

A Vendor-Buyer Inventory Model for Food Products Based On Shelf-Life Pricing

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ABSTRACT

Research on coordinated inventory policy for perishable items between a manufacturer and a retailer has been extensively done. The majority studies however assumed that the stored item starts to deteriorate instantaneously once its production process completed. This may be suitable for representing the characteristic of certain perishable items such as alcohol or radioactive materials. In many cases, particularly for food products such as fruits, vegetables, meat and bakeries, over the shelf-life the quantity remains constant while the value does degrade once the product is approaching its expiration date. Despite this phenomenon, less research addresses this issue, particularly in a multi-echelon supply chain system. Therefore, this research deals with inventory policy for a manufacturer-retailer system considering value degradation for food products. A mathematical model representing the system is proposed. A shelf-life based pricing function is applied to represent the value degradation of the product. The objective function is to maximise the joint profit per unit time which is achieved by optimising the length of manufacturer's production cycle (T) and the ordering frequency of finished goods (n) over the production cycle. The numerical test for the established model demonstrates that the model outperforms the existing model in terms of its potential capability of returning a significant profit improvement.

Keywords: *deteriorating items, inventory model, value degradation, shelf-life based function*

1. INTRODUCTION

Recently, the growth of research in the supply chain management area has created a new way in managing inventories of a multi-echelon system (Ben-Daya *et al.*, 2008). A conventional inventory management approach where a company only focuses on its own inventory, disregarding their partner's situation, may lead to sub-optimal improvement. Due to fiercer competition in the market nowadays, each company is advised to work collaboratively with their partners in managing the inventory

across the supply chain (Msimangira and Venkatraman, 2014) to achieve the optimal performance of the whole system.

A collaborative approach in managing the production and inventory between two parties i.e. manufacturer and retailer, can be achieved by determining the economic production and ordering lot sizes jointly between these two parties. This concept was initially introduced by Goyal (1977). In this scenario, the production and order quantities are decided by considering the joint variable cost between the manufacturer and the retailer. The model assumed an infinite production rate and a lot-for-lot shipment policy. Later, Hill (1997) relaxed this assumption to a general shipment policy and a finite production rate. Many other studies in this field (Avijit and Seung-Lae, 1995; Ha and Kim, 1997; Kim and Ha, 2003) eradicated the limitation of the requirement to have the production lot being completed before delivering the ordering batches to the retailer. More recently, other factors such as investment to reduce some related costs, stochastic demand and three layer systems are investigated by many scholars in this area (Ben-Daya *et al.*, 2008). All of the studies mentioned above, however, assume that the items can be stored infinitely.

In real life, it is often found that numerous items such as alcohol, food and radioactive materials perish over time. Ghare and Schrader (1963) firstly introduced a mathematical model representing the inventory profile for perishable items (Eq. 1),

$$\frac{dI(t)}{dt} + \theta I(t) = -D(t) \quad (1)$$

where $I(t)$ refers to the inventory level over t , $D(t)$ represents the demand rate at time t , and θ is the deterioration rate of the item. The equation explicitly demonstrates that an inventory for perishable items is depleted by demand rate and a fixed fraction of the inventory or $\theta I(t)$ which diminishes over time.

Since the model was introduced, it has been continuously developed to be more representative of capturing real life cases. Substantial literature reviews by Raafat (1991), Goyal and Giri (2001), Bakker *et al.* (2012) reveal that the majority research in deteriorating inventory areas are referred to this model, where extensive extensions have been conducted to accommodate various conditions such as, different characteristics of demand e.g. time varying demand (Goyal and Giri, 2003), stock dependent demand (Pattnaik, 2012) and price dependent demand (Maihami and Nakhai Kamalabadi, 2012) and different types of systems e.g. single echelon and multi-echelon systems.

The existing models might resemble inventory characteristics of some perishable items such as alcohol, gasoline and radio-active materials. They are however hardly applied to food (Nahmias, 2011) such as fruits, meat, milk and bakeries as for over the shelf-life, its quantity diminished only due to demand, while its quality or value is deteriorated over time. A study by Blackburn and Scudder (2009) introduced a product's marginal value of time (MVT) of a fresh product such as melon. They observed that as the sugar levels of a melon loses over time through a supply chain, controlling some variables such as picking rate and transfer batch size can be an appropriate strategy to minimize the value loss and maintain the product freshness across the supply chain. Unfortunately, this approach is not suited for managing food products which degrade in a different way, such as bakeries or noodles.

