Advanced preservation policy for deteriorating products during transportation and at retailer within a supply chain

Muhammad Waqas Iqbal and Yuncheol Kang*

Department of Industrial Engineering, Hongik University, Seoul, South Korea. waqas@hongik.ac.kr, yckang@hongik.ac.kr

Abstract

This paper contains a two-echelon supply chain model for deteriorating products considering advanced preservation policy during transportation and at retailer. The recent innovations regarding preservation of food products include several types of preservation technologies to reduce the deterioration rate. Use of such technologies increases the supply chain profit of such fixed lifetime products. Unlike other studies, who proposed continuous reduction in rates of deterioration with investment in preservation technology, we focus on more real circumstances by proposing model of such a preservation policy that minimizes the effects of deterioration in a way that magnitude of decrease in deterioration reduces for additional investment in preservation technology. The model is validated with numerical experiment by considering a case study on fresh fruits. Implication of investment in preservation technology is illustrated by evaluating increase in product's life time and profit which authenticates the proposed model.

Keywords

Supply chain, Deterioration, Advanced preservation policy, Preservation during transportation, Nonlinear programming

1. Background and motivation

Food products deteriorate during transportation and at retailers, which causes decrease in their sale and profit. Due to deterioration, quality of the food products is either reduced or these products become perishable after a certain period of time, thus making them unfit for human consumption. At retail stores, such food products, which deteriorated during transportation or at retailer are usually discarded, which merely incur the production, transportation and inventory costs. Such disposals not only create an economic loss but also affect the environment and natural resources. In the United States, approximately 15% of the food products expire due to deterioration before reaching their consumers. It is reported that, throughout the world, 1.3 billion tons of food products are discarded every year, which is approximately 33% of all the food produced for human consumption (Gustavsson et al., 2011). This study is focused to minimize these losses by providing preservation policies for food products during their transportation and storage.

Deterioration has been discussed in literature by many researchers. First model for deteriorating inventory was proposed by Ghare and Schrader (1963). Sachan (1984) developed an Economic Order Quantity (EOQ) model with shortages and time dependent product demand where inventory items deteriorate at a constant rate. Chang and Dye (1999) improved the model by considering backlogged shortages. This research dimension was further explored by Skouri et al. (2009) and they proposed an inventory model with time dependent rate of deterioration and ramp type demand rate considering partial backlogging. Sarkar (2013) proposed an Economic Production Quantity (EPQ) model considering three probabilistic (uniform, triangular, beta) deterioration rates to find the optimum lot size and number of deliveries. Chen and Teng (2014) developed an EOQ model with deteriorating items having maximum life time and permissible delay in payments to minimize the total cost. Goel et al. (2015) considered variable quadratic rate of deterioration in a deterministic inventory model and they proposed a supply chain model considering supplier, manufacturer and a retailer with stock dependent demand and partial backlogging. Sarkar et al. (2015) studied a two echelon supply chain system focusing on setup cost, system reliability and deterioration. They concluded that setup cost is directly and deterioration rate is inversely proportional to the system reliability. Lin et al. (2016) studied an inventory system considering deterioration that depends on life time and the product price is demand dependent.

Solution of the deterioration is provided with preservation technology (PT). Deterioration can be controlled either by adding preservatives to the product which stops or modifies the chemical reactions which cause deterioration or by controlling those ambient conditions which cause initiate or accelerate the deterioration. For the last decade, many

researchers explored the application of PT for deteriorating products. Hsu et al. (2010) considered a basic inventory system for deteriorating products with application of PT and maximized profit by finding optimal values of preservation investment, replenishment cycle, shortage period, and order quantity. Dye and Hsieh (2012) proposed an EOQ model with time varying rate of deterioration and application of PT. They discussed that the rate of deterioration can be reduced through investment in PT. Dye (2013) also studied an inventory system with non-instantaneous deteriorating items to observe inventory behavior under PT investment. They concluded that there is an increase in customer service by adopting PT in a relevant system. Idea of seasonal deteriorating products with application of PT was put forward by He and Huang (2013).

