Sustainable Dynamic Pricing for Perishable Food with Stochastic Demand

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Abstract - **In current competitive environment, retailers are facing a fierce competition and are aiming to manipulate customer purchasing attitudes. Dynamic pricing strategy is a major determinant of retailer's profitability when considering perishable food. Furthermore, increasing pressure from society and international organizations calls for food security, safety and decreased food waste and losses. This paper investigates dynamic pricing strategy with the objective of maximizing revenue and minimizing food waste to ensure sustainability. A simulation model with stochastic demand based on product price and age is developed using *ExtendSim*^{TM} *Suite*. The effect of inventory replenishment quantity on the performance measures is analyzed. Results reveal the superiority of dynamic pricing over fixed pricing strategy in terms of retailer profit and food waste.**

Keywords - **dynamic pricing, food waste, inventory, perishable, revenue management, sustainability**

I. INTRODUCTION

The United Nations Food and Agricultural Organization (FAO) stated in its report in 2011 that annually one third of the produced food for human consumption is lost or wasted, which amounts to around 1.3 billion tons of food wasted during its journey from farm to fork [1]. Food loss is defined as quantities lost in the early stages of the supply chain in production, postharvest and processing, while "food waste" are the quantities lost at the latest stages of the supply chain during distribution and consumption [1]. This work is concerned with food waste. The management of the final stages of the supply chain, retailer and consumer are of considerable importance in managing food waste; because, in final stages of supply chain, the product has the highest value of costs, since all previous supply chain costs are accumulated at this stage. Thus, wasting food at the end of the chain makes all previous processes and resources in vain. Therefore, retailers' practices can play influential role in reducing the amount of food waste.

Perishable food is considered as 50 percent of the food retail sector and it is claimed that consumers select their best retailer by perishable food gauge [2]. Fruits and vegetables are considered as the most organic food products with the highest share among other products as meat, diary, bakery and sweets [3]. Studying inventory management from the economic perspective has gained a lot of research interest. However, limited work considered the environmental and social aspects with the economic aspect [3]; although, elimination of food waste is one of the most important issues in the perishable inventory management [4].

In addition to inventory management, setting pricing policy is one other retailer practice that can affect food waste. Revenue management can be considered as the umbrella covering different pricing strategies. The concept of revenue management is widely defined in literature as selling the right product to the right customer at the right price; aiming to maximize the profit, through market demand forecasting and optimization of price and inventory. This concept was firstly introduced by the airline industry and then its application was widened to be used in different perishable products [5]. Dynamic pricing is one of the pricing strategies that was defined by Liu, Tang, and Huang [6] as the assignment of different prices to the product items of the same category, considering the individual product characteristics or the changes of the product status. Retailers use dynamic pricing to give the consumer a tradeoff between price and quality of perishable product.

The present study aims to study the effect of changes in inventory management and dynamic pricing strategy on the economic performance of the retailer as well as the amount of food waste. Using the *ExtendSim*^{TM} *9.2* simulation environment, retailer's operation under uncertain demand, based on age and price, are simulated and a set of system performance measures are assessed.

The remainder of this paper is organized as follows: Section 2 presents a literature review on dynamic pricing for perishable products. Section 3 depicts the problem definition and model development. In Section 4, the simulation results are discussed. Finally, Section 5 includes the conclusions.

II. LITERATURE REVIEW

In real life, firms tend to maximize their profits, while consumers tend to purchase products by weighing benefits and cost. It is claimed that 88% of consumers check the expiry date of deteriorating products before buying, or by consumer visual assessment to measure the quality of product such as in fruits and vegetables (when no expiry date is presented) [7]. Specifically, in the case of fruits and vegetables supply chains, visual quality (size and shape) plays an important role in the food waste as it is the main quality measurement for the consumer [8]. Scholz, Eriksson, and Strid [9] studied the food waste in six Swedish supermarkets for three years (2010 to 2012) for five departments meat, deli, cheese, dairy, fruits and vegetables, and concluded that fruits and vegetables contribute to 85% of the total wasted mass.

