Optimal deteriorating inventory models for varies supply life cycle

Gede Agus Widyadana *. Kun Jen Wang.**
Nyoman Sutapa *

**Industrial Engineering Department, Petra Christian University*
Surabaya, Indonesia (gedeaw@gmail.com)
***Industrial Management, National Taiwan University of Science and Technology,*
Taipei, Taiwan

Abstract: Some agriculture products such as fruits and vegetables are not always available during a year. They have a specific harvest period where the characteristic of the supply and demand is unique in some periods. There are some research has been conducted in deteriorating inventory item, however only a few models on different harvest period. In this paper, inventory deteriorating in them models for the beginning and the end of the harvesting period are developed. Since closed-form solutions cannot be derived from the models, Genetic Algorithm and heuristic methods are used to solve the problem. A numerical example and sensitivity analysis are conducted to illustrate the model and get some insights. The sensitivity analysis shows that at the beginning harvest period, the supplier will increase his price when supply is not reliable. The unreliable supply also susceptible to the total cost at the end of the harvest period.

Keywords: Inventory, Deteriorating Items, Unreliable Supply, Price Dependent, Optimization

1. INTRODUCTION

Efficiency in production has full attention since efficiency is one competitive advantage for companies to survive and compete. However, some products that are derived from nature such as fruits and vegetables have specific characteristics. One of their characteristics is decay or spoilage gradually within time. Therefore, fruits and vegetables can be included as deteriorated items. Some deteriorating items such as vegetables or fruits have different life supply. In the first phase, sometimes called as early harvest, not so many items can be ripped therefore only a few stocks available in the market. Therefore the price quite high. In this phase, customers are sensitive with the price. They are considering should they buy now or wait until stock available enough and price reduced or buy at current price. In the second phase, most trees are ready to be harvested, so the stock is enough and demand are stable. In this stable condition the model using a general deteriorating inventory model. In the third phase are called late harvest period, where only a few trees still productive and can be harvested. In this period, the stock is reduced and only a few useful items available in the market. The supplier also has difficulty to collect the items; therefore sometimes they delay their shipment. Usually, the customer wants to buy when the items which available on the shelf are exciting and has enough amount. Therefore in this phase, a stock dependent with the model can be used with unavailability supply can be used.