Generally customers examine the product freshness in two ways, by evaluating the physical condition of the products e.g. colour and firmness such as in fruits or simply checking the product shelf-life while they are unable to directly assess the product quality such as in bakeries, noodles, milk or other fully package products (Entrup, 2005). Regarding the former, Blackburn and Scudder (2009) strategy can be applied, for a fully packed product however a different approach is needed.

Research by Tsiros and Heilman (2005) reported that the customers perceive the quality of a fully packed food product by seeing its expiration date. The research also reveals that customer's willingness to pay (WTP) for this typical product decreases once the product's life is approaching its expiration date. Customers tend to purchase products with a longer remaining lifetime and avoid the one which is aging. Consequently, the demand rate of the products during the aging period will be slower. To manage this situation, retailers will initiate a price reduction or discount of the products to maintain the demand and prevent them being outdated. Though the mark down strategy may retain or even improve the demand rate, the margin of the products is accordingly reduced.

The issue discussed above makes the strategy to manage perishable items in retailers becomes more complicated. A coordinated inventory approach in managing food products between a manufacturer and a retailer needs to consider this situation before deciding the production and ordering lot policy. Yan *et al.* (2011) extended an integrated production-inventory model of Kim and Ha (2003) by considering deteriorating items. This model, however, still viewed the deterioration as a function of inventory i.e. a fraction number of inventory is instantaneously and continually lost over time. Therefore, this research proposes

a new approach in managing food inventory by accommodating the degradation value of the product perceived by customers based on its remaining lifetime. The aim is to determine the manufacturer's production cycle and the number of deliveries to the retailer over the production cycle to maximize the total profit of the manufacturer-retailer system.

The remaining sections of this paper are organised as follows: Section 2 presents model assumptions and notation while Section 3 discusses the modelling formulation stages. Numerical tests explaining the behaviour of the proposed model are provided in Section 4, and the last section summarises this paper.

2. ASSUMPTIONS AND NOTATIONS

The model is developed based on these following assumptions and notation:

Assumptions

- The manufacturers' production rate and the retailer's demand rate are constant.
- The production rate is greater than the demand rate
- The retailer pays transportation and order handling costs
- Lead time is neglected and no shortage is allowed
- Customer's willingness to buy a product decreases linearly once the product reaches time to deteriorate (T_{start})
- Price before T_{start} is maximum and price for outdated product is zero

Notations

For the manufacturer

- P : production rate
 C_m : manufacturing cost per unit
 S : setup cost for a production cycle
 h_m : inventory holding cost
 p_m : price of finished goods
 $TP_m(n, T)$: manufacturer's profit

For the retailer

- D : demand rate
 p_{max} : maximum price
 T_{SL} : product shelf-life
 T_{start} : time when customer's WTP starts decreasing
 E_i : age of batch i when entering the retailer system
 O_r : ordering cost
 h_r : inventory holding cost
 F : fixed transportation cost per delivery
 V : unit variable cost for order handling
 $R(n, T)$: retailer's revenue

- $TP_r(n,T)$: retailer's profit
- $TP(n,T)$: total profit of the integrated system (the objective function of the integrated inventory model)

Decision Variables

- n : number of deliveries per production cycle
- T : production cycle

3. MODEL DEVELOPMENT

This section presents the procedure for formulating a new inventory model considering food shelf-life and customers' WTP.

3.1 Revenue Model Accommodating Shelf-life Based Pricing Function

It is a common phenomenon in a retailer that customers prefer to buy a product with a longer remaining lifetime i.e. the customers' WTPs decrease once the product approaches its expiration date (Tsiros and Heilman, 2005). Consequently, to maintain the demand and avoid outdated items, the retailer offers a discount to those outdated products. It is also mentioned that the customers' WTPs over time can decrease linearly such as in pre-cut lettuce, pre-cut carrots, milk and yoghurt or exponentially such as in beef and chicken. In this research, a linear WTP decrease is assumed before establishing the model (Figure 1).