Price-based revenue management can be classified into fixed, dynamic, and promotional pricing [10]. For perishable products, dynamic and promotional pricing are usually applied to increase demand when product approaches the end of its lifetime. A study of the Danish food retail sector states that promotional offers may encourage consumer purchases; yet, these offers may also increase food waste in households [11]. Therefore, it is not of interest when targeting waste reduction. Hence, the current review focuses on dynamic pricing. Dynamic pricing solutions are proposed when demand is typically decreasing over time as is the case for fashion industry, fruits retail, hotels and airlines [12]. Dynamic pricing model with time-dependent elasticity is essential as it may manipulate customers buying attitudes as consumer refuses fixed price for deteriorating product during the entire selling period [12]. This will lead to maximum profitability for both customer and retailer, as well as ensure the sustainability of the products. Dynamic pricing helps the retailer to sell products before they expire by stimulating sales so wasted food is prevented and also increasing the revenue so it is a win-win situation [10].

Elmaghraby and Keskinocak conducted an extensive review on dynamic pricing and inventory management and how these can be used to maximize profitability by retailers, considering different inventory and customer classifications [13]. According to their classification, the case of perishable food as fruits and vegetables falls under the RIM category (Replenishment inventory, product demand Independent of time and Myopic customer). They also claimed that determining the initial inventory decision is influential in the pricing optimization. However, waste was not considered in their work.

The objective of revenue maximization and waste minimization was investigated via a deterministic mathematical model for a perishable product considering the effect of price, age and price elasticity of demand [14]. The authors proved that waste can be minimized by a dynamic pricing strategy. Even at the worst case, when decreasing the waste by 50%, the revenue loss can be around 20%. They suggested to replicate their experiment using Monte Carlo simulation.

Simulation for different dynamic pricing strategies was discussed by Chung and Li [15] to study the relation between the retail service efficiency, consumer purchasing and consumption patterns with respect to different pricing policies. The retailer offered a 30% discount when 30% of product life was remaining. From the proposed model it was concluded that 10% reduction in price increased sales by 5.8%. In 2014, they updated their simulation model using C language for a South Korean market [7]; where, four pricing strategies were tested; fixed price, discount price when product shelf life is imminent, discount price every day, and discount price with two days interval. The last two strategies were superior over the others. Only normally distributed consumption was used, and it was suggested to investigate other distributions in the future. F

Furthermore, Chen, Liu, and Xu [16] proposed a simulation model for a vegetable market in China to model the optimal pricing for perishable products considering customer preferences and uncertain demand; yet, no consideration for food waste management was made.

In [17] four models for dynamic pricing with and without menu cost (price adjustment cost, i.e. the extra cost produced due to price changes) were formulated in order to investigate how the number of price adjustments affected the profitability of deteriorating products. One of the work's conclusion was that multiple price adjustment was making the most benefit of dynamic pricing, when menu costs were small.

From the reviewed literature, it can be observed that the interest in using dynamic pricing is increasing in the latest years. Although profitability was initially the main driver for revenue management, the increasing global pressure for sustainable production and consumption; also, awareness of the importance of food safety and security and the criticality of food waste and losses, have pushed the research in the direction of including food waste minimization and environmental impact, when setting pricing strategy and managing inventory. For this reason, this paper studies the effect of pricing strategy and inventory management on retailer's economic performance and the generated food waste. Due to the stochastic nature of demand simulation is used in this work to assess the impact of inventory management and dynamic pricing on both profit and waste

III. SIMULATION MODEL DEVELOPMENT

A. Problem Definition

The problem considered is setting the pricing strategy and inventory management of a perishable product in a retail store/supermarket. The nature of items deterioration and perishability impose two problems for the retailer. First, unsold quantities approaching or attaining its lifetime are wasted. Second, profit loss due to unsold items, which have been ordered, put in inventory and/or displayed. Customers are reluctant to buying products of less quality unless their price is reduced. Thus, the retailer needs to identify the dynamic price of the products according to its age in addition to how much inventory to order. The ultimate goal of setting the price and the quantity to order is to reduce waste, lost sales, and increase profit.

B. Model Assumptions

In order to develop the simulation model, the following assumptions are made:

- Single product is considered.
- Myopic customer (purchases immediately when the price is lower than his estimate without looking at the future prices).
- Price depends on age.
- Demand depends on price and age.

- A periodic review policy for inventory replenishment, with products replenished daily.
- Items are discrete.
- Products are withdrawn from inventory following the first in first out (FIFO) rule.
- Menu costs, setup cost and holding cost are negligible.
- No backorders are allowed (*shortages or out of stock lead to lost sales*).

C. Performance Measures

The retailer's performance is assessed using the following performance measures:

- Revenue: from sold quantities USD/year
- Perished items: average cost of wasted items as they reached their end of lifetime at the retailer with no purchase USD/year
- Lost sales: unmet demand of customers USD/year.