Stock dependent inventory model was developed first by Gupta and Vrat (1986) then Mandal and Phaudjar (1989) developed an economic production quantity model for deteriorating items by considering stock-dependent consumption rate. Baker and Urban (1988) developed the inventory deteriorating items model with stock dependent demand. Pal et. al (1993) continued the work of Baker and Urban (1988). Hou (2006) developed deteriorating inventory model with stock dependent demand and also consider inflation and time discounting since in some countries that suffered from large-scale inflation and purchasing power declines, the effects of inflation and time value of money should be considered. Lee and Dye, (2012) developed a deteriorating inventory items model with stock dependent demand and considering investment cost for controlling deteriorating rate. The assumed that deteriorating rate could-be controlled using various effort by investing in technology. Giri et al. (1996) extended the excellent work of Urban (1992) by setting the constant deteriorating rate. Li et al. (2017) developed dynamic pricing and periodic order quantity model for deteriorating items and considering stock-dependent demand. In their model, they allowed shortages, and the backlogging rate is variable and dependent on the duration for the next replenishment. Teng and Chang (2005) developed a production economic quantity model for deteriorating items. They assumed great goods displayed in a supermarket could make more sales and profit. The demand does not only depend on some stock but also the selling price. They also assumed that the number of stock on display is limited by the amount of shelf or display space. They also mentioned that a considerable amount of stock on display is not good because too much stock gives a negative impression to customers. Das et al. (2010) developed a production lot size inventory with regular and overtime productions. They assumed that demand is depleted due to deterioration and demand. They also considered supplier give price discounts and delayed payments to increase demand. Teng et al. (2016) developed deteriorating inventory models with time-varying deterioration rate, allowed shortage and some percentage of the shortage items are backlogged. They also considered advance payment since for some seasonal items; the buyer needs to pay the acquisition cost in advance as a deposit. Banerjee and Agrawal (2017) developed deteriorating inventory models for industries which deal with freshness items whose declined with time. Their model included pricing and discount to increase sales and profit. The demand is also considered depend on price and freshness. Musa and Sani (2012) developed an inventory model with delayed deterioration. The items do not deteriorate immediately when they are stocked. They also assumed that supplier gives delay in payment for the buyer to boost sales. Tiwari et al. (2018) developed a deteriorating inventory model by considering pricing. They developed a model for the supplier-retailer-customer supply chain. Supplier and retailer offer partial trade credits to their customers. All players should determine the optimal selling price to optimise their profits. Chakraborty et al. (2015) developed supply chain deteriorating items model by considering stock dependent demand and multi items. They also assumed that the supply chain environments are fuzzy. Balkhi and Bankherouf (2004) developed a deteriorating inventory model by considering stock dependent and time-varying demand. Zhang et al. (2015) developed non-instantaneous deteriorating inventory items where customer demand depends on the number of the items displayed in the store and the sales price. Pando et al. (2018) developed an optimal profit of inventory deteriorating items with stock dependent demand and nonlinear holding cost. The holding cost depends on time and stock level. Tiwari et al. (2018) developed a deteriorating inventory model for a two-echelon supply chain by considering the limitation of the display area. They assumed demand rate is dependent on delayed stock price and displayed stock level. Liuxin et al. (2018) developed deteriorating items where the demand depends on three factors which are stock level, time and price. Duan et al. (2018) developed dynamic pricing for economic production deteriorating inventory items model with price dependent demand and stochastic process demand. Hsieh and Dye (2010) developed an inventory lot size model for deteriorating items by considering price and time demand function. They also considering partial -backlogging and the price is periodically adjusted upward and downward. Yang (2004) developed integrating deteriorating inventory model. The vendor offers quantity discount pricing to the buyer to tempt the buyer to buy more and profit sharing is balanced between two players.

Although there is intensive research on deteriorating inventory model and optimisation, only a few considering the supply life cycle of items such as fruits and vegetables. Many seasoned fruits and vegetables have supply life cycle. At the early phase, only a few fruits can be harvested; therefore the price tends to be high, and customer demand depends on the price offered by the supplier. The other characteristic is the supply is not always available. In the second phase which is harvest phase, the price and supply tend to be stable since there are more fruits available. After harvest phase then many fruits that can be harvested are less than harvest phase. In this phase, a number of the items on a shelf is less than the previous period, and the fruits are not as interesting as harvest period. Therefore customer's demand depends on stocks amount at the store shelf. This paper contributes by developing deteriorating inventory models for different supply life cycles; therefore many retailers can adapt their strategies depending on the items life cycle to optimise their profit. This paper is divided into four sections. In the first section, some relevant literature is introduced, and the contribution of the paper is shown. Some mathematical models are developed in Section 2, and a numerical example and sensitivity analysis are presented in Section 3 to give some management insight into the model. In the last section, some exciting conclusions are shown

2. MODEL DEVELOPMENT

In this study we develop two deteriorating inventory models for describing two situations in preliminary harvest stage and the last period of harvest stage. The situation in preliminary harvest stage can be seen in Figure 1. The replenishment period depend on the product price since demand depend on price. Most price dependent demand model assume replenished item come directly when needed, however in some condition such as preliminary harvest period, stock is not stable. There is possibility that items have not arrived when needed result in shortage in T_d period. The inventory level in the last harvest period in shown in Figure 2. Demand in the last harvest period depend on inventory level at certain period since at this period not many items have good appearance and consumer tend to buy when they see some fresh items such as fruits in vegetables. When the stock is high, demand is high and stock deplete quickly. Supply in the last harvest period is similar as preliminary harvest period when supply is no constant. Therefore there is possibility items have not arrived when needed and result in shortage for T_d period.