Dye and Hsieh (2013) studied the effect of PT on deterioration rate reduction under two-level trade credit. They proposed a deterministic retailer EOQ model with time varying demand and solved by Particle Swarm Optimization (PSO) algorithm to maximize total profit on optimal values of PT cost, trade credit policy, number of replenishments and time scheduling. (Shah et al., 2016) modeled manufacturer-buyer two echelon supply chain with time varying rate of deterioration which can be reduced at retailer with investment in PT. They assumed that reduced rate of deterioration is a continuous increasing function of investment in PT. Tsao (2016) supposed that deterioration is non-instantaneous and that deterioration will decrease by increasing investment in PT.

This research considers short lifetime deteriorating products which are preserved for longer time by the application of PT, the effect of which reduces with additional investment. Preservation is applied during transportation and at retailer. Moreover, this model introduces a variable component of selling-price, which depends on lifetime of the product. Objective of this research is to maximize the profit by finding optimal values of the cycle time and investment in PT.

2. Problem definition

This study considers a supply chain management system having a manufacturer and a retailer for deteriorating product. Manufacturer produces and delivers the product to the retailer. The costs at manufacturer include transportation cost, material cost, production cost, inventory holding cost, and cold storage cost during transportation. In order to reduce the effects of deterioration, PT is also used in form of cold storage, humidity, sanitation, etc. at retailer. Though the rate of deterioration is reduced by the application of PT, still some products deteriorate during the cycle. Therefore, retailer demands from manufacturer the amount of product which fulfills customers' demand and compensates the deteriorated quantity during planned cycle. Thus, manufacturer's demand is the sum of retailer's demand and the quantity that would deteriorated during the cycle. Manufacturer purchases raw material and produces exactly the same number of items as are demanded by the retailer, thus having no shortages. Manufacturer plans its product to the retailer. The cycle time of manufacturer is synchronized with that of the retailer. The costs at retailer include ordering cost, purchasing cost, inventory holding cost, and the cost of PT. As the system is considered to be a centralized supply chain, therefore, purchasing cost of retailer is the same as the selling-price of the manufacturer. Selling-price at the retailer is variable and depends on maximum lifetime of the product. Figure 1 illustrates the structure of the supply chain system we consider in this paper.



Figure 1. Process flow

© IEOM Society International

3. Model formulation

In this section we formulae the mathematical models for retailer and manufacturer to calculate the total joint profit of the supply chain.

3.1 Model Notation

The subscript R denotes retailer, while M denotes the parameters related to manufacturer.

Т	cycle time (time units)	d_M	demand per unit time (units/unit time)
p_a	cost of preservation technology for preservation	D_M	demand per cycle (units/cycle)
D_{h}	conditions at retailer (\$/unit/unit time) cost of preservation during transportation (\$/delivery)	P	rate of production (units/unit time)
P_{b} d_{R} D_{R} N_{D} (units/ PQ_{R} I_{R}^{o} I_{R}	customer's demand per unit time (units/unit time) customer's demand per cycle (units/cycle) number of items deteriorated per cycle at retailer 'cycle) purchasing quantity per cycle (units/cycle) on-hand inventory at any time $t, 0 \le t \le T$ (units) total inventory carried during one cycle	I_M^a (units) I_M^b (units) I_M manufac N_P (units/cy C_{SET}	on-hand inventory at any time t , $0 \le t \le t_1$ on-hand inventory at any time t , $t_1 \le t \le T$ total inventory carried during one cycle at turer (units/cycle) number of items produced per cycle rcle) setup cost per setup (\$/setup)
(units/ A_R PC_R h_R (\$/unit TC_R SP_R SP_R SP_R TP_R TP_R TP centra L θ	cycle) ordering cost (\$/order) purchasing cost per unit (\$/unit) inventory holding cost per unit per unit time t/unit time) total cost per unit time (\$/unit time) selling-price per unit (\$/unit) sales revenue per unit time (\$/unit time) total profit per unit time (\$/unit time) total profit per unit time of the supply chain as a lized system (\$/unit time) maximum lifetime of the product (time units) rate of deterioration	C_{MT} C_P h_M (\$/unit/u C_T TC_M SP_M SR_M TP_M η k demand	material cost per unit (\$/unit) production cost per unit (\$/unit) inventory holding cost per unit per unit time nit time) cost of transportation per delivery (\$/delivery) total cost per unit time (\$/unit time) selling-price per unit (\$/unit) sales revenue per unit time (\$/unit time) total profit per unit time (\$/unit time) degree of effectiveness of preservation cost proportionality constant within production and at manufacturer
α ϕ transp	degree of vulnerability to deterioration scaling parameter for the cost of preservation during ortation		

