Model of refrigerated display-space allocation for multi agro-perishable products considering markdown policy

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Abstract. Problems that need more attention in the agri-food supply chain are loss and waste as consequences from improper quality control and excessive inventories. The use of cold storage is still being one of favourite technologies in controlling product quality by majority of retailers. We considerate the temperature of cold storage in determining the inventory and pricing strategies based on identified product quality. This study aims to minimize the agri-food waste, utility of cold storage facilities and maximize retailer's profit through determining the refrigerated display-space allocation and markdown policy based on identified food shelf life. The proposed model evaluated with several different scenarios to find out the right strategy.

1. Introduction

In recent years, most of modern retailers not only selling processed food products, but also the fresh ones, like fruits and vegetables. Fruits and vegetables fall into agricultural product, and have perishable character. It means that their qualities are decreasing over time as a result of their natural metabolism. If the product is still not being sold at the end of its self life, either fruits or vegetables should be discarded because they cannot be consumed and caused food borne disease. Therefore they require an appropriate inventory management [1] and cold storage to control their quality [2][3]. The loss due to expired products is quite high, reaching 15% [4]. According to Herbon et al. [5], the right pricing strategy can increase sales number and reduce waste number of product. One of pricing strategy that suitable for agricultural product is markdown policy.

Product characteristics affect complexity level of food supply chain management [6]. The increasing of public awareness according to food health, safety, and quality, as well as the diversity of demand and prices, and limited lifetime of the product add the complexity of fresh food supply chain management [7]. As discussed before, there is a need of an appropriate inventory management to handle excessive inventory, especially in fresh food supply chain problem. There were much research on inventory management for perishable products [8][9][10]. One of them developed an EOQ model for food product by considering stochastic demand using a probability approach [11]. But those researches were not considering capacity of the cold storage facility yet. In this study, a model is proposed that can be used as a basis for managerial decision in operational activities (determining ordering number, display-space allocation, discount value, and discount time). The aim is to minimizing the number of waste and maximizing retailer's profit.

2. Literature review

Perishable products can be divided into three terms based on obsolescence reason according to Jia and Hu [12]. First, because of losing value such as air tickets, cinema tickets, hotel rooms, and newspapers; second, due to technological developments such as electronic goods: cell phones, laptops, television and so forth; third because of physical changes as a result of deterioration product quality caused by natural processes (metabolic) and the environment influence (temperature, humidity, and moisture content) such as fruits, vegetables, meat, fish and other food products. Out of them, the third one become a concern for some scientists in the last decade [13][14][15][16]

Some scientist have developed inventory model for perishable products [8][9][11][17]. However, on those studies did not consider capacity of storage facility and quality deterioration for perishable food products yet. Capacity of storage facility was take into consideration in inventory model by Bai and Kendall [18], and Piramuthu and Zhou [19]. Bai and Kendall [18] solved space-allocation and inventory management problem for various fresh food products by considering its freshness through non-linier optimization. There were several lack of model which built by Bai and Kendall [18]. First, they assumed that fresh product display on non-refrigerated facility (room temperature). In facts, some fresh products need cold storage to maintain quality. It means, their models would be appropriate for products that didn't need cold storage. Second, the value of decay rate was already known without numerical calculation. As a result, that assumption made the model was less able to capture the quality declining process in more specific way. Third, the discount value did not considering the identified quality of product yet. It would made the price that already set was too cheap for retailer or too expensive for customer according to the identified quality. Therefore, it needs a solution to accommodate both of them, which the discounts is adjusted to the remaining quality of products through a more specific approach.

The given discount value can influence inventory level. This is related to the change of sales level as the effect of differentiation price. Herbon et al. [5] mentioned that the different pricing strategy could increase sales number of perishable products. That is why, it is really important to include discount value as consideration in inventory decision. Markdown based on quality had been discussed previously [20]. In the study they conducted a pricing strategy approach based on identification of product lifetime. The aims of study were reducing the amount of wasted food products and maximizing retailer's profit. Product lifetime was identified by evaluating deterioration rate of product based on standard temperature and length of storage time before eventually sold or wasted. Zanoni and Zavanella [21] developed the study of Rong et al. [22] which's using coefficient of performance ratio as a consideration in determined storage cost. The study also explained that the precise standard temperature determination could reduce energy costs. Based on that study, storage cost for products which's using a refrigerated facility can be determined based on reference and ideal storage temperature.

