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Modeling and optimization of a product-service system with additional service capacity and impatient customers

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ABSTRACT

Product-service system is a business model, in which a company offers a mix of products and services to maintain competitive edge, satisfy customer needs, and produce lower environmental impact than that produced by a traditional business model. This paper studies the modeling and optimization problems for a basic product-service system from the view point of operation management. The proposed system, modeled as a block structure Markov chain, features additional service capacity and impatient customers. The Matrix geometric methodology is applied to obtain the stationary distribution of the system. The performance indices for the system are derived based on the distribution, and the sensitivity of the performance with respect to the parameters is considered by numerical experiments. Meanwhile, the decision process of obtaining the optimal sets of additional service capacity opening threshold and the base store level is discussed from the point of view of profit optimization We propose algorithms to solve the problem, which are shown to be effective and efficiency by numerical experiments. The studies of the sensitivity of the optimal decision to the parameters propose some insight on system demand management and system improvement.

1. Introduction

A product-service system aims to provide sustainability of both consumption and production [1]. The concept of product-service system has been defined in [2,3] simply as a system offering a mix of products and services. Along with increased product customization, many traditional manufacturing systems, such as those used by the automobile [4], office furniture [5] and health care industries [6], recognize that services combined with products can generate higher profits than products alone. Based on such principle, proper product-service system models have been designed.

Although numerous studies on the product-service system have been done, these are mainly focused on the concept, business design, and case analysis. To our knowledge, no study has been done about operation management issues related with product-service system, such as inventory control and service capacity control. Take a logistic equipment provider for example, it changed its business model to not only provide the equipment but help design logistic lines and install the equipments. In the system, the order fulfilled rate depends on both the production and the service capacity. How to control the inventory of the system to fit the service and manage the service capacity to cope with the production are critical operation decisions. In this paper, we extract a basic product-service model involving impatient customers. With this model, we study the operation management issues of the product-service system.

The proposed basic product-service system model includes two parts: the production operation and the service operation. The production part works with a base-stock strategy to cover the demand variability. Given that service cannot be stored, we propose an additional service capacity strategy to help address demand variability in service operation. The product only fulfills an order by combining it with the service process. In addition, the customer is assumed to be impatient, which makes the demand backlog-dependent.

Production systems with impatient customers have been studied in recent years. Tan and Gershwin [7] point out that the actual demand applied to a production-inventory system with impatient customers is backlog-dependent, i.e., a new customer always observes the state of the backlog and decides whether or not to join the waiting line (called "balking"). The authors studied the production and subcontracting strategies of manufacturers with limited capacity. Gershwin and Tan [8] represent the customers' response to waiting as a defection function and show that the optimal production policy for the proposed model has a hedging point form. Veatch [9] considers

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a continuous one-part type, single-machine model with Markov modulated demand and deterministic production and studies the impact of customer impatience on production control. Benjaafar and Gayon [10] study an M/M/1 make-to-stock queue with impatient customers and clarify that the optimal policy of the system can be described by two thresholds: a production base-stock level, which determines when production takes place, and an admission threshold, which determines when orders should be accepted. Similarly, Ioannidis and Kouikoglou [11] study a joint admission/inventory control problem for a single-stage CONWIP(Constant Work In Process) production system. Abad [12] also assumes that the demand is backlogged for impatience of customer and investigate the optimal price and lot size for a reseller.

For other related works, we can refer to Singer [13]. In our model, we apply a base-stock strategy to the production operation, in which the system only manufactures products when the stock level is lower than a designed value S. For other works related to base-stock strategy, readers can refer to [14–16].

As to the service operation system with impatient customers, many systems, such as call centers [17, 18], bank ticket queues [19] and taxi-passenger queues[20], have been studied in detail. Setting additional servers or outsourcing service capacity to ease customer impatience has been proposed as a way to improve service performance. Several studies [21–25] consider queuing systems with queue-dependent servers which enable the additional service capacity at some thresholds to reduce the number of customers waiting to be served. Oliver and Julian [26] as well as Lui and Leana [27] study a system, which enables and disables the additional servers at different thresholds, namely, forward threshold values and reverse threshold values. The authors prove that the method can help avoid frequent changing of the state of the additional servers. Baron and Milner [28] study outsourced call centers with alternate service-level agreements and staffing problems. In this paper, the proposed system has some additional service capacity (reserved by itself or outsourced from other organizations). The control policy, which opens the additional service capacity only when the order list is more than the designed control threshold H, is applied. This policy aims to balance service cost and order-waiting cost (or lost order cost).