3.2 Model Assumptions

A supply chain system consisting of a manufacturer and a retailer for a single product is considered, where customer demand at the retailer d_R is known and constant. Product under consideration is deteriorating in nature, which

deteriorates at a variable rate θ . Practically, the product does not deteriorate at manufacturer and starts deteriorating during transportation and when delivered to retailer. This fact is considered in this research. The rate of deterioration is controllable through preservation techniques which are applied in the form of cold storage during transportation and preservation conditions at retailer. The magnitude of decrease in deterioration decreases with additional investment in

PT. The cold storage during transportation totally prevents the products from deterioration. Short-lifetime product is sold at higher price when it is preserved and has longer expiration time. Therefore, this research assumes that the

variable component of the product's selling-price is a function of its maximum lifetime $v = \delta L$ i.e., a product with a longer time to expire is sold at a higher price compared to the same product with a shorter expiration time. The rate of production depends on and is higher than the rate of demand (Qin and Liu, 2014) i.e. $P = kd_M$, where P is the

rate of production and d_M is the rate of demand at manufacturer, and k > 1. Shortages are not allowed and demand at the retailer is fulfilled during planning horizon. The supply chain is vertically integrated, such that optimal value of profit of the supply chain is obtained as a centralized system. A food product, once expired, cannot be repaired to recover for the same consumption. Therefore, deteriorated items are considered non-repairable, thus removed from inventory and disposed.

3.3 Model Development

The deterioration is a function of lifetime of the products, therefore the rate of deterioration varies with variation in lifetime when PT is applied. The decreased rate of deterioration of a product is exhibited in following equation.

$$\hat{\theta} = \frac{\alpha}{1 + \left(1 + \eta p_a^{\gamma} + \phi p_b\right)L}$$

Value of γ is proposed to be less than one to represent the effect of preservation on lifetime and deterioration in real cases. In contrast to many researchers, who proposed the effect of investment in PT on deterioration in a conventional way, this study suggests that magnitude of decrease in deterioration keeps decreasing with additional investment in PT and after a specific amount of investment, the decrease in deterioration will be negligible, no matter how much preservation cost is invested.

3.3.1 Retailer's model

The proposed system considers a retailer, who receives the finished product from a manufacturer. The rate of demand of the product at retailer is d_R number of items per unit time and the rate of deterioration is $\hat{\theta}$. Figure 2 shows the behavior of inventory level at retailer. The governing differential equation for the inventory of the product at retailer

is as given below, which shows that the rate of change of inventory from 0 to T is the negative rate of its demand and deterioration, as the items are taken out of inventory.



Figure 2. Behavior of inventory level at retailer

$$\frac{dI_R^o(t)}{dt} = -d_R - \hat{\theta}I_R^o, \ 0 \le t \le T$$

© IEOM Society International

The above expression is the slope of the function of on-hand inventory at retailer. The value of the function $I_R^o(t)$, at any time t, is calculated from the given slope by using the inventory condition $I_R^o(t) = 0$ at t = T, as

$$I_{R}^{o}(t) = \frac{d_{R}}{\hat{\theta}} \left(e^{\hat{\theta}(T-t)} - 1 \right), \ 0 \le t \le T$$

Retailer's total cost per unit time

The total cost at the retailer is the sum of its ordering cost, purchasing cost, inventory holding cost, and preservation cost, which is given per unit time in below equation.

Total cost
$$(TC_R) = \frac{1}{T} (A_R + PC_R PQ_R + h_R I_R + p_a I_R)$$

The individual costs are briefly explained below.