From those explanations, it is really important to determine the right storage temperature for refrigerated display facility that still using by retailer to storage (display) fresh product. In other hand, set temperature can influence product lifetime and decay rate which have impact on the right pricing strategy during the selling periods. Storage temperature, product quality and pricing strategy can be used as consideration in determine the order number and space allocation for each product in accordance with the refrigerated display capacity. Therefore, based on the studies of Wang and Li [20] Zanoni and Zavanella [21], and Bai and Kendall [18] we develop refrigerated display-space allocation model by considering markdown policy for multi agro-perishable products multi temperature with aim to maximize the retailer's profit.

3. Problem definition and notation

This study develops refrigerated display-space allocation and inventory management model considering markdown policy according to quality deterioration over times until its end lifetime. The system studied consist a retailer that procure and selling the fresh perishable food product like fruit and vegetable (item $= 1,2,3,..k$) which have different attribute: size, shape, and ideal storage temperature. The model development on this study conducted based on several model that already built by Wang and Li [20], Zanoni and Zavanella [21], and Bai and Kendall [18]. On proposed model, there are two markdown

policies based on the frequency ($n = 1,2$). First, single price markdown ($n = 1$) and, second, double price markdown ($n = 2$). The formulation of purposing model for each item's profit (F_i) per hour at selling period T_i can be seen on this equation:

$$F_i = T_i^{-1}[p_i ED_{0i} + \sum_{n=1}^{l} p_{ni} ED_{ni} - (Q_i - ED_{0i})C_p - \dots - (Q_i - \sum_{n=1}^{l} ED_{n-1i})C_p - Q_i\left(UC_i + C_o + \frac{1}{2}HC\rho_{T_R}T_i\right) - A_i AC_i S_i - OC_i] \quad (1)$$

with p_i is normal selling price at the beginning of selling period, ED_0 expected demand with normal selling price, p_{ni} is discount price, ED_{ni} expected demand with discount price, Q_i ordering number, A_i displaying number (allocation number), S_i Space that needed by a unit product, and some costs that involve such as ordering cost (OC_i), unit cost (UC_i), operational cost (C_o), holding cost based on ratio of COP ($HC\rho_{T_R}$), and additional cost for used a unit space (AC_i).

Then, the objective function of this proposed model becomes:

$$\text{Max} \sum_{i=1}^{l} F_i \quad (2)$$

Subject to

$$\sum_{i=1}^{k} A_i S_i \leq W \quad (3)$$
$$L_i \leq A_i \leq U_i \quad (4)$$
$$\sum_{n=0}^{l} ED_{ni} \leq Q_i \quad (5)$$
$$Q_i \geq 0 \qquad\qquad i = 1,2,3, \dots, k \quad (6)$$

Constraint (3) ensures the used space is not more than display-space capacity (W). Constraint (4) ensures that displayed product numbers are not less than the lower limit and exceed the upper limit. Constraints (5) and (6) ensure that the total expected demand does not exceed procured number, in other words all customer requests can be fulfilled and procured number is more than or equal to 0.

In this study, some of the procured product will automatically fill display facility, and rest of them will be storage as back inventory in the facility which's has been set at same storage temperature. It assumed that display facility will always in full state, in other words, as soon as the number of displayed product is decrease it will be filled by back inventory product as much as the decreasing number. Demand of this system is continue-deterministic and influenced by price and identified quality of product over times. Therefore, it needs a right markdown strategy that appropriate to identified quality of product which afterwards this decision is used as consideration in procuring product (number of order). In other words, hopefully the order number can fulfil costumer's demand in certain price and quality until the end of product lifetime. Markdown frequency which maximizes retailer's profit becomes one of variables that must be found.