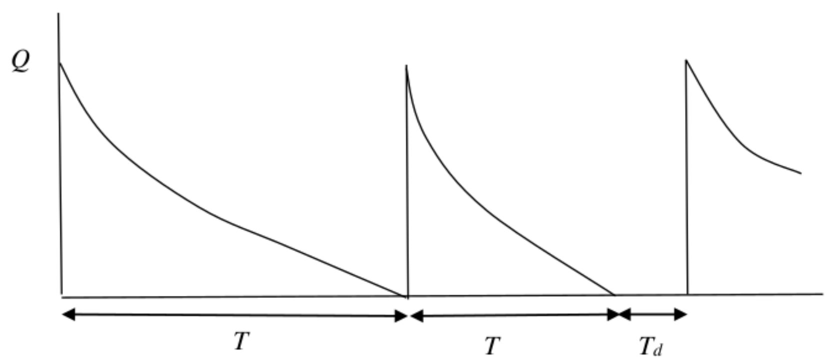

Figure 1. Inventory level for preliminary harvest period

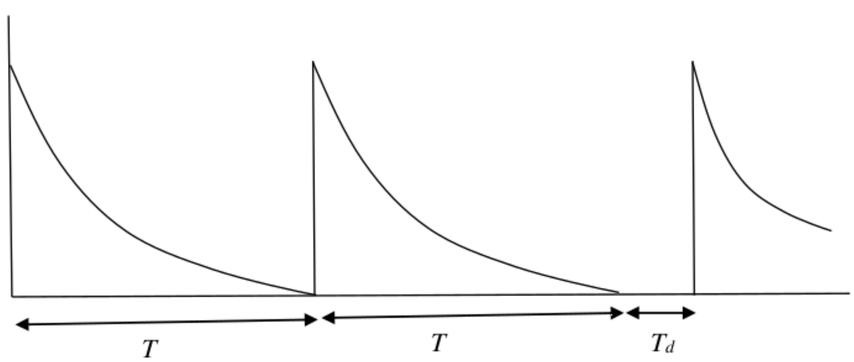

Figure 1. Inventory level in the last harvest period

Notations:

I_t = Inventory level at t period

p = price rate

α = price constant rate

ε = price sensitivity rate

β = stock sensitivity rate

d = demand rate

θ = deteriorating rate

K = setup cost

H = holding cost

S = lost sales cost

TC = total inventory cost

T = total replenishment time

T_d = shortage period

TP = total profit

1.1. Deteriorating inventory model with price dependent

In the price dependent inventory deteriorating model, the inventory level depends on the deteriorating rate and demand, where the demand depends on the price rate. The following equation can denote the inventory level in this model:

$$\frac{dI}{dt} + \theta I_t = -\alpha p^{-\varepsilon}, \qquad 0 \le t \le T \tag{1}$$

Since $I_{(0)}=Q$ when $t=0$, then one has:

$$I_t = \frac{\alpha p^{-\varepsilon}}{\theta}(e^{-\theta(T-t)} - 1) \quad \text{for } 0 \le t \le T \tag{2}$$

Total inventory for $0 \le t \le T$ is

$$\int_0^T I(t)dt = \int_0^T \frac{\alpha p^{-\varepsilon}}{\theta}(e^{-\theta(T-t)} - 1)\,dt$$

$$= -\frac{\alpha(e^{-\theta T} + \theta T - 1)p^{-\varepsilon}}{\theta^2 p^{\varepsilon}} \tag{3}$$

Total profit can be derived from the total revenue minus cost of placing an order, and cost of carrying inventory. The total profit can be modelled as:

$$TP = p(\alpha p^{-\varepsilon}) - \frac{K}{T} - \frac{HI_t}{T}, \tag{4}$$

substitute I_t from (3) to (4) , one has:

$$TP = p(\alpha p^{-\varepsilon}) - \frac{K}{T} - \frac{H\left(-\frac{\alpha(e^{-\theta T} + \theta T - 1)p^{-\varepsilon}}{\theta^2 p^{\varepsilon}}\right)}{T} \tag{5}$$