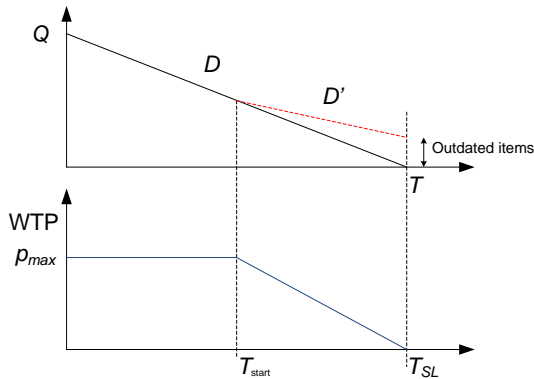


Figure 1. Customer's WTP starts decreasing at time = T_{start}

From Figure 1, customers' WTPs start decreasing at T_{start} . Without any action, the demand of the product would change from D to D' (where $D' < D$) leading to outdated stocks at the end of the cycle. To avoid the system producing outdated items, the retailer will apply a markdown strategy to stabilize the demand. Over T_{start} - T_{SL} period, the price is reduced linearly. In other words, the price of each product depends on its age when entering the retailer. Therefore, for each batch, every product has three possible pricing conditions as defined by Equation 2,

$$p(t) = \begin{cases} P_{max} & 0 \leq t < T_{start} \\ \frac{P_{max}}{T_{SL} - T_{start}}(T_{SL} - t) & T_{start} \leq t < T_{SL} \\ 0 & t \geq T_{SL} \end{cases} \quad (2)$$

where $p(t)$ represents the shelf-life based pricing function, p_{max} denotes to the maximum price while T_{sl} and T_{start} symbolize the shelf-life and the decreasing time respectively. After defining the price function, then the revenue of each batch can be generated as demonstrated by Figure 2.

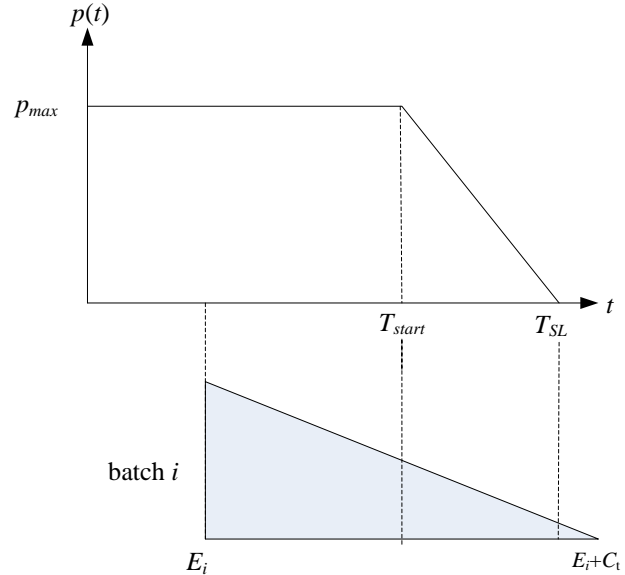


Figure 2. Shelf-life based pricing of batch i

Referring to Figure 2, E_i represents the age of batch i received by retailer and C_i is the ordering cycle. Noting that every batch has different age when entering the retailer then the structure of retailer's revenue for each batch per unit time can be defined as the followings:

1. Case 1: if $(E_i + C_i) < T_{start}$ then the revenue can be obtained by selling all product in batch i at maximum price as defined by Equation 3

$$R(n,T) = \frac{DC_i p_{max}}{T} \quad (3)$$

2. Case 2: if $T_{start} \leq (E_i + C_i) < T_{SL}$ then the revenue of batch i is denoted by Equation 4

$$R(n,t) = \frac{1}{T} \left[Dp_{max}(T_{start} - E_i) + D \int_{T_{start}}^{E_i + C_i} p(t) dt \right] \quad (4)$$

