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Decision Support

Demand seasonality in retail inventory management

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ABSTRACT

We investigate the value of accounting for demand seasonality in inventory control. Our problem is motivated by discussions with retailers who admitted to not taking perceived seasonality patterns into account in their replenishment systems. We consider a single-location, single-item periodic review lost sales inventory problem with seasonal demand in a retail environment. Customer demand has seasonality with a known season length, the lead time is shorter than the review period and orders are placed as multiples of a fixed batch size. The cost structure comprises of a fixed cost per order, a cost per batch, and a unit variable cost to model retail handling costs. We consider four different settings which differ in the degree of demand seasonality that is incorporated in the model: with or without within-review period variations and with or without across-review periods variations. In each case, we calculate the policy which minimizes the long-run average cost and compute the optimality gaps of the policies which ignore part or all demand seasonality. We find that not accounting for demand seasonality can lead to substantial optimality gaps, yet incorporating only some form of demand seasonality does not always lead to cost savings. We apply the problem to a real life setting, using Point-of-Sales data from a European retailer. We show that a simple distinction between weekday and weekend sales can lead to major cost reductions without greatly increasing the complexity of the retailer's automatic store ordering system. Our analysis provides valuable insights on the tradeoff between the complexity of the automatic store ordering system and the benefits of incorporating demand seasonality.

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1. Introduction

The main challenge in managing retail inventory is to match replenishment and demand, that is providing items on the shelf justified by an upcoming shopper demand. Economies of scale in supply, inadequate store execution and demand variation often lead to out-of-stocks and excess inventory. While store execution and retail out-of-stocks have received considerable attention in academia and business practice (see Aastrup & Kotzab, 2010), the impact of demand variation has largely been overlooked (Bijvanc & Vis, 2011).

Demand in retailing is known to vary depending on the day of the week and time of year, around important holidays such as Christmas, and the seasons. For example, ice cream is in higher demand in the summer months. Demand is also generally not evenly distributed within the day. For instance, in business districts more customers shop just after working hours on weekdays. Retailers can, to some degree, reduce demand variation, for instance by reducing promotions or offering "everyday low prices". However, customer buying habits, like shopping on weekends, limit a retailer's ability to completely smooth demand variations. This creates the need for retailers to account for seasonality in their inventory control and shelf inventories, in (partial) synchronization with the demand pattern (Aviv & Federgruen, 1997).

Not accounting for demand seasonality leads to systematic mismatches in demand and supply at the item-store level, resulting in higher than needed costs. For example, Gruen and Corsten (2008) show that out-of-sync replenishment and demand lead to recurring out-of-stocks in retail stores on specific days of the week. Yet, from our conversation with retailers, it appears that many of them lack the capabilities or skills to incorporate demand seasonality into their store ordering and shelf replenishment systems. Six medium-sized European retailers reported to us that their automated store ordering (ASO) systems do not have the technical capabilities to account for demand seasonality within the week. Similarly, two of Europe's largest retailers told us that even though their ASO system allows for different yearly seasonality patterns for each item, they currently refrain from using refined seasonality pattern analysis because of the added level of complexity. We also

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spoke to a company which sells forecasting and ERP-type software for retailers. They reported that their program has the technical capability of monitoring sales patterns to a very fine granularity, yet so far none of their clients has ever asked for this information to be incorporated into replenishment decisions; it was only used for planning checkout staffing. All the retailers we spoke to were aware of the possible inefficiencies of not exploiting seasonality but were unsure of the return on investment for updating their systems. One retailer we met was in the process of investigating the mismatch between intra-day sales patterns and the replenishment times and building its own tool to address the problem.

We study a setting where demand has a known seasonality pattern with two types of variations: within-review period and across-review periods (the review period is defined as the time between when two replenishment orders are placed). We apply our findings to real-life examples where demand follows a seasonality cycle over the days of the week and the times of the day. Fig. 1 illustrates the type of seasonality pattern under investigation. It shows the sales of a specific cigarette product (global brand, single box of 10 cigarettes) at a European retail store for two months in 2010. Demand varies depending on the day of the week: weekly sales peak on Saturday and Sunday. Demand is also not evenly distributed within a day: on Saturday, most of the sales occur before 5 pm while on Sunday most of the sales occurs after 5 pm. In essence, the demand rate varies across days of the week and within the day, but displays the same periodic pattern every week.

Given seasonal customer demand, we research the following questions: (1) What is the cost of neglecting demand seasonality in retail inventory control? (2) For which type of products is this cost most significant? (3) How much can be gained by partially incorporating demand seasonality into an ASO system and what is the best way to do so? We answer these questions in a setting which is suitable for retail environments: we consider a single location, single item, lost sales inventory problem with handling costs, fractional lead time (i.e., a lead time shorter than the review period) and batch ordering. Further, we assume that demand is non-stationary, in particular the distribution of demand is different before and after the order is received within a review period and also exhibits a seasonal pattern. This means there are two types of demand variations: within-review period variations and across-review periods variations.