2.2. The lost sales case

The total profit for lost sales consists of total revenue minus setup cost, holding cost and loss of goodwill. Lost sales occur when supply unavailability period is longer than the replenishment period. The total profit can be expressed as:

$$TP = p(\alpha p^{-\varepsilon}) - \frac{K}{E(T)} - \frac{H\left(-\frac{\alpha(e^{-\theta T} + \theta T - 1)p^{-\varepsilon}}{\theta^2 p^{\varepsilon}}\right)}{E(T)} + S\alpha p^{-\varepsilon}\frac{\int_{t=T}^{\infty}(t-T)f(t)dt}{E(T)} \tag{6}$$

Replenishment time consists of replenishment period and supply unavailability time which is longer than replenishment period. The expected replenishment time can be written as:

$$\begin{aligned} E(T) &= T + E(T_d) \\ &= \left[T + \int_{t=T}^{\infty}(t-T)f(t)dt\right] \end{aligned} \tag{7}$$

The total profit can be derived by substituting (7) into (6) as follows:

$$TP(p,T) = \frac{E\left[p(\alpha p^{-\varepsilon}) - K - H\left(-\frac{\alpha(e^{-\theta T} + \theta T - 1)p^{-\varepsilon}}{\theta^2 p^{\varepsilon}}\right) + S\alpha p^{-\varepsilon}\frac{\int_{t=T}^{\infty}(t-T)f(t)dt}{E(T)}\right]}{T + \int_{t=T}^{\infty}(t-T)f(t)dt} \tag{8}$$

2.3. Uniform distribution case

In this case, we assume that the unavailability time t is a random variable that is uniformly distributed over the interval [0, b]. The uniform probability density function, $f(t)$, is given as:

$$f(t) = \begin{cases} 1/b, & 0 \le t \le b \\ 0, & otherwise \end{cases}$$

For uniform distribution, the value of T can be expressed as:

$$E(T) = T + \frac{(b-T)^2}{2b} \tag{9}$$

Substitute uniform probability density function in (8), one has:

$$TCT(p,T) = \frac{\left[Kp(\alpha p^{-\varepsilon}) - K - H\left(-\frac{\alpha(e^{-\theta T} + \theta T - 1)p^{-\varepsilon}}{\theta^2 p^{\varepsilon}}\right) + S\alpha p^{-\varepsilon}\left(\frac{b-T}{b}\right)\right]}{T + \frac{(b-T)}{2T}} \tag{10}$$

Since the closed form solution cannot be found and there are two decision variables. The model is solved using a genetic algorithm and run in Matlab. A simple Genetic Algorithm is used to solve the model and run in Matlab.

Chromosome

Chromosome represents the optimal price (p) and the optimal ordering time (T). The population type is bit string with 14 cells where seven cells are for the optimal price, and seven cells are for the optimal ordering time.

Initial solution and population

The initial solutions are generated randomly, and the population size is equal to 200.

Selection and reproduction

For each generation, the parent chromosomes are chosen using roulette wheel where chromosomes with the highest profit have a high probability to be chosen as parents. The reproduction using crossover and mutation. The crossover scheme is two points crossover, and the mutation scheme is uniform with probability 1%. Elitism scheme is using to guarantee the best chromosome for every generation will be a child in the next generation.

