribution of this paper is finding the optimal policy for rationing and pricing decisions in these two situations.

The remainder of this paper is organized as follows: In Section 2 we review the literature of pricing and inventory rationing. Assumptions and required notation for formulation are prepared in Section 3. Formulation of the problem by Markov decision process and finding the structure of the optimal policy are carried out in Section 4. Numerical examples are presented in Section 5. We end the article by a conclusion and suggestions for future research in Section 6.

2. Literature review

In this section we review the literature of two revenue management fields: (i) stock allocation and rationing in the case of multiple demand classes, and (ii) pricing in inventory systems where demand for product or service is price-sensitive.

The first paper which introduces inventory rationing is Topkis [2] that introduces the rationing strategy for a single period inventory system. Nahmias and Demmy [3] consider two demand classes in both (s, S) and (r, Q) inventory systems. Frank et al. [4] study a periodic review inventory system with two priority demand classes; demand from the first class is deterministic and demand from the other class is stochastic. They prove that a (s, k, S) policy is optimal, wheresand S are inventory parameters and k is a rationing level. This policy says: it is optimal to stop selling to class 2 customers when the inventory level reaches k or is below it. Deshpande et al. [5] investigate an (r, Q) inventory system with two demand classes and propose a (r, Q, K) policy where K is the rationing threshold. Arslan et al. [6] propose a critical-level control policy and a backorder clearing mechanism for a continuous review (r, Q) policy with deterministic replenishment lead time. Teunter and Haneveld [7], and Fadiloglu and Bulut [8] introduce dynamic rationing policies. In dynamic rationing policy, the rationing level depends on the remaining time until the arrival of the next order. Thus, instead of having static rationing levels, the levels are dynamic.

Models similar to our model are studied in the papers which use rationing policy in a production system with exponential production time. These papers include: Ha [1], Ha [9], Ha [10], De vericourt et al. [11], De vericourt et al. [12], and Huang and Iravani [13]. These papers have assumed the main assumptions of Markovian queuing systems. The main assumptions of these papers are: customer arrival distribution follows a Poisson process and production time is exponential. We can classify these papers into two categories based on shortage treatment: Lost sales and backorder related papers. Ha [1] analyzes a production system with several demand classes and his treatment to shortages is lost sales. Ha [9] studies the case of backorder with just two demand classes because of the complexity of several demand classes in the case of backorder. De vericourt et al. [12] finds the structured optimal policy for the case of backorder with several customer classes after a few years. They use dynamic programming for determining the structure of optimal stock allocation policy. Huang and Iravani [13] formulate a production system with several demand classes and backordering when arrivals follow a compound Poisson by using Markov decision process. A thorough survey on rationing papers considering main assumptions of inventory system, shortage treatment, number of classes, rationing policy (static or dynamic), and ordering policy is presented by Teunter and Haneveld [7].

The second stream of the literature is the literature of applying pricing in inventory systems. The majority of papers which consider pricing in inventory systems use dynamic pricing. Static pricing is determining an optimal price for the problem, while dynamic pricing is finding a rule for changing the price dynamically. The primary reason for using dynamic pricing in inventory systems is dynamic nature of the inventory. We categorize the literature of pricing in inventory systems