 A_R is the ordering cost per cycle at the retailer. Purchasing quantity per cycle of the retailer is the sum of customer demand per cycle and the number of items that would deteriorate in a cycle. In order to calculate the purchasing quantity per cycle, the demand that the retailer faces per cycle is calculated in the following equation.

$$D_R = \int_0^T d_R dt = d_R T$$

Similarly, the number of items that deteriorate at the retailer during one cycle of inventory are computed and given as under.

$$N_{D} = \hat{\theta} \int_{0}^{T} I_{R}^{o}(t) dt = \frac{d_{R}}{\hat{\theta}} \left(e^{\hat{\theta}T} - \hat{\theta}T - 1 \right)$$

The purchasing quantity of the retailer is $PQ_R = D_R + N_D$ and the purchasing cost of product per cycle for the retailer is calculated and expressed in following equation.

Purchasing cost per cycle =
$$PC_R PQ_R$$

The stock of product's inventory that is carried by the retailer during one cycle [0,T], on which the inventory holding cost is considered, is calculated and expressed in below equation.

$$I_{R} = \int_{0}^{T} I_{R}^{o}(t) dt = \frac{d_{R}}{\hat{\theta}^{2}} \left(e^{\hat{\theta}T} - \hat{\theta}T - 1 \right)$$

Using above expression, inventory holding cost of the retailer for one cycle is calculated and expressed in following equation.

Inventory holding cost per cycle = $h_R I_R$

The preservation cost p is divided into two categories i.e. the cost for preservation conditions p_a at retailer and cost of cold storage during transportation p_b . By using the preservation cost per unit per unit time and the total inventory carried per cycle, the investment per cycle in PT at the retailer is calculated in the equation as under.

Investment in preservation technology per cycle = $p_a I_R$

The variable component of selling-price v depend on the maximum lifetime of the product, as $v = \delta \hat{L}$. By using fixed and variable components, the selling-price of one item is calculated below.

S

elling-price per unit
$$(SP_R) = \varepsilon + v = \varepsilon + \delta L$$

Sales revenue per unit time of the retailer is computed by using its selling-price per unit and demand per unit time, as is expressed in the below equation.

$$SR_R = SP_R d_R$$

Retailer's profit per unit time

The retailer earns profit by selling its product during planning horizon. The profit per unit time of the retailer is calculated by using the sales revenue per unit time and the total cost per unit time, and is given in following equation.

$$TP_R = SR_R - TC_R \tag{1}$$

3.3.2 Manufacturer's model

The manufacturer's demand per cycle is given below.

Manufacturer's demand $(D_M) = PQ_R = D_R + N_D$

By using the demand per cycle and its cycle time, the rate of demand per unit time at manufacturer is as given below.

$$d_M = \frac{D_M}{T} = \frac{D_R + N_D}{T}$$

Manufacturer produces the products as per demand and the rate of production is proportional to the rate of demand, which is expressed in below equation.

$$P = kd_M = k\frac{D_R + N_D}{T}$$

The governing differential equations of current inventory at manufacturer are expressed below. The cumulative effect of production and demand on the rate of change of inventory level is positive because production rate is higher as compared to the rate of demand. Therefore, inventory stock is replenished during production time. The inventory stock starts depleting when production time is over.



Figure 3. Behavior of inventory level at manufacturer

$$\frac{dI_M^a\left(t\right)}{dt} = P - d_M = \left(k - 1\right)d_M, \ 0 \le t \le t_1$$
$$\frac{dI_M^b\left(t\right)}{dt} = -d_M, \ t_1 \le t \le T$$

The value of the functions $I_M^a(t)$ and $I_M^b(t)$, at any time t, is calculated by using following inventory conditions.

$$I_{M}^{a}(t) = 0 \text{ at } t = 0$$
$$I_{M}^{b}(t) = 0 \text{ at } t = T$$
$$I_{M}^{a}(t) = (k-1)d_{M}t, \ 0 \le t \le t_{1}$$
$$I_{M}^{b}(t) = d_{M}(T-t), \ t_{1} \le t \le T$$

From Figure 3, it can be observed that, for an instant, the level of inventory for both the intervals is same when $t = t_1$. Equating these equations at the point t_1 , one can get.

$$(k-1)d_M t_1 = d_M (T-t_1)$$

 $\Rightarrow t_1 = \frac{T}{k}$

The usual operations, which are carried out at manufacturer that incur some cost include; purchasing of raw material, production setup, manufacturing/production process, inventory holding of the finished product, and transportation. Several costs, which are considered by manufacturer are provided below.