Stopping criteria

The genetic algorithm is stopped after 100 generations

2.4. Deteriorating inventory model with stock dependent demand

In the last harvest period, demand depends on the level of stock which is shown to the customers. The following equation can denote the inventory level for stock dependent demand deteriorating inventory:

$$\frac{dI}{dt} + \theta I_t = -d(I(t)), \qquad 0 \le t \le T \tag{11}$$

One has:

$$I(t) = \frac{1}{\theta+\beta}(e^{(\theta+\beta)(T-t)} - 1) \qquad 0 \le t \le T$$

Total inventory for $0 \le t \le T$ is

$$\int_0^T I(t)dt = \int_0^T \frac{1}{\theta+\beta}(e^{-(\theta+\beta)(T-t)} - 1)\, dt$$

$$= \frac{(e^{-(\theta+\beta)T} - \theta T - T\beta - 1)}{(\theta+\beta)^2} \tag{12}$$

2.5. The lost sales case

Since supply is not always available, therefore there is lost sales possibility when supply available after replenishment period. So the total inventory cost for lost sales consists of setup cost, holding cost and loss of goodwill. The total inventory cost can be modelled as:

$$TC(T) = E\left[K + h\left(\int_0^T \frac{1}{\theta+\beta}\left(e^{-(\theta+\beta)(T-t)} - 1\right)\right) + S\frac{\int_{t=T}^{\infty} e^{-\beta t} f(t)dt}{\beta} \right] \tag{13}$$

We can use the same replenishment period as (7), so the total cost per unit time can be derived as follows:

$$TCT(T) = \frac{E\left[K + h\left(\int_0^T \frac{1}{\theta+\beta}\left(e^{-(\theta+\beta)(T-t)} - 1\right)\right) + S\frac{\int_{t=T}^{\infty} e^{-\beta t} f(t)dt}{\beta} \right]}{E\left[T + \int_{t=T}^{\infty}(t-T)f(t)dt\right]} \tag{14}$$

2.6. Uniform distribution case

Substitute uniform probability density function in (13), one has:

$$TCT(T) = \frac{K + h\left(\frac{(e^{-(\theta+\beta)T} - \theta T - T\beta - 1)}{(\theta+\beta)^2}\right) + Sd\left(\frac{(b-T)^2}{2b}\right)}{E(T)} \tag{15}$$

Substitute (9) into (15), one has:

$$TCT(T) = \frac{K + h\left(\frac{(e^{-(\theta+\beta)T} - \theta T - T\beta - 1)}{(\theta+\beta)^2}\right) + Sd\left(\frac{(b-T_2)^2}{2b}\right)}{T + \frac{(b-T)^2}{2b}} \tag{16}$$

The optimal T can be found by derivate (16) concerning T and set the result to zero

$$\frac{dTCT(T)}{dT} = \frac{\left(K + h\left(\frac{(e^{-(\theta+\beta)T} - \theta T - T\beta - 1)}{(\theta+\beta)^2}\right) + \frac{S\left(\beta^2 b^2 - 2T\beta^2 b + 2e^{-\beta b}(1+\beta b - T\beta) + \beta^2 T^2 - 2e^{-T\beta}\right)}{2\beta^3 b}\right)\left(1 - \frac{b-T}{b}\right)}{T + \frac{(b-T)^2}{2b}} - \frac{\left(h\left(\frac{(\theta+\beta-(\theta+\beta)e^{T(\theta+\beta)})}{(\theta+\beta)^2}\right) - \frac{S\left(-2\beta^2 b + 2T\beta^2 - 2e^{-\beta b}\beta + 2\beta e^{-T\beta}\right)}{2\beta^3 b}\right)}{T + \frac{(b-T)^2}{2b}} = 0 \tag{17}$$

Since the closed form solution of (17) cannot be derived, a simple heuristic from Maple is used to solve the model.

3. A NUMERICAL EXAMPLE AND SENSITIVITY ANALYSIS

A numerical example is shown to illustrate the model. We use $K = 100$, $\theta = 0.05$, $\alpha = 1000$, $\varepsilon = 1.2$, $h = 1$, $S = 10$ and $b = 1$ as a problem for the price dependent model. The Genetic Algorithm is run five times, and the best solution is used. The optimal price (p^*) for the problem above is 8, the optimal ordering period (T^*) is 0.5078, and the optimal profit is 714.125. The result shows that the optimal ordering period is almost half of the maximum unavailability time. We use similar data for the stock dependent cost problem with some additional parameter which is stock dependent parameter $\beta = 10$. Since the closed form solution cannot be found, the model is solved using numerical analysis in Maple. The optimal ordering time (T^*) is equal to 0.691 with the optimal cost is 149.23.