There are several steps on numerical calculation to get the maximum profit, as follows:

1. Determine the reference storage temperature T_R.
2. Calculate the COP ratio value between reference storage temperature and ideal storage temperature for each product.

$$T_{Ei} = \frac{T_{Ei_L} + T_{Ei_H}}{2} \quad (7)$$
$$COP cooling = \frac{T_{cold}}{T_{hot} - T_{cold}} \quad (8)$$
$$\rho_{T_R} = \frac{COP_{T_{Ei}}}{COP_{T_R}} \quad (9)$$

with T_{Ei} ideal storage temperature of product i, T_{Ei_L} minimum temperature recommendation for product i, T_{Ei_H} maximum temperature recommendation for product i, T_R storage temperature on *retail* (K), T_{cold} temperature that used for cold storage, T_{hot} is 293.15 K (environment temperature).

3. Calculate the quality deterioration rate (σ), quality level ($q_{(t)}$) and the remaining life of product due to storage temperature differences.

$$\sigma = k_A e^{-\left[\frac{E_A}{RT_R(t_h)}\right]} \quad (10)$$
$$q(t) = q_0 - \sum_{h=1}^{m} \sigma_h t_h \quad (11)$$

With k_A is quality deterioration constants, E_A activation reaction energy which control quality *loss* [J/unit], R gas constants [J/unit ^{o}K], q_0 initial quality of product (it assumed 1), and t_h storage duration $(0, T)$ [hour].

4. Determine the discount value for each product based on markdown startin time and quality deterioration rate.
5. Find the number that must be ordered and displayed, as well as retailer's profit based on used set parameters.

4. A numerical simulation and discussion

In this section, the proposed model approach is applied in an illustrative case study. In order to capture model performance numerical simulation is performed with generated data which resembles the real conditions on the retailer. Parameters in proposed model are simulated with various values to investigate their impacts on model performance. By using the proposed model from equation (1) until equation (11) we get the result that represent in table 1. It shows that uniform discount in single price markdown ($n = 1$) with storage temperature 275,15 K gives the biggest profit 7,30495 £/hour. Meanwhile, quality discounts in double price markdown ($n = 2$) with storage temperature 281,15 K gives the smallest profit 0,37876 £/hour. The use of higher set temperature (T_R) than its ideal temperature for some product increasing its deterioration rate and fastening the decaying process. This condition will influence visual performance of product which can decreasing consumer's interest. It also affects consumer's willingness to pay. That is why, the use of higher temperature will decreasing total profit per hour.

Table 1. Profit's profile for each discount type.

Discount Type	Discount Frequency	Tm1	Tm2	TR	Total profit (£/hour)
Uniform	n=1	50%	-	275,15	7,30495
		50%	-	278,15	6,92976
		50%	-	281,15	1,91413
	n=2	50%	75%	275,15	6,17360
		50%	75%	278,15	5,94875
		50%	75%	281,15	2,27950
Quality Based	n=1	50%	-	275,15	6,04061
		50%	-	278,15	5,84738
		50%	-	281,15	1,95256
	n=2	50%	75%	275,15	2,95605
		50%	75%	278,15	2,82077
		50%	75%	281,15	0,37876

Table 2. Order quantity (Q_i*) for each product dependent on markdown policy.

item	S(n=1)	K(n=1)	S(n=2)	K(n=2)
1	61	78	83	102
2	45	58	62	76
3	27	27	36	42
4	49	59	66	80
5	25	27	33	39
6	54	83	74	94
7	90	122	123	152
8	73	98	99	123
9	92	122	125	155
10	64	92	87	110

S : uniform discount
K : quality based discount

The order quantities are different from one discount strategy to others. On single price markdown, the discount types give different order quantities. This is related to given discount value where uniform discount give same value which is 40% of the initial sales price, while quality based discount give different value for each product depend on remaining product lifetime, initial product quality and quality deterioration rate. The gap of given discount moves the number of expected demand and impacted on order quantity. It also applies to double price markdown. Because of order quantity more than the upper limit of displayed product, it makes displayed product number is same with the upper limit for each product, 13 unit per item. This is reported in table 2.

