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Newsvendor problems with demand forecast updating and supply constraints

Meimei Zheng [a,*], Kan Wu [a], Yan Shu [b]

[a] School of MAE, Nanyang Technological University, Singapore
[b] Google Inc., Mountain View, CA, USA

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ABSTRACT

This study investigates an extension of the newsvendor model with demand forecast updating under supply constraints. A retailer can postpone order placement to obtain a better demand forecast with a shorter supply lead time. However, the manufacturer would charge the retailer a higher cost for a shorter lead time and set restrictions on the ordering times and quantities. This prevents retailers from taking full advantage of demand forecast updating to improve profits. In studying the manufacturer-related effects, two supply modes are investigated: supply mode A, which has a limited ordering time scale, and supply mode B, which has a decreasing maximum ordering quantity. For supply mode A, it is proven under justifiable assumptions that a retailer should order either as early or as late as possible. For supply mode B, an algorithm is proposed to simplify the ordering policy by appropriately relaxing the ordering quantity restrictions. Numerical analysis is conducted to investigate the influence of product and demand parameters on the value of demand forecast updating in the two supply modes. A comparison of the different supply scenarios demonstrates the negative effects of increased purchasing cost and ordering time and quantity restrictions when demand forecast updating is implemented.

1. Introduction

In a contemporary supply chain, an increasing number of companies participate in markets populated by innovative products [1] with short life cycles and high demand uncertainty. To satisfy quickly changing customer needs, companies must speed up their creation of new products. For example, Apple launches new electronic devices within short timeframes to lure customers and retain its competitive edge. Fashion companies must respond to customer preferences quickly and update clothing styles frequently. The acceleration of new product development leads to short product life cycles. Due to limited historical data and unpredictable customer tastes for new products, demand forecasting presents a high level of uncertainty. In such an environment, retailers must make good use of demand information to place the right product quantities at the right time. They may postpone their orders to obtain better demand information by paying cost premiums [2–4], as forecasts for longer time horizons are more uncertain than those for shorter time horizons [5].

Much of the literature incorporating demand forecast updating into ordering decisions has focused on the trade-off between demand accuracy and additional costs by implicitly or explicitly assuming that a supplier's capacity is infinite. However, this capacity is limited in practice and plays a critical role in supply chains. A considerable amount of research has considered the effect of capacity, such as inventory controls in a capacitated system [6], capacity reservation [7] and contracts with capacity constraints [8]. Due to limited supplier capacity, supply lead times should be related to order quantities. Glock [9] pointed out that lead times may be shortened by decreasing lot sizes. Karmarkar [10] and Kim and Benton [11] approximated the relationship between lot size and lead time using a positive linear function. Both of these studies suggested that supply lead times increase along with ordering quantities in many manufacturing systems.

However, due to demand uncertainty, a retailer's ordering quantity is unknown to a supplier (or manufacturer) in advance. In this setting, the manufacturer can adopt two possible supply modes. In supply mode A, the manufacturer specifies the available ordering timespan based on the largest estimated ordering quantity. For instance, Das and Abdel-Malek [12] pointed out that the quickest delivery is restricted by the minimum lead time, and Chan and Chan [13] indicated that a coordination mechanism presents a range of delivery due dates. In supply mode B, the manufacturer places a maximum limit on the ordering quantity. This maximum limit decreases as the supply lead time becomes shorter, an observation that has also been commonly made in the

* Corrreponding author. Tel.: +65 850 42348; fax: +65 6792 4072.
E-mail address: meimeizheng2009@gmail.com (M. Zheng).

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literature. Fisher and Raman [14] considered a capacity constraint at the second period in a two-stage model with demand forecast updating. Li and Liu (2008) and Chen, Gupta [15] showed that a supplier prefers to supply a retailer's regular order quantity in full while placing a restriction on the fast-ship order size. Due to limited capacity, the manufacturer may impose restrictions on the ordering time or quantity, in addition to charging a higher premium for a shorter lead time. These supply constraints may hamper the benefits of updated demand information. In this study, we are going to analyze the following research questions:

1. What are the relationships among the supply constraints (i.e., the higher purchasing cost, restrictions on the ordering time and quantity)?
2. What are the optimal ordering policies for retailers in the two supply modes? What's the value of demand forecast updating?
3. Which supply mode is more beneficial to retailers? How do the supply constraints differ in the impact on the value of demand forecast updating?

For an innovative product with a short life cycle, the supply lead time can be relatively long, and the time required by the manufacturing may comprise a considerable portion of it. Hence, the effect of manufacturing cycle time is investigated in this study. In practice, manufacturing systems are composed of multiple workstations, and can be viewed as a queuing network [16–18]. Jackson [19] modeled a queuing network through M/M/1 queues, and proposed the product form solutions. Inspired by the Jackson network, cycle time of a manufacturing system in this study is modelled through a series of M/M/1 queues. The detailed justification is given in Section 3.2. With the help of queuing theory, the increasing purchasing cost function, latest ordering time (supply mode A) and decreasing maximum ordering quantity (supply mode B) can be determined.

