Journal of Manufacturing Systems 41 (2016) 31–44

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

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

Technical Paper

Production control policies to maintain service levels in different seasons

Sanket Bhat*, Ananth Krishnamurthy

Industrial and Systems Engineering, University of Wisconsin-Madison, USA

ARTICLE INFO

Article history:
Received 26 August 2015
Received in revised form 19 April 2016
Accepted 3 June 2016

Keywords:
Production control
Seasonal demands
Service levels
Dynamic programming

ABSTRACT

We analyze a manufacturing system that produces a single type of product to serve multiple classes of customers with seasonal demands. The manufacturer has the flexibility to vary production rates to adapt to seasonal demands. We model the seasonal demand using a Markov modulated Poisson process, and analyze the underlying Markov decision problem to derive optimal production and inventory control policies for the manufacturer. We show that the optimal policy is characterized by a season dependent inventory threshold vector for adjusting production rates and rationing inventory. Further, we impose service level constraints according to the customer classes in each season, and analyze the impact of the service level constraints on the optimal policy and cost under different seasonal demand conditions.

1. Introduction

Our research is motivated by collaborations with several small and medium sized manufacturers (SMMs) that form Tier 1 suppliers to manufacturers such as John Deere, Harley-Davidson, Caterpillar, etc. These SMMs often experience seasonal demands due to various factors such as market conditions, sales initiatives, seasonal behavior of customers, or model changes. In many cases, these demand variations could be significant: the demand during a peak season could be twice the demand observed in a low season. In addition to the challenges posed by such seasonal variations, the suppliers also have to deal with multiple classes of customers that have different utility or value for a given product. These are often reflected through expectations in delivery lead time and/or penalties for stockouts. These expectations put further stress on manufacturing operations that have to strike a balance between internal production efficiencies and external constraints imposed due to seasonality and customer expectations. Manufacturers usually respond to these challenges by investing in capacity flexibility. We analyze such settings to understand how manufacturers could leverage flexible capacities to deal with challenges posed by seasonality in demands and varying service level expectations.

Manufacturers face high variation in demands across the seasons since the demand at any given time period is the superposition of demands of multiple classes of customers. For instance, SMM supplies the same component to an assembly facility that processes orders for new equipment as well as to dealers that place orders for spare parts to repair old equipment. Orders for spare parts are low in volume but come with a high expectation in terms of delivery and stringent penalties for delays or stock outs. In contrast, orders from the assembly facility are higher in volume and total revenue, and hence deserve a high degree of importance. Further, the demands of each class of customer, in turn, have their own seasonal characteristics. For instance, the demands for a particular component (transmission, gear) from a facility assembling new farm equipment and demands for the same component from a dealer repairing used equipment might have seasons that are synchronized so that the peak demand seasons overlap (over summer). Alternatively, if the same component is used in both lawn mowers and snow blowers, the demands might have complementary seasonality balancing each other.

Further, both the assembly facility and the spare parts dealer might impose contractual conditions that guarantee certain desired service levels and impose penalties for stockouts. When overall workloads on the SMM fluctuates over the year, the SMM has to determine when to leverage their capacity flexibility and incur the costs of overtime (second shift, weekend shifts, adding additional temporary workforce) and when to rely on inventory flexibility to build ahead during low demand periods and incur the additional costs (inventory holding,

* Corresponding author. Tel.: +91 819 725 0496.
E-mail addresses: sanketbhat@gmail.com (S. Bhat), ananth.krishnamurthy@wisc.edu (A. Krishnamurthy).

http://dx.doi.org/10.1016/j.jmsy.2016.06.001
0278-6125/

warehouse operations, and obsolescence). Even when inventory is available, the manufacturer must decide whether the available inventory is enough to satisfy demands in subsequent seasons or if inventory must be rationed in particular seasons among various customer classes to meet the service level expectations in the peak season.

These challenges could be generalized to the following questions. In a manufacturing setting supporting multiple classes of customers with seasonal demands, how should the capacity flexibility investments be leveraged to optimally respond to seasonal demand trends? How should a system respond to scenarios where demands of multiple customers have synchronized seasons? To what extent do complementary seasons of customer demands help the manufacturing system lower costs? When customers impose individual service level requirements, how would the optimal policies vary – to what extent should the system build in advance in particular seasons versus rely on leveraging its capacity flexibility? We aim to address these questions in this paper.