A sensitivity analysis is conducted to show the effect of some parameters to the decision variables and the fitness value. For the sensitivity analysis, a parameter is changed, and the other parameters are set constant. The sensitivity analysis for price-dependent demand is shown in Figure 2-4. Figure 2 shows the optimal price in varies of parameters. The figure shows price is the most sensitive parameter in varies of price parameters. Therefore when a product is susceptible to price, it is challenging to find the optimal decisions. The second parameter which has the biggest effect on price decision is supplied unavailability time. The optimal price tends to increase as the supply unavailability time increase. The supplier tries to reduce demand by increasing product price; therefore it will reduce customer demand and reduce the probability of lost sales products and costs. The optimal price also tends to rise as inventory cost increase to increase the supplier's profit. At the other way, the price will be reduced as the ordering cost decrease to get high demand from the customer.

3.1. Price-sensitive demand

The price constants parameter is also the most sensitive parameter for the optimal replenishment period; therefore it is challenging to obtain precise optimal replenishment time if the demand is very sensitive to the price. For fruit commodities at pre-harvest period, the demand is not too sensitive to the price; therefore it is not challenging to get precise optimal replenishment time. The second most sensitive parameter for the optimal price is the maximum unavailability time. When supply is not reliable, the supplier tries to optimise his profit by increasing their price. This situation is relevant in practice where price tends to high as items are not available enough in the market. Replenishment time has similar sensitivity pattern with the sensitivity analysis of the price where the most sensitive parameter for replenishment time is the price constants parameter and the second most sensitive parameters is holding cost and lost sales cost. Replenishment time decrease as inventory cost increase. The supplier tries to optimize his profit by reducing replenishment quantity. The parameter that related to unavailability supply is maximum unavailability time. When the replenishment process become more unreliable which is shown by a higher maximum unavailability time, the supplier tries to extend the replenishment time result in higher ordering quantity. A similar decision is taken to deal with higher lost sales cost.