D. Model Conceptualization

To formulate the problem defined in the previous section, a simulation model has been developed. The model represents a supermarket with inventory and displayed perishable items on shelves. Inventory replenishment at the supermarket is daily; hence, at the beginning of each day the supermarket receives a new lot from the supplier. The supermarket displays the perishable item with different prices depending of the age of the product.

Customers arrival at the supermarket is considered as the demand for the perishable product. Customers buy their required products and exit the supermarket at the cashier where revenue from sold items is calculated based on its age. Customers who do not find their request leave the supermarket and are considered lost sales. Product reaching their full lifetime (expiry date) cannot be sold and are thus considered as perished product. A flowchart describing the conceptual model for the system under study is illustrated in Fig. 1.

E. Setting Model Parameters

Essential to studying retailer's performance is to identify the revenue, which depends on sales price and demand. In this study the calculation of price and demand functions are adopted from [14], where demand depends on both age *a* and price *p* as indicated in (1). Furthermore, three parameters were used in [14] to describe price and demand relationships: the price elasticity of demand (α), the influence of age on demand (β), and the influence of age on price (γ).

$$D(p,a) = Do\left(\frac{p}{p_0}\right)^{-\alpha}\left[1-(^{a}/_{L})^{\beta}\right] \qquad (1)$$

Do and p_0, are initial demand and price, respectively, and L is the lifetime of the product ($a \leq L$). Price function is described in (2) [14]. Substituting (2) in (1) results in consumer demand based on age as given in (3).

$$p(a) = po\left[1-(^{a}/_{L})^{\beta}\right]^{\gamma} \qquad (2)$$

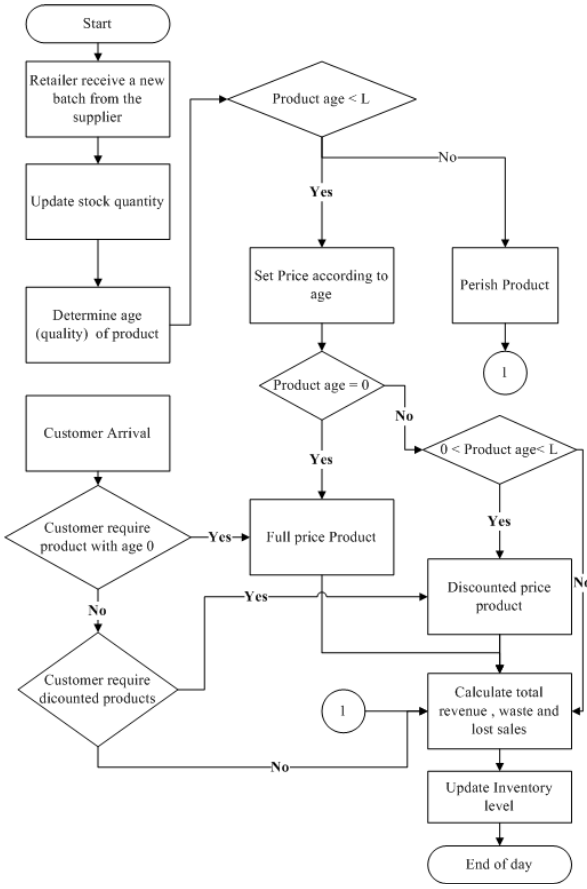

Fig. 1 Flowchart for retailer's operations

$$D(a) = Do\left[1-(^{a}/_{L})^{\beta}\right]^{1-\alpha\gamma} \qquad (3)$$

The developed model considers a single product with a lifetime of 10 days sold by a retailer under stochastic demand described by a Poisson distribution with a mean given by (1). Products are replenished daily with a quantity of 1,000 units. The initial unit-selling price of product is 5 USD. For perished products, a penalty of 1 USD/unit is added to the original price in order to calculate the loss in revenue from perished items.

The parameters α and β describe the customer response to price and product age, respectively. Hence, the only parameter the retailer can control is γ (influence of age on price) defining thus the dynamic pricing strategy.

The relationship between α, β and γ was studied in [14]. Based on (3), for $\gamma = 1/\alpha$, the demand remains constant as the product ages (i.e., fixed pricing policy, which is not sound for the customer). When $\gamma < 1/\alpha$, demand decreases with age; while for $\gamma > 1/\alpha$, demand increases with product age, which is the case when extreme discount strategy is applied. These relations are described in Fig. 2. It can be observed that $\alpha = 1/\gamma = 2$ presents the fixed pricing case, thus no change in demand over product lifetime. For α values ranging from 1/3 to 2 ($\alpha < 1/\gamma$), increasing the value of α results in slower rate of change in demand. For $\alpha = 3$ ($\alpha > 1/\gamma$), demand increases with age which is not practical in the case of fruits and vegetables.