Manufacturer's total cost per unit time

Total cost per unit time at manufacturer is calculated and expressed in below equation.

Manufacturer's total cost per unit time
$$(TC_M) = \frac{1}{T} (C_{SET} + C_{MT}N_P + C_PN_P + C_T + p_b + h_MI_M)$$

The setup cost at manufacturer per cycle is C_{SET} . Similarly, the cost of transportation per delivery is C_T . Material cost per manufacturer's cycle is calculated and expressed in below equation.

Material purchasing cost per manufacturer's cycle = $C_{MT}N_P$,

where N_p is the number of items produced per manufacturer's cycle and is expressed below.

$$N_P = \int_{0}^{t_1} P dt = D_R + N_D$$

Production cost per cycle is computed by using the quantity produced per cycle and production cost per unit.

Production cost per manufacturer's cycle $= C_p N_p$,

The inventory carried by the manufacturer for one cycle I_m , which incurs inventory holding cost, is expressed below.

$$I_{M} = \int_{0}^{t_{1}} I_{M}^{a}(t) dt + \int_{t_{1}}^{T} I_{M}^{b}(t) dt = \frac{(k-1)d_{M}T^{2}}{2k}$$

Total inventory holding cost per manufacturer's cycle is provided below.

Inventory holding cost per manufacturer's cycle $= h_M I_M$

The produced food products tend to deteriorate during transportation. In order to avoid the deterioration and deliver exactly the same quantity to the retailer as is demanded, cold storage trucks are used. The cost, which is incurred by to maintain cold storage conditions during transportation is considered as preservation cost during transportation.

Preservation cost during transportation = p_h

Sales revenue of the manufacturer per unit time is calculated as following.

$$SR_M = SP_M d_M$$

As the manufacture sells its product to the retailer, the selling-price of manufacture is same as the purchasing cost of the retailers. Therefore, $SP_M = PC_R$.

Manufacturer's profit per unit time

The total profit per unit time of manufacturer TP_M is calculated by using sales revenue per unit time and the cost per unit time, which is expressed in the equation below.

$$TP_M = SR_M - TC_M \tag{2}$$

Total profit per unit time of the supply chain

Adding Equation 1 and 2, and simplifying the results, one can obtain the following expression for total supply chain profit per unit time.

$$TP(p_a, p_b, T) = TP_R + TP_M = SR_R - \frac{1}{T}(A_R + h_R I_R + p_a I_R + C_{SET} + C_{MT} N_P + C_P N_P + C_T + p_b + h_M I_M)$$

$$= \left\{ \varepsilon + \delta \left(1 + \eta p_a^{\gamma} + \phi p_b \right) L \right\} d_R$$

$$- \frac{1}{T} \begin{bmatrix} A_R + \left(h_R + p_a \right) \frac{d_R}{\hat{\theta}^2} \left(e^{\hat{\theta}T} - \hat{\theta}T - 1 \right) + C_{SET} + \left(C_{MT} + C_P \right) \left\{ d_R T + \frac{d_R}{\hat{\theta}} \left(e^{\hat{\theta}T} - \hat{\theta}T - 1 \right) \right\} \\ + C_T + p_b + h_M \frac{\left(k - 1 \right) \left(e^{\hat{\theta}T} - 1 \right) T d_R}{2k\hat{\theta}} \end{bmatrix}$$
(3)

where $\hat{\theta} = \frac{\alpha}{1 + (1 + \eta p_a^{\gamma} + \phi p_b)L}$.

Objective of this study is to maximize the total profit per unit time TP by finding optimal values of T (retailer's cycle time), p_a (cost of preservation per unit per unit time for preservation conditions at retailer) and p_b (cost of cold storage per delivery during transportation).

