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Display, disposal, and order policies for fresh produce with a back storage at a wholesale market

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ABSTRACT

Traditional wholesalers of fresh produce in China display and sell all the products that they have brought to the wholesale market every day. Products left by the end of the day are deteriorated due to high temperatures at which products are displayed, and are thus sold at a low price or disposed. Modern wholesalers can preserve product quality and carry over unsold products to the next day, by using a back storage with cooling facilities at or close to the market site. Modern wholesalers thus face a multi-period decisions problem, with decision related to amongst other the number of products to keep behind in the cooled back storage, and the number of products to display in the open air from each quality class. During a market day these decision can be revised. Hence the decision problem is not only a multi-stage problem because of carrying over products from one day to the next, but also because of intra-day periods at which the display decision is updated. The price decreases over the day. So does the demand, and the demand depends on the quality of the displayed products. Products that are of (too) low quality are sold/disposed to a secondary market. We modeled the inventory control problem as a Markov decision process model that maximizes the profit of the wholesaler. Based on the model and numerical result for a realistic setting, we analyze the structure of the optimal policies and derive heuristics for practical use. The heuristic methods perform close to the optimal policy, resulting in managerial insights to practitioners.

1. Introduction

This research is established on the observation of the Chinese fresh food supply chain connected by a wholesale market. A typical wholesale market has a large scale and large amounts of participants. The market gathers buyers and sellers, matches the different sources of supplies and demands, and prices the products. Traditionally, the wholesalers operate in daily cycle for highly perishable products (i.e., purchase the products from the upstream, bring them to the market, sell them, and dispose all the left products to a secondary market every day). Nowadays with the cooling facility becoming cheaper and more accessible, more wholesalers begin to change their way of operation. The decisions faced by the wholesaler become more complicated for (1) the warehouse doesn't have the booth's function of displaying and selling. The modern wholesaler has to decide how many and which products are displayed, while the traditional wholesaler just bring all of them to the booth. (2) The products are better stored with the cooling facility. At the end of the day, the modern wholesaler decides how to dispose the left products instead of disposing all of them. (3) The ordering decision is influenced accordingly, and all these decisions are mixed. Besides, in the wholesale market the price and the demand are non-stationary. The price is decreasing like the declining price anomaly observed in wholesale auction markets where the perishable products are also sold sequentially. The demand is also decreasing since the decreasing price actually reflects the relatively decrease of demand. With the above features, the complicated new problem for the wholesalers requires a further study.

To make the problem clear, let's take a glimpse at the submarket of strawberry as an example. The wholesalers sell strawberries at their booths. All the booths are clustered geographically. At night, e.g., at 0:00 a.m., the sales begin and the market becomes busy. The retailers come to the market at different times during the market's busy period instead of arriving together. With the time going by, the market's price and the potential demand decreases. Due to the price's and demand's decrease as well as the quality's decrease, the wholesaler makes several decisions at different times on how many and which products are brought to the booth and displayed. The retailer's demand is influenced by the displayed product's quality. Meanwhile the displayed products

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decay faster because of the higher temperature without cooling facility. After the market busy period, the market becomes idle and few sales happen. In this market idle period, the wholesalers dispose some old products and order new products. The disposed products are sold to a secondary market with a salvage value. The new order will arrive just before the next market busy period. During the market idle period, the products are stored in the warehouse and deterioration is counted in one time.

To conclude, the wholesaler makes three decisions: the display decision during the market busy period, the disposal and ordering decisions in the market idle period. We are curious about how to make optimal decision under the varying market environment. We also want to investigate what heuristics suit the problem and how they perform comparing to the optimal decision.

The paper will be organized as following: in Section 2 we review the related literature, then come to the formulation of Markov decision model in Section 3. The followed section is the analysis on a base case and the discussion on designing heuristics. In Section 5, we study a group of experiments and mainly validate the performance of the separated heuristics on different decisions. In Section 6, we analyze the performance of the combined heuristics that reflect different wholesaler's policy in use, and the discussion is closely related to the real scenarios. In the last section, we come to the conclusion.