This study considers an extension of the newsvendor model with multiple ordering opportunities under demand forecast updating and supply constraints. Based on supply constraints and demand forecast updating, retailers' optimal ordering decisions are investigated according to the two supply modes. In supply mode A, under justifiable assumptions, the optimal ordering time is proved to be either the earliest or latest time epoch among the feasible ordering times, independent of demand forecast evolution. Hence, under time constraints, demand forecast updating can be either valuable or completely valueless to a retailer. In contrast, in supply mode B, the optimal ordering time may depend on demand forecast evolution. Due to the quantity restrictions, it is difficult to obtain a closed-form solution for the optimal ordering time. An efficient algorithm is proposed to determine the time by relaxing the restrictions with justifiable assumptions.

Numerical results are analyzed to investigate the effects of product and demand characteristics on the value of demand forecast updating in the two supply modes. If a product has a high initial purchasing cost, low additional purchasing cost or small salvage value, demand forecast updating is beneficial to the retailer. Furthermore, in supply mode A, the value of demand forecast updating can increase or decrease in price, but it decreases in price in most of the examined cases in supply mode B. In terms of demand, retailers are found to obtain more benefits from demand forecast updating with higher forecast efficiency in most cases.

Through the queuing models, different supply scenarios can be compared and some managerial insights can be obtained. The numerical results show that retailers tend to choose supply mode B rather than A if the manufacturer is risk-averse, especially when the demand is highly uncertain, and vice versa. Moreover, if the demand uncertainty is low, the benefit of demand information decreases largely due to the increase in purchasing cost. Otherwise, the retailer should persuade the manufacturer to relax the ordering time and quantity restrictions to make good use of the updated demand information.

Overall, the main contributions of this study are as follows. First, supply constraints are derived through modelling manufacturing systems. Although the significant impacts of them are demonstrated in inventory management with demand forecast updating, they are rarely examined in detail. For instance, the increased purchasing cost in Wang, Atasu [20], the latest second ordering time in Milner and Kouvelis [21] and the available second ordering quantity in Vlachos and Tagaras [22]. Second, the optimal ordering time is proved to be one of two endpoints of the feasible timespan if there is no constraint on the ordering quantity (supply mode A). The result is counterintuitive since the optimal ordering time is expected to be some point in the middle of the timespan. It implies that the latest ordering time plays a critical role in determining whether to take advantage of the demand forecast updating. Third, the ordering policy in supply mode B is investigated to balance the increasing demand forecast accuracy and decreasing maximum quantity. To the best of our knowledge, the decreasing maximum quantity has not been discussed in forecast-updating literature. In practice, it is more general to consider that the available quantity is related to the supply lead time. Fourth, three types of supply constraints are considered at the same time in a multi-period model with demand forecast updating. By comparing them numerically, interesting insights are obtained.

The rest of this study is organized as follows. Section 2 provides a literature review. Section 3 presents the relevant models and analyzes optimal ordering decisions. Section 4 investigates the role of demand forecast updating in a purchasing plan based on numerical results. Section 5 summarizes the results.

2. Literature review

In this section, the literature related to (a) supply lead times and flexibility and (b) demand forecast updating in various settings is reviewed and discussed.

Supply lead time has been identified as an important decision variable in many studies because a reduction in lead times can decrease inventory and improve the level of service [23–25]. Furthermore, lead times play different roles according to the corresponding costs. Liao and Shyu [26] proposed a continuous inventory model to optimize a lead time consisting of n components, with different crashing costs per unit time. Chandra and Grabis [27] studied the trade-off between the benefits of lead time reduction and linear or even nonlinear procurement cost increases through a single-stage variable lead time inventory model.

Supply flexibility, especially that related to time and quantity, also has a great effect on supply chain performance. Milner and Kouvelis [21] investigated the value of time and quantity flexibility for different types of product demand and identified the environments in which a buyer should invest a particular type of flexibility. Das and Abdel-Malek [12] proposed a measure for estimating supply chain flexibility as a function of the constraints placed on delivery lead times and ordering quantities, which are the two most common changes arising within the buyer-supplier relationship.

These prior works analyzed the effects of supply lead times and flexibility in inventory models. By the same token, this study considers how supply lead times and constraints affect ordering decisions through an extension of the newsvendor model with multiple ordering opportunities.

Demand forecast updating is another factor considered in this study. Better forecasting can decrease inventory costs, particularly