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A dynamic product quality evaluation based pricing model for perishable food supply chains

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ABSTRACT

Waste stemmed from inappropriate quality control and excessive inventories is a major challenge for perishable food management in grocery retail chains. Improvement of visibility and traceability in food supply chains facilitated by tracking and tracing technologies has great potential to improve operations efficiency. This research aims to reduce food spoilage waste and maximise food retailer's profit through a pricing approach based on dynamically identified food shelf life. The proposed model is evaluated through different pricing policies to exploit the benefits from utilising accurate product shelf life information captured through innovated tracking and monitoring technologies. Numerical analysis is conducted in an illustrative case study.

1. Introduction

Perishable foods are increasingly important to grocery retailers as they have become a main reason for many consumers to choose one supermarket over another. Despite their strategic importance, the management of perishable products is far from satisfactory, and perishable food loss at grocery retailers can be as high as 15% due to damage and spoilage [1]. The loss in a grocery supply chain mainly stems from inappropriate quality control or excessive inventories that have to be either marked down before the "sell-by-date" or thrown away after it. The financial consequence of waste for retailers and manufacturers is severe. In the European grocery sector, products that are not purchased before their sell-by date are estimated to cause costs running into billions of dollars each year [2].

Due to the nature of perishable food, its quality can be considered as a dynamic state that decreases continuously until the point when it is unfit for sale or consumption. There is a limited length of time during which the food is fit for sale and consumption. This is also known as product shelf life and printed on product labels. According to IFT [3], shelf life can be defined as the period between manufacture and retail purchase of a food product during which the product is of satisfactory quality. In practice, the shelf life information printed on food labels is coded when products are packed by producers. However, most perishable foods are temperature sensitive and their shelf life is therefore a function of product characteristics, conditions under which the product is maintained, and time [4]. One limitation of current practice is that the printed "sell-by-date" does not reflect the real temperature variations that occur through its life cycle. In fact, actual conditions frequently deviate from specified conditions through food storage and transportation processes, and food quality can be compromised due to unexpected development of different kinds of bacteria such as botulism, listeriosis and salmonella [5]. It may affect product quality and result in a difference between the actual remaining shelf life and that printed on the product label. The consequence of such a difference can be anything from increased waste to legal action.

As a commitment of food supply chain management, perishable foods must be sold to consumers before foods spoil to ensure food safety and quality while maximising profit. This research deals with this challenge through managing retailing price dynamically against enriched food quality information. The research attempts to prove the proposition that pricing decisions based on dynamically identified food shelf life can improve the retailers' operations performance by minimising the consumer health risk and reducing food waste at grocery stores. The emergence of advanced product identification and sensory technologies such as ratio frequency identification technology (RFID) and time temperature indicator (TTI) provide great opportunities for effective management of perishable food. While these technologies are more widely adopted [6–9], it enables to automatically capture

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product information regarding product identity, properties and related data (e.g. temperature, humidity, and the time period during which products have been exposed to the temperature in the supply chain process, etc.) in real time. Such transparency generates the possibility that, as products pass through a supply chain, the shelf life can be dynamically predicted based on the environmental conditions during storage and transportation as well as the varied time required for these operations. In this paper, the proposed pricing approach focuses on utilising dynamically identified food shelf life information to support the pricing decision when retailers mark down the price of food products, which are approaching their expiration dates. The benefit of such an approach is evaluated by modelling the retailer's operational performance under different pricing policies. The technical details and implementation issues are not discussed in the research.

2. Literature review

Inventory control for perishable products has been given much attention in the inventory literature due to its prevalent existence in the industry. The basics of production and inventory systems with deteriorating products have been extensively studied, as reported in the review articles by Nahmias [10], Raafat [11], Goyal and Giri [12] and Karaesmen et al. [13]. Based on the characteristics of perishability, inventory models are classified into three categories: (1) models for inventory with a fixed lifetime; (2) models for inventory with a random lifetime; and (3) models for inventory, which decays corresponding to a proportional inventory decrease in terms of its utility or physical quantity [11]. In this research, the third type of inventory issue is investigated. The perishable food inventory decays in terms of its quality (shelf-life) or utility in the selling period. However, the model in this paper investigates a special situation where the shelf-life or freshness, which is a main quality indicator of perishable food, is dynamically identified or considered for pricing. The price of the food is as a result set dynamically in a series of discrete time as the shelf-life changes in a selling period.