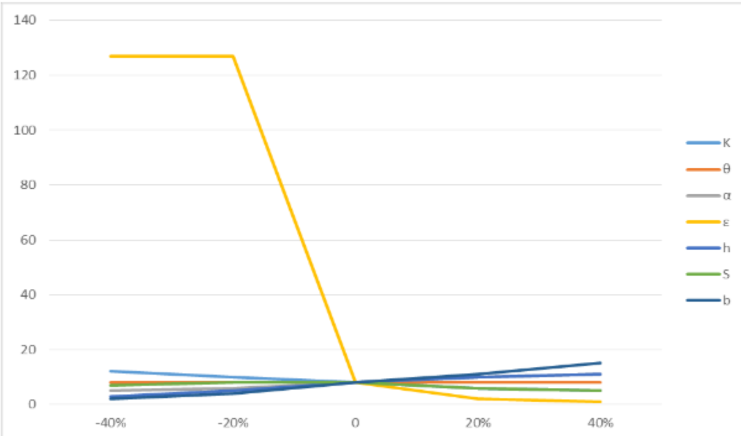

Figure 2. The sensitivity analysis for optimal price

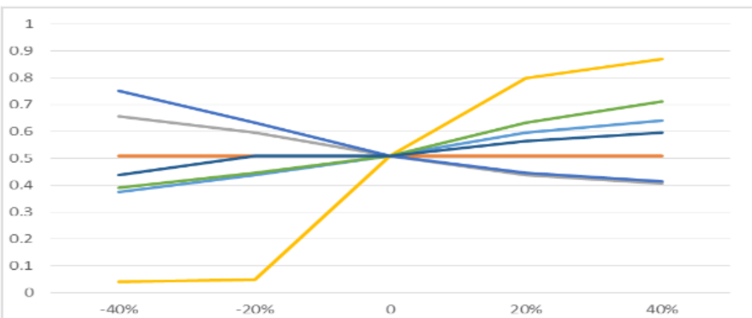

Figure 3. The sensitivity analysis for optimal replenishment time

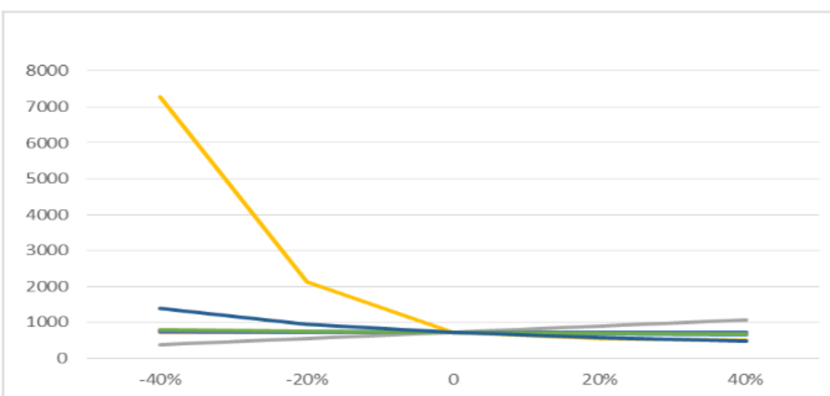

Figure 4. The sensitivity analysis for optimal total profit

Figure 4 shows the sensitivity analysis for the optimal total profit. It is shown that the most sensitive and the third sensitive parameter to the optimal total profit is the price sensitivity parameter. The profit decrease when the price becomes more sensitive. However, the price sensitivity parameter depends on the customer that cannot be managed by the supplier. The second parameter that has high sensitivity to the total profit is supply unavailability time. The total profit tends to decrease as the supply unavailability time increase. Since the supplier can manage the parameter, the supplier can try to make the supply more reliable to keep the high profit.

3.2. Stock dependent demand

The sensitivity analysis for the stock dependent model is shown by analyzing the optimal replenishment time and the optimal total cost. Figure 5 shows that the most sensitive parameter to the optimal replenishment time is the stock dependent demand parameter. The optimal replenishment time tends to decrease as the dependent demand parameter increase. When the dependent demand parameter increase, the supplier tries to reduce the total cost by reducing the replenishment time. The optimal replenishment time is also susceptible in varies of the unavailability time (b) and ordering cost (K). When the ordering cost increase, the supplier tends to reduce cost by increasing the replenishment time. At the other side, the supplier decreases the replenishment time as the unavailability time increase. The supplier wants to reduce his cost by order fewer items as the reliability of the process increase to cut his lost sales risk.

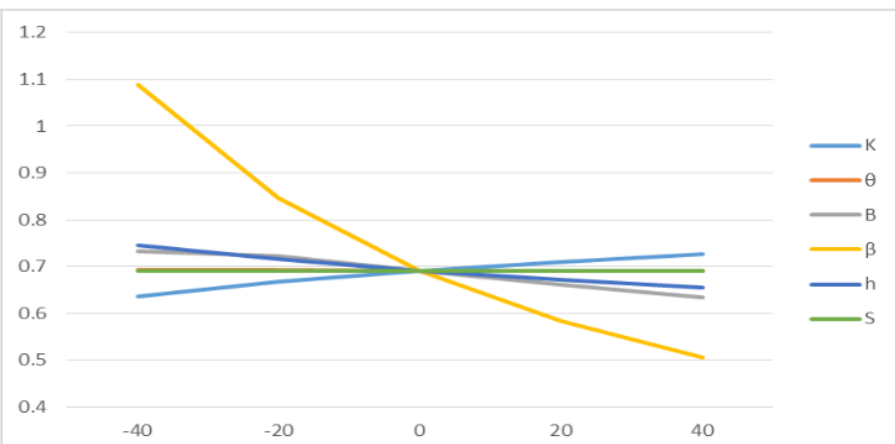

Figure 5. The optimal replenishment time sensitivity analysis for stock dependent demand