The rest of the paper is organized as follows. Section 2 provides literature review on work related to serving multiple classes of customers and seasonal demands. Section 3 provides an analytical model for a manufacturing system with flexible capacity to deal with seasonal demands from multiple classes of customers. For this system, we analyze the underlying Markov decision problem and show the existence of the optimal solution and policy under the infinite horizon discounted expected cost and average expected cost criteria. In Section 4, we provide additional properties of the optimal solution and derive an analytical expression for the optimal policy. Though these results are not surprising and may be roughly predicted from literature, our contribution lies in providing a formal proof for these results and addressing all the technical nuances, which have not been shown before for such systems. In Section 5, we determine the impact of service level constraints imposed by the customers on the optimal policy. In Section 6, we derive managerial insights based on the interactions between the seasonal demand patterns and service level constraints of different customer classes. Finally, we provide concluding remarks in Section 7.

2. Relevant literature

Most of the related literature can be classified into two groups: (i) studies that analyze systems with single class of customers and seasonal demands and (ii) studies that analyze manufacturing systems with multiple classes of customers with stationary demand (no seasonality). For instance, Song and Zipkin [23] determine optimal ordering policies in a manufacturing system with a single class of customer with seasonal demands and stochastic lead times that are independent of the order quantities. They show that for linear ordering costs, a phase dependent base-stock policy is optimal while, for fixed ordering costs, a phase dependent (s, S) policy is optimal. Under similar settings, but with bounded ordering size and constant lead time, Kapuscinski and Tayur [16], Yossi and Federgruen [27] show that a cyclic up-to level policy is the optimal inventory replenishment policy. Hu et al. [13] analyzes production-inventory system with finite, variable production rates in a seasonal demand setting where demands and production processes are deterministic. They show that the optimal production policy is a two level inventory hedging policy. Capacity flexibility in the context of service centers has been analyzed by Kumar et al. [17]. They model seasonal demands as a Markov-modulated Poisson process and use dynamic programming to identify the optimal policy as one where capacity is varied based on the system state. Bhat and Krishnamurthy [2] analyze production systems where capacity and inventory flexibility are leveraged to satisfy seasonal demands of customers. They show that the optimal policy is a season dependent target inventory level policy with state dependent production rates. Bhat and Krishnamurthy [3] determine different seasonal characteristics and analyze the impact of their joint interaction on a production system, which is a generalized version of the production system analyzed in [2]. [5] analyze a stochastic inventory model with auto-correlated demands and lost-sales feature. The auto-correlated demand is modeled as a Markov-modulated demand, and near-optimal solutions are determined using simulation-based optimization methods.

There are several studies that analyze manufacturing systems with multiple classes of customers with stationary demands (no seasonality). Ha [10] analyzes make-to-stock production system with several customer classes and lost sales and shows that the optimal policy is of control limit type with base-stock policy for production decisions and class dependent rationing levels for inventory allocation decisions. Ha [11] extends the analysis to multi-class systems that permits backordering of unsatisfied demands. For systems with only two customer classes, they characterize the inventory allocation policy by a single monotone switching curve. Ha [12] analyzes a make-to-stock production system modeled as an $M/E_k/1$ queue to analyze the impact of low variability in service times. ElHafsi et al. [6] analyzes a system that is similar to Ha [12]. In addition to modeling the production time as a random variable with Erlang distribution, they also model the inter-arrival time of the customer demands of each class as a random variable with Erlang distribution. De Véricourt et al. [4] also analyze make-to-stock systems with multi-class customers and backordering of unsatisfied demands. Huang and Iravani [14] examine the impact of non-unitary order sizes on the manufacturing system's optimal cost and policy under two conditions: (i) lost sales environment with multiple customer classes and random batch size, (ii) backordering environment with only two customer classes and fixed batch size. [25] extend the analysis of [14] to incorporate multiple customer classes with backordered demands and varying order sizes arriving demands. They show that the optimal rationing policy is a critical level policy which is a generalized version of the multilevel rationing policy proposed in [4]. However, none of these studies consider systems that have capacity flexibility. Mayorga et al. [19] analyzes a system with flexibility in production rates and determines the optimal policy that adjusts capacity and rations inventory in a system with two customer classes, but under stationary demand conditions.

Gayon et al. [9] analyze a system with multiple customer classes where unmet demands are backordered. They considered two cases depending on whether the production can be interrupted or not. For the uninterrupted production case, they fully characterize the optimal policy based on work storage level, but only partially characterize the optimal policy for the interrupted production case. Benjaafar et al. [1] analyze a system with two customer classes system where the manufacturer can satisfy, backorder, or reject an arriving customer demand. They characterize the structure of the optimal policy and demonstrate the value in the flexibility to either backorder or reject an arriving customer demand. Zhou et al. [28] analyze a manufacturing system with finite capacity serving multiple customer classes under lost sales environment. They showed the optimality of a modified based stock policy with multi-level rationing. In contrast to these above work, we analyze systems with endogenous lead time and flexible production capacity under seasonal demand conditions.

Several research also focus on developing heuristic policies that are computationally less intensive for multi-class manufacturing systems (see [7,20,15,24]).