4. Computational experiment

In order to exhibit applications of the proposed model, numerical study is carried out. For the numerical experiment, a case study of fresh fruits having a reasonable span of lifetime, such as apple, is considered. The production setup of apple consists of the agriculture field, its preparation for the crop, and maintenance of the land during production. One unit of the ready-to-delivery crop is considered to be a pack of 10 Kilograms of apples. It is assumed that there is a constant demand of 2000 such units per month being sold at a consumer price \$50. The material cost to produce the one unit includes cost of water, minerals, sprays, fertilizers, containers, and packaging. Similarly the production cost includes the cost of fuel, manpower, and other utilities. We consider a centralized supply chain system, where the ordering cost of the retailer does not include purchasing cost. After harvesting, manufacturer packs the required quantity of apples within each pack and saves it as inventory, where the required demand of retailer is fulfilled. The manufacturer delivers the finished units to the retailer in such vehicles, where the preservation conditions are maintained such that no items deteriorate during transportation. The manufacturer bears the setup cost, material cost, production cost, transportation and preservation cost, and cost of inventory holding. Retailer receives the packed units of apples and sells them to the customers at the prescribed price. It bears the ordering cost, inventory holding cost, purchasing cost, and preservation cost. In this section, we are calculating the optimum level of preservation during transportation and at retailer, optimal length of cycle time, and maximum value of the profit per unit time. The values of the relevant input parameters are taken in appropriate units, which are provided below.

 $A_R = 300 /cycle , $C_{SET} = 2000 /cycle , $C_{MT} = 10 /unit , $C_P = 4 /unit , $C_T = 400$, L = 1.5 months ,

 $h_R =$ \$0.8 /unit/month , $h_M =$ \$0.5 /unit/month , $d_R =$ 2000 units/month , $\alpha = 0.1$, $\eta = 1.2$, $\delta = 1$, $\varepsilon =$ \$50 /unit ,

$$k = 4$$
, $\gamma = 0.4$, $\phi = 0.001$.

Optimum values of the cycle time and preservation costs are computed by using Mathematica 9. By using the optimal results, value of total profit per unit time is calculated. The optimum results are provided as below. $TP^* = \$73\$15/month$, $T^* = 0.\$3$ month, $p_a^* = \$2.59/unit/month$, $p_b^* = \$91/delivery$.

The investment in preservation per cycle of the proposed setup is calculated and provided below.

Optimal investment in preservation technology per cycle = $p_a^* I_R = \$1783.5$.

Comparative analysis of the results with and without preservation technology

The results of the comparative analysis are exhibited below in Table 1.

Parameters	Without preservation	With preservation	Percent improvement
Lifetime (month/s)	1.50	4.27	184.67
Rate of deterioration	0.04	0.019	-52.50
Profit (\$/month)	70631	73815	4.51

Table 1. Comparative analysis

Comparative analysis of optimal results with and without application of PT shows that the application of PT increases lifetime of the product and total profit per unit time of the proposed supply chain system, while the rate of deterioration is reduced.

5. Concluding remarks

This paper discussed a supply chain system in which preservation technology is used to increase life time of short life deteriorating products and proposed a model to find optimal value of investment in preservation technology during transportation and at retailer. The proposed model suggested that lifetime of a deteriorating product is increased significantly by applying preservation technology and consequently the rate of deterioration is decreased. The authors also recommended that product having longer time to expire is sold at higher price and it contributes to increase the profit. The hypothesis was verified through the results of numerical illustrations that demonstrated a remarkable increase in profit of the supply chain when the proposed preservation policy was adopted. Moreover, it was proved that the investment for preservation conditions as well as cold storage during transportation is significant. This research can further be continued to study the effects of preservation technology on maximum lifetime of the product. Moreover, several storage conditions during transportation of food products can be investigated.