2. Literature review

2.1. Related problem

The display decision itself is a research topic in inventory management. Fujiwara, Soewandi, and Sedarage (1997) consider the separated storage in the cool-room and at the shelf. They investigate the joint ordering and display problem for perishable products. To model the two echelon system, ordering is simplified as a single-period decision with the product's lifetime exactly one cycle. The display decision is embedded in the cycle. Once the product is displayed at the shelf in one sub-period, it is not fresh any more. This single-period model suits the traditional wholesalers but does not solve the problem faced by the modern wholesaler with cooling facility. Beyond that, there are some other studies related to the display where the impact of display is usually described as a stock-dependent demand. These approaches are reviewed in Goyal and Giri (2001) and Urban (2005).

The wholesale market's features also matter. The price is decreasing like the wholesale auction market's declining price anomaly. This decreasing tendency is also shown in a general wholesale market. For instance, a series of studies on fresh product wholesale market (e.g., Graddy, 1995, 2006; Giulioni & Bucciarelli, 2008, etc.) report this feature. Furthermore, the impact of exogenous decreasing price on the single-period inventory model is studied in Banerjee and Meitei (2010) and Meitei and Banerjee (2013).

2.2. Related model

The modern wholesalers make the display decision together with the multi-period ordering and disposal decisions. This suggests us to follow the framework of multi-period perishable inventory models with ordering and disposal decisions. There are plenty of literature on this topic. The early work could trace back to Martin (1986) which models the disposal independent of ordering. Li, Yu, and Wu (2013) consider the joint replenishment and clearance sales with the inventory segregated into new and old part and offered to different markets. They also develop heuristics to solve their problem. Haijema (2014) models the optimal disposal quantity together with the ordering and issuance process for the perishable product, e.g. at a blood bank. Small scale numerical experiments are used to make comparisons among different combination of policies in this study. We employ the similar methodology as Haijema (2014), but the context is much more complicated for a number of reasons: (1) the whoesale market problem includes a back storage and the optimization of a display policy; (2) demand is not stationary but depends on the quality of displayed products as proposed by Ferguson and Ketzenberg (2006); and (3) the sales price is non-stationary. The inventory management has features of a revenue management(RM) problem.

Actually improving the profit by careful deciding about the quantity to display is like a capacity control problem (see the review in Talluri & Van Ryzin, 2006). The sales capacity is set by the quantity displayed at the booth: displaying many products results in a higher deterioration of product quality, which reduces sales and profit in the future. An alternative RM approach is the pricing approach for fresh products, see Jia and Hu (2011), Chen and Sapra (2013), Chintapalli (2015) and Chen, Pang, and Pan (2014). We assume wholesaler cannot individually set the market price.

The paper contributes to the existing studies from three aspects: (1) we investigate and optimize the displaying process for a perishable inventory management problem at the wholesale market. (2) The optimization model integrally optimizes the order, display and the disposal quantities, which seems to be a new application to the wholesale market as well as to revenue management. (3) Heuristic rules are derived for practical use, based on different realistic scenarios that are studied numerically by simulation.

3. Markov decision model

Similar to Haijema (2014), the process in the wholesale market includes ordering, issuance, and disposal. But in a wholesale market problem, the issuing process is more complicated and is influenced by the seller's display decisions which works within a much smaller time slot in real market environment. By dividing a day into market idle period and market busy period with several subperiods, we incorporate more information such as the retailer's reaction to the displayed product's quality and the varying market price. With the additional information considered, either the wholesaler's objective or his decisions are updated. In this section, we will first sketch the wholesaler's controlling processes, describe them in discrete time, then build the model based on those sequential events.

3.1. Discrete time view: decisions and inventory dynamics

As shown in Fig. 1, a day is divided into two periods: a market busy period and a market idle period. During the market busy period products are displayed and sold. During the market idle period the market is closed and products are stored to put them for sale in the next market busy period. During the market busy period the sales price usually decreases over time, which we model in discrete time by dividing a busy period into U sub periods. From one (sub) period to the next the product quality decreases, especially of products displayed in open air. Sales depend on the sub period and the quality of the displayed products, which the wholesaler can influence by its displaying policy which states which products to display and which products to keep behind in a back storage. Every sub period the wholesales needs to decide about how many product to display, and of which quality. Displaying the freshest will increase the demand in this period, but results in a lower quality and demand in future periods, also because displayed products will deteriorate faster than the products kept in the back storage.