We consider four different settings in which the retailer accounts for varying degrees of seasonality. In the first setting, the retailer accounts for both types of demand variations. In the second setting, the retailer only accounts for across-review periods variations. In the third setting, the retailer only accounts for within-review periods variations. In the fourth setting, the retailer ignores all form of seasonality, which often corresponds to current retail practice.

In each setting, we calculate the inventory policy which minimizes the long-run average cost criterion by solving a Markov decision process and show that it does not have a simple structure. Then, the performance of the inventory policies in last three settings is evaluated using the true distribution of demand. This allows us to discuss when it is most important to incorporate within- and across-review periods variations into the ASO system and which type of variation is the most crucial. Third, we apply the problem to a real-life setting, using Point-of-Sales (POS) data from a European retailer and replenishment information. We also explore simplified policies of only distinguishing between weekday and weekend sales.

We find that incorporating seasonal variations can lead to a substantial decrease in costs – on average 4.91% in our application using POS data. Not surprisingly, we find that product categories with more variable demands lead to the highest optimality gaps but there is more to the story. First, we see that optimality gaps increase with average demand and decrease with case pack size, and the costs associated with ordering, handling and purchasing. Second, we see that from our POS data analysis that across-days variations have a greater impact than intra-day variations. In fact, taking intra-day variations into account without acknowledging across-days variations can lead to an increase in costs, i.e., more information is not always better. Finally we see that, in many cases, a very significant portion of the cost savings can be achieved with a simple distinction between weekday and weekend sales, provided the weekend is defined appropriately for each product category.

The closest paper to ours is a recent study by Tunc, Kilic, Tarim, and Eksioglu (2011), who investigate the best stationary policy given that demand is non-stationary. They find that a stationary policy may be a good approximation only if demand uncertainty is high, setup costs are high and penalty costs are low. Our papers have fundamentally different approaches. Tunc et al. (2011) search for the best stationary (s, S) policy given non-stationary demand: the retailer knows that demand is non-stationary but restricts himself to a stationary policy because it is easier to implement. In contrast, this paper considers the best non-stationary inventory policy given a demand pattern that leaves out some seasonality, for example because the retailer uses weekly demand estimates. Further, Tunc et al. (2011) use a model with backorders, no lead time, a batch size of one, no handling costs and finite horizon, which

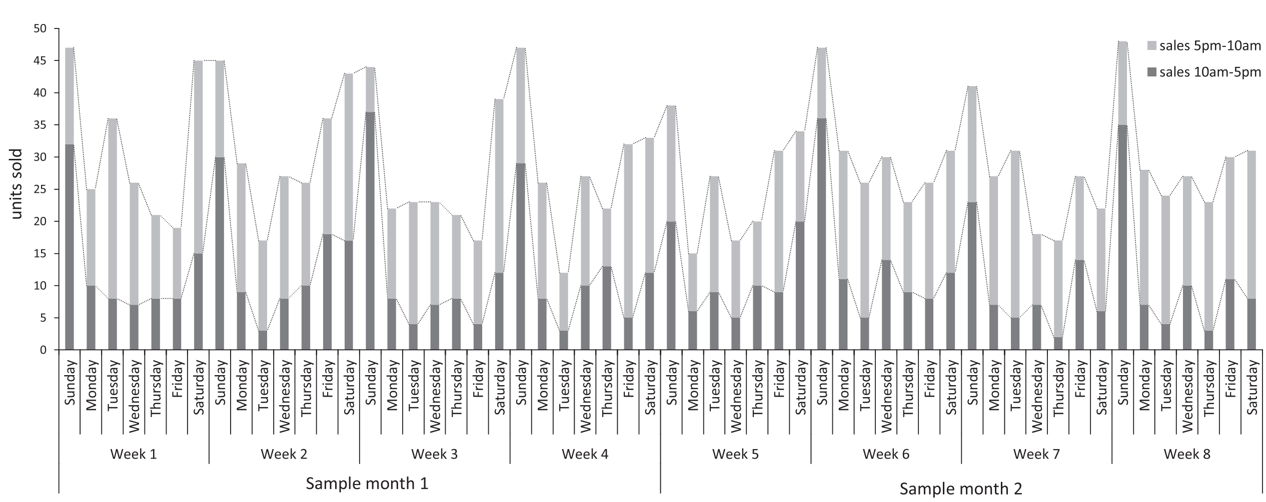

Fig. 1. Sales seasonality in cigarette sales during a two-month period in 2010.

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