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RFID and perishable inventory management with shelf-space and freshness dependent demand

Selwyn Piramuthu [a,c,*], Wei Zhou [b,c]

[a] Information Systems and Operations Management, University of Florida, USA
[b] Information & Operations Management, ESCP Europe, Paris, France
[c] RFID European Lab, Paris, France

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ABSTRACT

Although there is an extensive set of literature on inventory management for perishable items, a majority of these operate at a higher level where all items are assumed to have a fixed shelf-life. However, depending on how they are handled in transit as well as during storage, the remaining shelf-life of perishable items can vary. We consider perishable inventory management with demand that is directly dependent on the amount of shelf-space allocated to the item of interest as well as its instantaneous quality. We assume the existence of detailed information at the item-level generated through auto-ID technology such as RFID with necessary sensors. Specifically, we extend the model in Bai and Kendall (2008) to incorporate item-level quality information and use Genetic Algorithms to solve our model. Our results show that the incorporation of item quality increases the resulting overall profit to the retailer.
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1. Introduction

Perishable item inventory management has been studied by researchers in the area for over four decades (e.g., Broekmeulen and van Donselaar, 2009; Cohen, 1976; Fries, 1975; Nahmias, 1975; Nahmias and Pierskalla, 1973; Pierskalla and Roach, 1972; Prastacos, 1981; Van Zyl, 1964). Bakker et al. (2012) provide an excellent overview of research on inventory systems with deterioration. Managing inventory of perishable items is different from those for items that have a relatively longer shelf-life simply because of additional shrinkage that arise due to unsaleables as well as related dynamics. Regardless, the general dynamics in this area is known to be a good degree of accuracy for reasonably accurate planning purposes. However, given the thin margins faced by retailers that are more often a norm than an exception, any improvement in the accuracy of managing inventory would result in significant tangible benefits in terms of less wastage, more profit, increased customer satisfaction, among others.

Given the higher level of granularity afforded by the identification technology of choice – bar codes – a majority of the literature on perishable item inventory management model and perform analysis at the class level where an instance of this class is not differentiated even though the conditions encountered may not necessarily be identical across different instances. While these suffices as a good approximation, it is far from reality since (1) given the short remaining shelf life of perishable items, the consequences of even minor over- or under-estimation could be profound – it is relatively easy to over- or under-shoot in estimates and (2) perishables are notorious for exhibiting different rates of degradation, resulting in different remaining shelf lives even within the same pallet due to their exposure to different environmental conditions in transit and during storage.

Perishable items are generally maintained in a controlled environment (e.g., refrigeration, low humidity) to slow down their quality degradation rate. However, it is extremely difficult to maintain consistency in ambient conditions even within a pallet (e.g., Jedermann et al., 2010; Praeger et al., 2012). Reasons for this include the density of surrounding material(s), relative distance from cooling units, etc. Therefore, given that different items are exposed to different ambient conditions, it helps to know as accurately as possible the ambient condition profile over time for each individual perishable item as it passes through the supply chain until it reaches the final customer. Recent developments in sensor and auto-identification technologies such as Time–Temperature Indicators (TTI), RFID (Radio-Frequency IDentification) tags (e.g., Becker et al., 2010; De Marco et al., 2012; Ngai et al., 2008), among others, facilitate the ease of accomplishing the generation of item-level information. TTI stickers are placed on the perishable object and a change in color in these stickers is used to determine the extent of spoilage of the perishable. However, a drawback of TTIs (vs. RFID) is that these are passive and cannot communicate with a reader. RFID tags, on the other hand, can communicate with a reader for continual status updates.

* Corresponding author at: Information Systems and Operations Management, University of Florida, USA. Tel.: +1 352 392 8882; fax: +1 352 392 5438.
E-mail address: selwyn@ufl.edu (S. Piramuthu).

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We consider inventory management of perishables where the demand for an item is determined by its allocated shelf-space *as well as its instantaneous freshness*. As information at a finer level of granularity (e.g., through item-level RFID tags) become available (e.g., Zhou, 2009), there is a concomitant need to be able to utilize this rich information for improved performance (e.g., Jedermann et al., 2009; Laniel et al., 2011; Piramuthu et al., 2012). To our knowledge, there is a lack of the existing literature that cover this topic. We attempt to address this gap in current literature by studying inventory management of perishable items using item-level information generated through semi-passive RFID tags with appropriate (e.g., temperature) sensors. Specifically, we extend the model presented in Bai and Kendall (2008) to include RFID-generated item-level information and consequently model the facings based directly on the quality profile of items on the shelf. We solve the resulting problem using Genetic Algorithm-based Evolutionary Solver. Evolutionary Solver is Frontline Systems' implementation of Genetic Algorithm in their Premium Solver for Education (solver.com) product that runs on Microsoft Excel Spreadsheets.