3. Case 3: if $(E_i + C_i) \geq T_{SL}$ then Equation 5 represents the revenue function of this condition

$$R(n,T) = \frac{1}{T} \left[Dp_{max}(T_{start} - E_i) + D \int_{T_{start}}^{T_{SL}} p(t) dt + D \int_{T_{SL}}^{E_i + C_i} p(t) dt \right] \quad (5)$$

Since it is assumed that the price of expired products is zero then the revenue function in Equation 5 can be represented by Equation 6.

$$R(n,T) = \frac{1}{T} \left[Dp_{max}(T_{start} - E_i) + D \int_{T_{start}}^{T_{SL}} p(t) dt \right] \quad (6)$$

From Equation 4-6, it can be seen that revenue is influenced by C_i and E_i . The length of ordering cycle (C_i) depends on n and T where $C_i = T/n$. The age of batch i (E_i) is

calculated by examining the storage time of batch i at the manufacturer (St_i) as illustrated by **Figure 3**.

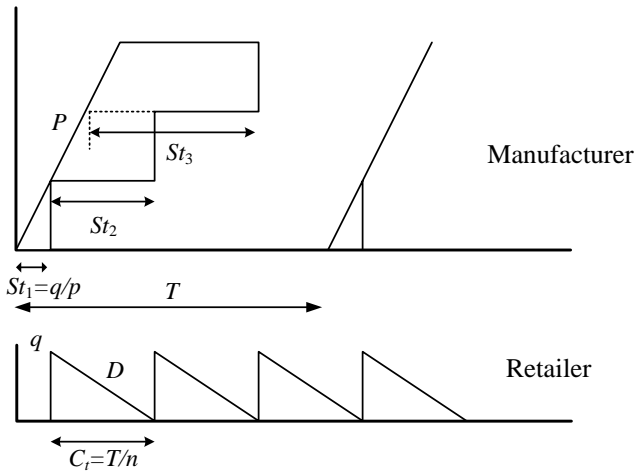


Figure 3. Inventory in a manufacturer-retailer system

Assuming that the transportation lead time is insignificant or can be considered as zero then E_i is equal to St_i . As illustrated by Figure 3, St_i starts from time when batch i is produced until time when it is received by the retailer. For instance, the storage time of batch one or St_1 is equal to q/p while the storage time of the next batch is represented by $q/p+q/d$. Since $q=DT/n$, generalizing the formula of calculating St_i or E_i leads to Equation 7.

$$E_i = (i-1)\frac{T}{n} - (i-2)\frac{DT}{nP} \quad (7)$$

3.2 An integrated production-inventory model considering shelf-life based pricing function

This research is an extension to the integrated production-inventory model by Kim and Ha (2003). A manufacturer and a retailer collaborate to decide the best production and inventory policies considering the shelf-life of the food products. The main aim is to find the maximum joint profit $TP(n, T)$ of the manufacturer and the retailer by specifying the best set value of manufacturer's production length (T) and the number of deliveries to the retailer (n) over the production length.

In the manufacturer's system the total profit, $TP_m(n, T)$, is obtained by subtracting the total cost from the revenue where the costs involved in the manufacturer's system are manufacturing, set up and carrying costs as represented by Equation 8. Similarly, the retailer's profit, $TP_r(n, T)$, is attained by deducting the costs i.e. procurement, ordering, carrying and transportation costs from retailer's revenue in which the shelf life based pricing function is considered as described by Equation 9. Further, the total profit of the system $TP(n, T)$ is achieved by combining Equation 8 and Equation 9 as symbolized by Equation 10.

$$TP_m(n, T) = DP_m - C_m D + \frac{S}{T} + \frac{DT}{2n} \left[\frac{D}{P}(2-n) + (n-1) \right] h_m \quad (8)$$

$$TP_r(n, T) = R(n, T) - D(V + p_m) + \frac{O_r}{T} + \frac{DT}{2n} h_r + \frac{n}{T} F \quad (9)$$

$$TP(n, T) = TP_m + TP_r \quad (10)$$

As expected, the two decision variables namely n and T should be simultaneously determined to maximize the total profit in Equation 10. In this study, the optimization tool in Matlab R2014a is used to find the optimal values of both n and T .

4. NUMERICAL EXAMPLE

A numerical test is conducted in this research to examine the behaviour of the proposed model. The parameter used in the numerical test is adopted from Kim and Ha (2003) with a slight modification to suit the proposed model as shown by **Table 1**.