Quality based discount gives smaller value than uniform discount, either single or double price markdown policy. Profit per hour for each unit product is decreasing by the increasing of markdown

frequency. Even so, for item 3 profit per hour is negative on double price markdown with quality based discount strategy (figure 1). It means that for some product, double price markdown could not be appropriate because it makes the consumer lose their confidence in the product quality itself.
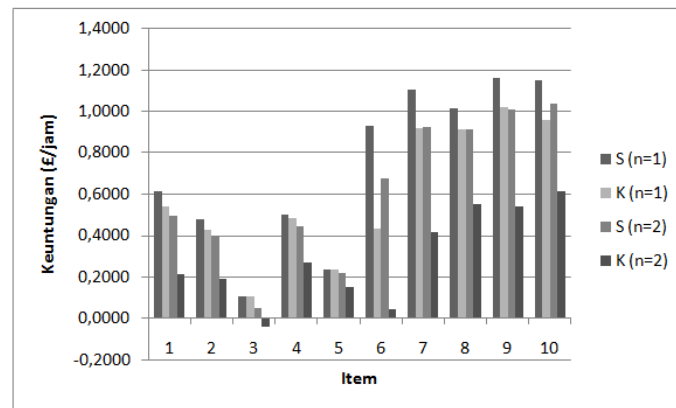

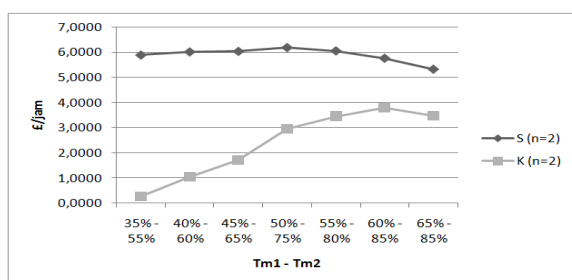**Figure 1**. Profit for each product depend on markdown policy.

Figure 2 Single price markdown's total profit ($T_R = 275{,}15\ K$).
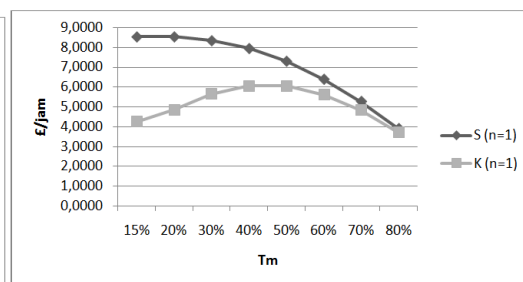
Figure 3. Double price markdown's total profit ($T_R = 275{,}15\ K$).

Profit fluctuation pattern for single and double price markdown can be seen on figure 2 and figure 3. Figure 3 shows markdown starting time which gives biggest profit per hour is 20% from remaining product lifetime with uniform discount strategy. After 20% point, total profit per hour is decreasing continuously with the increasing of T_m value. Figure 4 shows uniform discount strategy's profit reach the highest point at $T_{m1} = 50\%$ and $T_{m2} = 75\%$, then decreasing after the markdown starting time move to $T_{m1} = 55\%$ dan $T_{m2} = 60\%$. Meanwhile, on quality-based discount strategy, retailer's profit increasing continuously until $T_{m1} = 60\%$ dan $T_{m2} = 85\%$ point, then decreasing after it moves to $T_{m1} = 65\%$ dan $T_{m2} = 85\%$.

5. Conclusion and future research

This paper attempts to develop allocation space and inventory model by considering deterioration quality of various fresh food products multi temperature to improve the performance of perishable food supply chain. This approach aims to avoid waste at the end life of perishable product. Based on result of proposed model, decision maker can make the right decision to solve operational problem (procurement number, displayed number, markdown policy, and markdown time). As the consequences, we can minimize number of waste and maximize profit. From the numerical simulation known that low storage temperature gives greater profit than the high ones; and single price markdown with markdown starting time delayed until certain point gives optimal display-space allocation and order quantity, it also give maximum profit.

The limitation of the research is, for simplification, that a linier deterministic demand is assumed, and the upper and lower displayed number is assumed. It will be useful to investigate further research problems using stochastic, and each product have different priority displaying level.

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