In all cases, demand is zero when product reaches its full lifetime ($a = L$). Thus, an α value of 1 is chosen.

The second parameter to set is β, which describes the influence of age on demand. As per (1), for $\beta = 1$ demand decreases linearly with age. When $\beta > 1$ demand reduction with age is lower at first, then it increases with product aging. Finally, $\beta < 1$ presents a situation where demand reductions are high at the beginning of the product lifetime. This case is not practical, and is thus neglected.

The relationship between price and age for different values of β is shown in Fig. 3 The linear decrease can be seen for $\beta = 1$. Increasing the value of β, causes minor changes in price at the beginning of the product lifetime. The illustrated case of $\beta = 5$ may represent a product with slow quality degradation over time, so price is almost constant until the product age reaches its half lifetime. Based on the results obtained from Fig. 3, a β value of 2 is chosen as moderate case representing typically the case of fruits and vegetables.

The third parameter is γ. The effect of changing γ on the relation between demand and age is illustrated in Fig.4. Based on (3), fixed pricing strategy is presented by $\gamma = 1/\alpha = 1$. Thus, there is no change in demand over product lifetime. For γ values of 0.8 and 0.7, age slightly affects demand at the beginning of the product life, which is not the case for vegetables and fruits. For $\gamma = 2$ ($\gamma > 1/\alpha$), demand increases with age which is not practical for fruits and vegetables. Meanwhile, for γ values below 0.7, demand decreases as product ages as expected for fruits and vegetables. So, a γ value of 0.5 has been selected.

IV. SIMULATION RESULTS AND ANALYSIS

This section presents results of the dynamic pricing model using $\beta = 2$, $\alpha = 1$, $\gamma = 0.5$ and product lifetime of 10 days. Initial demand (*Do*) is expressed by a Poisson distribution with mean based on (3). Results are summarized in Table I for a constant inventory order quantity of 1,000 units. The net revenue is calculated based on (4); where, *RLC* is revenue less cost, *RS* is revenue from sold items, *LP* is the revenue loss from perished items and *LL* is the revenue loss from lost sales.

$$RLC = RS - LP - LL \qquad (4)$$

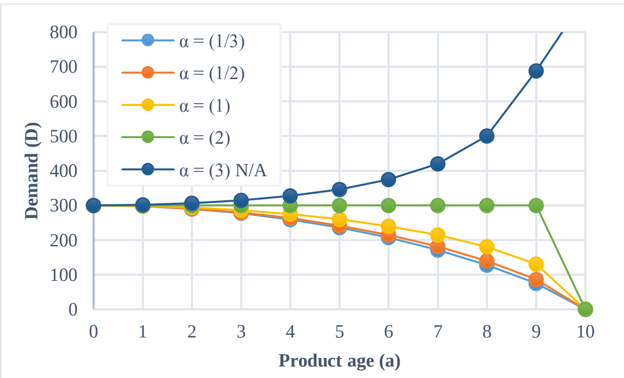

Fig. 2 Relationship between demand and age based on (3) for different α values, using γ =0.5 and β =2