Decisions regarding H and S are important to the system. To obtain these, we first evaluate the performance of the system with fixed H and S values using a block-structured Markov model, after which we analyze how the system is influenced through numerical experiments. Next, the net profit rate function is derived and an optimization algorithm is devised in order to decide the optimal values of the control parameters.

This paper has three main contributions to literature. First, it provides a quantitative analysis of a basic product-service system model. In the future, similar models can be developed to analyze product-service systems with complex features to help managers understand operation issues. Second, we construct the problem using the block-structured Markov model, providing an efficient solution using the Matrix geometric method. Third, it offers insights on how to make decisions concerning the production policy and additional service capacity strategy by considering the net profit economic function.

The remainder of this paper is organized as follows. In Section 2, the details of the proposed problem are described, including the notations and the assumptions. In Section 3, the system is constructed as a block-structured Markov model, and its performance measures are identified based on the matrix geometric methodology. Numerical studies provide a better understanding of how the system is influenced by the production control value and the additional service opening threshold, as well as other system parameters. In Section 4, the optimal policies concerning the setting of S and H values are examined by maximizing the net profit. Section 5 concludes the study and proposes future research opportunities.

2. Problem description

The proposed system provides the customers a combination of product and service (Fig. 1). The assumptions regarding this system are as follows: first, we assume that the raw materials of products are plenty and are available all the time; the system has a single manufacturing facility that produces one type products, and the production rate has an exponential distribution with parameter μ_p; the production system applies base-stock strategy which manufactures products only if the inventory is less than a value S; and the product, along with the service, is provided to the customer who places the order. We assume that one order only includes one product and the corresponding service. Furthermore, in the given model, the service time is exponential distributed with parameter μ_{S1}. Given that the service cannot be stored, the system applies an additional service capacity strategy. When the order list is more than a level H, the additional service capacity is opened; however, if the order list is less than a level H, the additional service capacity is closed. We assume

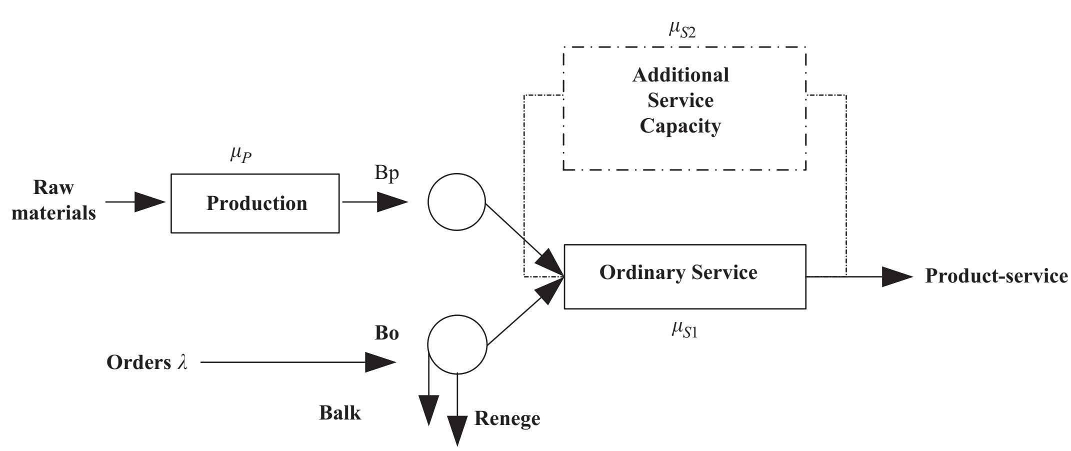

Fig. 1. Model for the production-service system with additional service capacity.