The contribution of this paper is three-fold: (1) we model the number of facings at a finer (i.e., at the item level) level of granularity based exactly on the instantaneous quality of each individual items on the shelf, (2) we consider the possibility for the retailer to display items based purely on their remaining shelf-life, and (3) we show that the dynamics when item-level information are available is disparate from the case where only class-level information is available. The way we model the number of facings based purely on each of the item's instantaneous quality is significant for perishables since, for example, any number of perishables with quality below consumable-level will not generate demand, i.e., number of facings has to take the quality of the items into account and none of the existing literature does that, to our knowledge.

The rest of the paper is organized as follows: we provide a brief background on the domain of interest to this study in the next section. We then present our model and analysis in the following section. We conclude with a very brief discussion in the concluding section.

2. Background

It is generally known that the amount of sales of items in retail stores directly depends on the displayed inventory. For example, Wolfe (1968) empirically showed that the displayed inventory of women's dresses or sports clothes proportionally influenced their sales. These results were confirmed by Silver and Peterson (1985). Several studies have attempted to determine the reasons for the effect displayed inventory has on demand stimulation, which Larson and DeMarais (1990) call the “psychic shock.” For example, Levin et al. (1972) observe that the existence of retail displayed inventory has a motivational effect on the customer. Schary and Becker (1972) also observe that the sheer availability of the product stimulates the demand.

Given that retail displayed inventory stimulates demand, several researchers have attempted to develop shelf-space allocation models for a set of products in a retail setting. For example, Anderson and Amato (1974) developed a model for the simultaneous determination of product assortment and shelf-space allocation. Corstjens and Doyle (1981) model demand rate as a function of shelf space allocated to the product and used geometric programming to solve the model. This was later extended by Bultez and Naert (1988), who developed a general theoretical formulation utilizing marginal analysis. Zufryden (1986) used dynamic programming to solve the shelf-space allocation problem and determined integer solutions to the problem. Hansen and Heinsbroek (1978) considered simultaneous optimal product selection and the allocation of shelf space to these products. Borin et al. (1994) and Borin and Farris (1995) considered the integrated product assortment and shelf-space allocation problem and incorporated cross-elasticity effects of substitute items to study the effect on product demand when other products are excluded in the assortment.

To our knowledge, there is a lack of published research on shelf-space allocation and inventory management of perishables where the items are considered individually at a lower level of granularity. Unlike non-perishables, where every instance of a class remains more or less in the same state for a long period of time, the rate of decrease in quality of perishables varies among instances. Moreover, the pre-determined ‘expiry date’ on the item does not necessarily tell the complete story. For example, it is not uncommon for a perishable item to ‘expire’ before its ‘expiry date.’ On the other hand, it is also quite common for perishables to remain in good condition even after their ‘expiry dates,’ due in part to the conservative nature in which ‘expiry dates’ are determined with a high safety factor. There is, therefore, a need to incorporate the idiosyncracies of different item instances for planning and managing perishable inventory. Given current state-of-the-art of related technologies, RFID tags are the most appropriate choice for such applications. The need to study the use of RFID tags to generate item-level information is clearly compelling in this application area.

One of the very few research publications in this area is that of Chande et al. (2005). They propose a model for inventory control of perishable products to determine the optimal timing for discount offers and also the optimal order quantity based on the age of all available items.

Bai and Kendall (2008) base their problem definition from that in Urban (1998) and Borin et al. (1994) and model using a multiplicative demand function that depends on the item's instantaneous inventory and its freshness (i.e., quality). They separate the effects of the item's quality and its allocated shelf-space while assuming the quality of every item on the shelf to be the same. Clearly, not all items are exposed to the exact same set of conditions and, therefore, degradation of their quality occurs at different rates. We observe that given current state-of-the-art auto-ID technology, it is possible to generate detailed information on an item and its ambient conditions in real-time (e.g., Zhou, 2009). Moreover, given the differences in quality of items on the shelf, the allocated shelf-space is effectively reduced by the quality of the items that are not of the highest quality. We use this information to develop our model. For comparison purposes, we use the data sets used in Borin et al. (1994) and Bai and Kendall (2008).

3. Model and analysis

We use the following notations throughout the remainder of the paper:

t	time
q_{ti}	quality of item i at time t ($0 \le q_t \le 1$)
q_{oi}	quality of item i at time zero. This is the highest possible quality for this item
q_i^*	demand for item i begins to decrease when its quality decreases below this level
q'_i	demand for item i is zero when its quality reaches this level
λ	decay parameter for the perishable item
i	index for item i ($1 \le i \le n$)

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