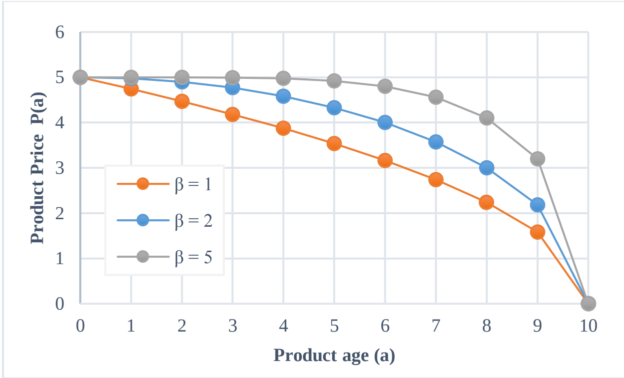

Fig. 3 Relationship between price and age using γ= 0.5 for different β values

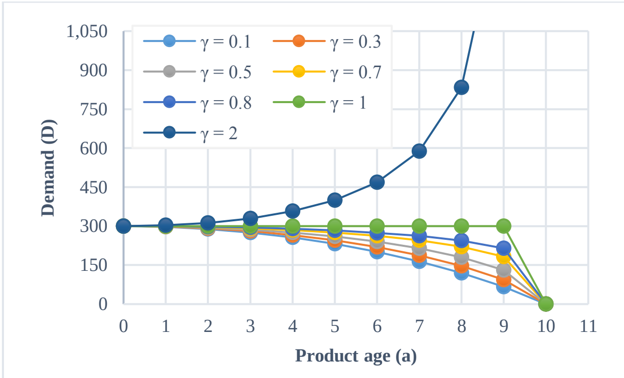

Fig. 4 Relationship between demand and age for different γ values, at α =1, β =2

In order to investigate the effect of changing daily replenishment quantity on different performance parameters, the model has been run using different replenishment quantities. Results are displayed in Fig. 5, quantities less than 500 unit/day lead to great loss due to the large percentage of unmet demand. Increasing inventory order quantity of 800-950 unit/day leads to an increase in net revenue till reaching the peak profit at 1,000 units/day. When inventory level increases reaching 1,400 unit/day although revenue from sales increases but eventually revenue less cost decrease by almost 45% from the peak, which occurs due to the huge number of perished products. Hence, it can be concluded that a replenishment quantity of 1,000 units best meets the economic objective and the food waste minimization objective. Using the same model parameters, we investigated the effect of altering daily replenishment for the fixed pricing on the different performance measures. Fig. 6 shows that the maximum annual profit obtained was USD 227,567 for an inventory order quantity of 130 units/day.

TABLE I
BASE MODEL RESULTS

Performance measure	Average (USD/Year)
Revenue from sold items (*RS*)	1,588,260
Revenue loss from perished items (*LP*)	17,826
Revenue loss from lost sales (*LL*)	54,085
Total revenue less cost (*RLC*)	1,516,349

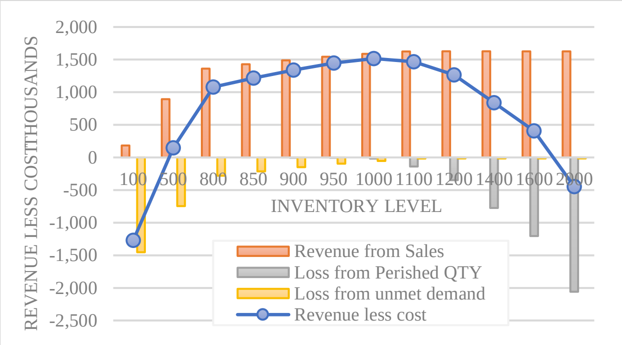

Fig. 5 Revenue less cost vs. inventory level with dynamic pricing

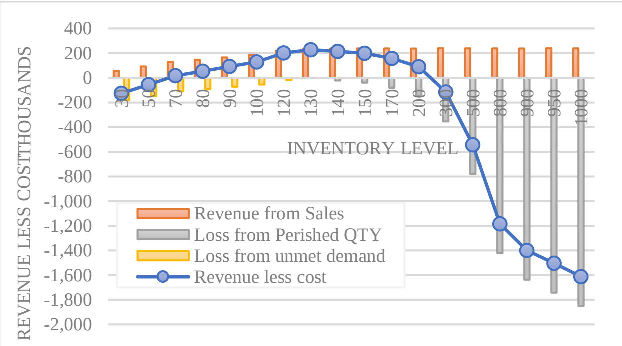

Fig. 6 Revenue less cost vs. inventory level with fixed pricing strategy

Compared to USD 1,516,349 for the dynamic pricing strategy, this massive loss in net revenue is due to the increase in perished amounts as fixed pricing does not encourage sales of aged products. Consequently, dynamic pricing can help the decision maker in achieving the desired profit without sacrificing the environmental aspect.

V. CONCLUSION

This paper addresses the problem facing retailers, what price to offer for aging perishable food and what quantity to order, in order to maximize their revenue and minimize food waste. A simulation model with stochastic demand is proposed to model the problem and assess retailer performance. The results revealed that when decreasing the inventory level, though almost no items deteriorate, still a loss in revenue occurs due to lost sales depending on customer demand. However, increasing the inventory level to meet all customers demand leads to an excess inventory and due to deteriorating nature of products they are wasted.

Furthermore, a comparison between fixed pricing strategy and dynamic pricing shows that the former is way less profitable for retailer, and more harmful for environment due to large perished quantities. In general, consumer refuses a fixed price for a product with decreasing quality, so dynamic pricing satisfies both the interest of retailer, customer, environment, and society.

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