Table 1. Parameters in the proposed model

Notation	Value	
P_m	30	\$/unit
P	19,200	unit/year
C_m	5	\$/unit
S	600	\$/order
h_m	6	\$/unit/year
D	4,800	unit/year
P_{max}	50	\$/unit
T_{SL}	0.208	year
T_{start}	0.167	year
O_r	25	\$/order
h_r	7	\$/unit/year
F	50	\$/delivery
V	1	\$/unit

The proposed model is used to solve the problem and the profit is compared to that of obtained from the established model in Kim and Ha (2003). The decision variables (n and T) and the profile of total cost, revenue and total profit for each party and each approach are then presented in **Table 2**.

As depicted in **Table 2**, the proposed model yields a better total profit of \$204,397.1per year with 3 times deliveries ($n=3$) over 0.1825 year where the delivery size (q) is 292 units. Contrarily, the model of Kim and Ha (2003) in which the product deteriorating value is unconsidered, results in \$171,642.9 of total profit per year with a longer T and a higher q (0.2406 year and 385 units respectively). Hence, the total profit of the proposed model is \$32,754.2 higher (19% increase) than that of Kim and Ha (2003). This indicates that the proposed model potentially yields a better performance in terms of the total gained profit.

Table 2. Total cost, revenue and profit of the proposed model and the previous model

Kim and Ha (2003)	$n=3; T=0.2406 \text{ year}; q=376$		
	Manufacturer	Retailer	Total
Total Cost	28,514.8	150,874.7	179,389.5
Revenue	144,000.0	207,032.4	351,032.4
Total Profit	115,485.2	56,157.7	171,642.9
Outdated items	≈58 units per production cycle		
The proposed model	$n=3; T=0.1825 \text{ year}; q≈292$		
	Manufacturer	Retailer	Total
Total Cost	28,820.7	150,780.9	179,601.6
Revenue	144,000.0	239,998.6	383,998.6
Total Profit	115,179.3	89,217.7	204,397.1
Outdated items	0 unit per production cycle		

It is important to note from **Table 2** that the proposed model, with smaller delivery size and shorter production cycle, results in zero outdated items while its counterpart has 58 expired units. It is also found that T significantly affects the total gained profit which means that a small change of T leads to a significant profit reduction as clearly shown in **Figure 3**.

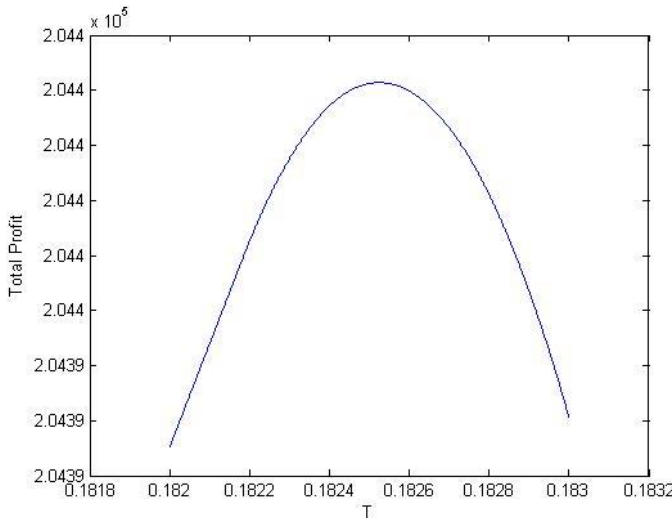


Figure 2. Correlation between T and total profit

4.1 Sensitivity and Error Analysis

As discussed earlier, the proposed model assumes that all parameters are constant over time. In reality, over the planning horizon they might change due to unmanageable factors. As a result, the performance of the model might be affected. To deal with this situation, a sensitivity analysis is applied to examine the robustness of the solution and model while the error analysis is utilised for calculating the potential loss because of changes in parameters (Daellenbach and McNickle, 2005).