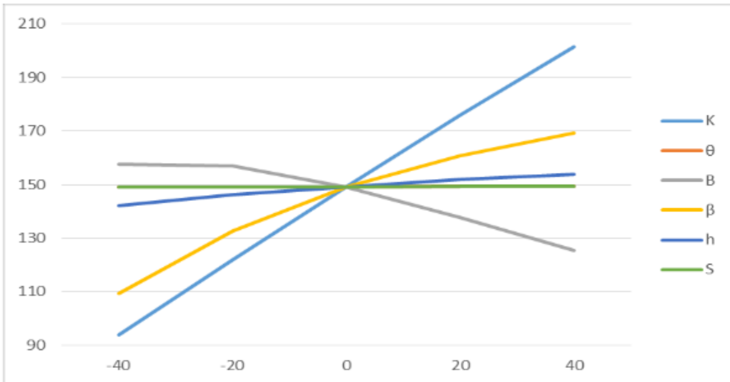

Figure 6. The optimal total profit sensitivity analysis for stock dependent demand

Figure 6 shows the sensitivity analysis of the optimal total cost in varies of the parameter. It shows that the most sensitive parameters for the optimal total cost are ordering cost (K). The total cost increases significantly as the ordering cost increase. Therefore a supplier should try to reduce their ordering cost to keep their total cost low. The other parameter that significantly affects the optimal total cost is the unavailability time (b) and the stock dependent parameter (β). The total cost tends to decrease as the unavailability time increase. In the other side, the total cost increase as the stock dependent parameters increase. Supply unavailability parameter is also sensitive to total cost where the total costs tend to decrease as the supply unavailability time increase.

4. CONCLUSION

Some fruits and vegetables have a limited supply period, and they are not available every time in a year. The fruits and vegetables have a period where not many fruits and vegetables ready to be harvested therefore they have limited supply and high demand. In this phase, the items have price-dependent demand characteristic, where supplier set high price and customer still sensitive with a new price offered by the supplier. When more fruits and vegetables available in a market, the price becomes stable, and supply can meet customer demand. After the pass, the harvest period, supply in the market and customer demand decreasing. Items quality is decreasing; therefore, retailers try to put good products on their shelf. The customer is not too interested in the product since they think they already consumed enough fruits and vegetables. Customers still interesting to buy the items if they see many fruits still available on a shelf with high-quality products. In this phase, customer demand depends on stock they can see in shelf and supply is not always available continually. This period will end when the supplier cannot supply the products again, and we call the whole period as supply life cycle.

Many researchers gave attention to develop deteriorating inventory models; however, no paper ever discuss deteriorating inventory items by considering price-dependent demand and unreliable supply for the first period of supply life cycle and also considering stock dependent demand and unreliable supply as the last period of supply life cycle. The model is solved using Genetic Algorithm and heuristic methods since closed-form solution cannot be derived. The model is illustrated using a numerical example, and a sensitivity analysis is conducted to show some insights 0f the model.

The sensitivity analysis shows that at the beginning harvesting period, the most sensitive parameters to price decision is price constants parameter and inventory cost. It is more challenging to find the best price where demand is very sensitive to price. The second most sensitive parameter to the price is supplied unavailability parameters. The supplier will increase his price to reduce cost because of supply unavailability. At the end of the supply period when demand depends on the stock, the total cost mostly sensitive in varies of ordering cost and unavailability supply. Therefore it is essential for the supplier to keep ordering cost low since it is challenging to keep low unavailability supply sine the harvest period almost end.

The models show that different period has a different situation and affect the decision to get optimal profit and cost. At the beginning and the end of harvest period sometimes it is better to deliver items in any quantity in a specific time. Therefore fixed replenishment period model for deteriorating inventory models with price dependent demand and stock dependent demand can be considered to be developed for the future research.

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