Another area of related research combines pricing and inventory control for perishable products. As Ramasesh [14] suggested that the problem of determining the economic order quantities for an inventory item, when the vendor offers limited-time price reduction incentives has captured the attention of researchers over the past several decades. Banerjee and Turner [15] presented a flexible model, which addresses the problem of assigning optimal prices to perishable assets. Rajan et al. [16] and Abad [17] considered the combined pricing and inventory setup in a deterministic setting. They assumed that demand is affected by a product's remaining shelf life. The demand is deterministic for the product and is a decreasing function of the price and age of the product. In addition, Rajan et al. [16] stated that perishable products exhibit two characteristics differentiating them from the common pricing problem: (i) physical deterioration of inventory; (ii) decrease in market value or value drop associated with each unit of inventory held. Perishable food has to be removed from the shelf when it reaches its expiration date.

Customers are usually sensitive to quality changes of the expiring products and, as a result, give them a lower valuation. Food quality can be defined as the assemblage of properties which differentiate individual units and influence the degree of acceptability of the food by the consumer [18]. For many products, their quality is observable before purchase. It is an important factor influencing a consumer's purchase decision. Rosa Diaz [19] argued that the influence of price on consumers' decisions depends on the manner in which the price is perceived and evaluated. In particular, for perishable food products, many consumers consider that a new product has a higher quality than an expiring one. Considering supermarket customers, they will prefer to buy newly replenished goods instead of expiring ones. When prices are the same, they will prefer the newer ones. Hardie et al. [20] developed the notion of reference quality and empirically demonstrated that differences between observed and reference quality can significantly affect purchase probabilities.

Price discount is often used in practice when perishable products approach their expiration date [15,21–23]. Tajbakhsh et al. [23] developed an inventory model with random discounted prices and a numerical analysis that demonstrates cost savings through discount offers. Dynamic pricing and inventory control models for the perishable food have been reported extensively in the literature. One type of the research considers maximising business profits through pricing or allocating perishable products in an operation process according to their fixed shelf life [24–26]. In such research, the product shelf life is a constraint to the pricing or delivery planning decision. Another type of research employs the concept of product quality or product value, to represent product utility attributes on which decisions on pricing are made [27,28]. Kopalle et al. [27] presented a dynamic pricing model incorporating the relationship between expected quality and reference price. While much of the literature focuses on perishable products with fixed shelf life, for many food products, the moment of spoilage is variable and highly dependent on environmental conditions such as temperature. Although this issue is covered in the automatic tracking enabled business model developed by Li et al. [28], which employs a dynamic pricing approach to optimise retail chain profits, the cost of price changes and the uncertainty in consumer behaviour caused by changing prices make the dynamic pricing model difficult to implement in current retail operations.

Two issues are involved in this research, which have not received much attention in the existing literature: (1) impacts of the accuracy of quality or shelf-life indicator, which underlies the pricing and sales management decisions at retailing operations, on retailing performance; (2) the impact of pricing in terms of timing and frequency of discount in a selling period on retailing performance. As the shelf-life indicator is one of the major decision factors in the management of price, inventory and quality of perishable foods, the accuracy of it significantly affects operations cost, waste, profit and food quality [29–31]. With advancement of traceability technologies, the accuracy of the indicator can be significantly improved [4–6,8], and as a result, the pricing approach can be adapted accordingly to maximise profit using more accurate food quality information. This potential is analysed in this research.

The rest of the paper is organised as follow: Section 3 provides a brief background on quality deterioration of perishable food products in terms of time and temperature. In Section 4, a dynamic quality evaluation based pricing model is presented. It is followed by investigation of optimal solutions under different pricing policies in Section 5. An illustrative case study dealing with a perishable food supply chain is given in Section 6 in which sensitivity analysis is provided. Finally, Section 7 discusses the results of the paper and presents some future research opportunities.

3. Modelling quality deterioration of perishable food

Quality prediction is a complex task for food products, due to the range of quality attributes, dynamics of product characteristics and storage conditions. Most approaches used in quality prediction models are based on the fact that there is normally one leading quality characteristic for a given product [32,33].