In this scenario, the sensitivity analysis is conducted by changing the value of one parameter to -20% and +20% while keeping the rest parameters unchanged. Then, a new total profit is obtained by optimizing the model with the altered parameters. The percentage of change between the new and the current total profit is calculated to examine the model sensitivity to each parameter as presented in **Table 3** column a-c.

In general, result in **Table 3** Column c demonstrates that the optimal solution is relatively insensitive to the changes of majority parameters. It is indicated by fluctuating the parameters by 20% only cause changes in total profit by less than 1%. A slight change of 4.9% is observed in the total profit by the variation in T_{start} . This change, however, is still far from 20%. The demand rate and price are the only parameters that influence the total profit; 20% change in those input parameters proportionally affects the total profit.

In case that the supply chain system has adopted the optimised solution while the actual value of the parameter deviates from its expected value, it is important to investigate the potential loss caused by this decision (also known as error analysis). The error analysis is performed by calculating the difference in percentage between the profit resulted from the optimised decision (**Table 3** column a) and the actual profit when the actual parameter differs from its expected value (**Table 3** column d). It is depicted in column e that variations in majority input parameters insignificantly influence the total profit.

Either overestimating or underestimating the most of inputs by 20% only results in less than 1% variation in total profit. T_{start} is the only parameter which contributes to the benefit loss i.e. underestimating the value of this input by 20% may lead to 4.8% decrease in the total profit. T_{start} is time when customer's WTP starts decreasing and its value depends on the customer's perception on a specific food product. A careful investigation relating to the customer's behaviour is important to ensure a sufficient accuracy for this parameter.

Table 3. The summary of sensitivity and error analyses

Parameter	Parameter changes	New total profit	Current total profit	Total profit changes (a-b)/b*100%	Actual total profit	Total profit changes (a-d)/a*100%
	%	(a)	(b)	(c)	(d)	(e)
D	-20%	162491.8	204,397.1	-20.50%	162593.9	-0.06%
	+20%	246180.0		20.44%	246214.4	-0.01%
P	-20%	204453.2	204,397.1	0.03%	204509.8	-0.03%
	+20%	204233.8		-0.08%	204334.9	-0.05%
S	-20%	205054.6	204,397.1	0.32%	205054.7	0.00%
	+20%	203739.5		-0.32%	203732.8	0.00%
O _r	-20%	204424.5	204,397.1	0.01%	204424.5	0.00%
	+20%	204369.7		-0.01%	204369.7	0.00%
F	-20%	204561.4	204,397.1	0.08%	204569.1	0.00%
	+20%	204232.7		-0.08%	204232.7	0.00%
h _m	-20%	204703.7	204,397.1	0.15%	204704.3	0.00%
	+20%	204090.5		-0.15%	204090.5	0.00%
h _r	-20%	204601.5	204,397.1	0.10%	204520.6	0.04%
	+20%	204192.7		-0.10%	204199.3	0.00%
T _{start}	-20%	194366.4	204,397.1	-4.91%	203855.4	-4.88%
	+20%	204398.4		0.00%	204574.7	-0.09%
p _{max}	-20%	156397.3	204,397.1	-23.48%	156397.5	0.00%
	+20%	252396.8		23.48%	252396.8	0.00%

5. CONCLUSION

A production-inventory model considering a shelf-life based price function which incorporates the value loss because of customers' perception on product quality has been established. The numerical test reveals that the proposed model may lead to a reduction in the number of outdated items and increase in the total profit of the manufacturer-retailer system in comparison to the existing model. The sensitivity analysis indicates that the optimal profit is relatively steady as the majority input parameters fluctuate. From the error analysis it is further shown that this deviation insignificantly affects to the total expected profit. These results demonstrate that the proposed model not only outperforms the benchmark model but also it is robust to any parameter change.

The vendor-buyer inventory model proposed in this research has not incorporated the procurement of raw material. Thus, it is expected that the total profit could be further extended by accommodating the raw material procurement planning. In addition, noting that deterioration characteristics of raw materials may behave differently from finished goods, proposing different approaches to dealing with quality loss in raw materials can be a challenging subject for investigation. Therefore, extending this model to an integrated production-inventory system which covers a raw material procurement strategy and accommodating efforts to preserve the quality or value loss to lengthen the product shelf-life could be potential for further research avenues.

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