6. References

- CHANG, H.-J. & DYE, C.-Y. 1999. An EOQ model for deteriorating items with time varying demand and partial backlogging. *Journal of the Operational Research Society*, 1176-1182.
- CHEN, S.-C. & TENG, J.-T. 2014. Retailer's optimal ordering policy for deteriorating items with maximum lifetime under supplier's trade credit financing. *Applied Mathematical Modelling*, 38, 4049-4061.
- DYE, C.-Y. 2013. The effect of preservation technology investment on a non-instantaneous deteriorating inventory model. *Omega*, 41, 872-880.
- DYE, C.-Y. & HSIEH, T.-P. 2012. An optimal replenishment policy for deteriorating items with effective investment in preservation technology. *European Journal of Operational Research*, 218, 106-112.
- DYE, C.-Y. & HSIEH, T.-P. 2013. A particle swarm optimization for solving lot-sizing problem with fluctuating demand and preservation technology cost under trade credit. *Journal of Global Optimization*, 55, 655-679.
- GHARE, P. & SCHRADER, G. 1963. A model for exponentially decaying inventory. *Journal of industrial Engineering*, 14, 238-243.
- GOEL, R., SINGH, A. P. & SHARMA, R. 2015. Supply chain model with stock dependent demand, quadratic rate of deterioration with allowable shortage. *International Journal of Mathematics in Operational Research*, 7, 156-177.
- GUSTAVSSON, J., CEDERBERG, C., SONESSON, U., VAN OTTERDIJK, R. & MEYBECK, A. 2011. Global food losses and food waste. *Food and Agriculture Organization of the United Nations, Rom.*
- HE, Y. & HUANG, H. 2013. Optimizing inventory and pricing policy for seasonal deteriorating products with preservation technology investment. *Journal of Industrial engineering*, 2013.
- HSU, P., WEE, H. & TENG, H. 2010. Preservation technology investment for deteriorating inventory. *International Journal of Production Economics*, 124, 388-394.
- JAWLA, P. & SINGH, S. 2016. A reverse logistic inventory model for imperfect production process with preservation technology investment under learning and inflationary environment. Uncertain Supply Chain Management, 4, 107-122.
- LIN, F., YANG, Z.-C. & JIA, T. Optimal Pricing and Ordering Policies for Non Instantaneous Deteriorating Items with Price Dependent Demand and Maximum Lifetime. Proceedings of the 6th International Asia Conference on Industrial Engineering and Management Innovation, 2016. Springer, 411-421.
- QIN, J. & LIU, W. 2014. The Optimal Replenishment Policy under Trade Credit Financing with Ramp Type Demand and Demand Dependent Production Rate. *Discrete Dynamics in Nature and Society*, 2014.
- SACHAN, R. 1984. On (T, S i) policy inventory model for deteriorating items with time proportional demand. *Journal* of the operational research society, 1013-1019.
- SARKAR, B., SETT, B. K., ROY, G. & GOSWAMI, A. 2015. Flexible Setup Cost and Deterioration of Products in a Supply Chain Model. *International Journal of Applied and Computational Mathematics*, 1-16.
- SHAH, N. H., CHAUDHARI, U. & JANI, M. Y. 2016. Optimal Policies for Time-Varying Deteriorating Item with Preservation Technology Under Selling Price and Trade Credit Dependent Quadratic Demand in a Supply Chain. *International Journal of Applied and Computational Mathematics*, 1-17.
- SKOURI, K., KONSTANTARAS, I., PAPACHRISTOS, S. & GANAS, I. 2009. Inventory models with ramp type

demand rate, partial backlogging and Weibull deterioration rate. *European Journal of Operational Research*, 192, 79-92.

TSAO, Y.-C. 2016. Joint location, inventory, and preservation decisions for non-instantaneous deterioration items under delay in payments. *International Journal of Systems Science*, 47, 572-585.

Biographies

Yuncheol Kang is an Assistant Professor in Industrial Engineering at Hongik University, Seoul, Republic of Korea. His research interests include decision-making problems and the use of information technology in a variety of industrial domains including logistics, supply chain and health care. He was a Research Associate in Industrial and Manufacturing Engineering at the Pennsylvania State University from Sep/2014 to Feb/2016. He received a PhD in Industrial Engineering in 2014 from Pennsylvania State University, and an M.S. in Industrial Engineering in 2004 from the Seoul National University. Between his M.S. and Ph.D. studies, he was a system designer at LG CNS, Seoul, Republic of Korea and a researcher at Automation and Systems Research Institute, Seoul National University, Seoul, Republic of Korea. He also received a B.S. in Industrial Engineering from KAIST in 2002.

Muhammad Waqas Iqbal is a post-doctoral researcher in the department of Industrial Engineering at Hongik University, South Korea. He earned his PhD from Hanyang University, South Korea in Industrial & Management Engineering in 2018 and received Best Thesis Award. He has earned B.Sc. Engineering degree in Textiles from National Textile University, Pakistan in 2010. He has won prestigious scholarship from Higher Education Commission, Pakistan to pursue Masters and PhD studies in Industrial & Management engineering (2014-2018). He is an active researcher in the field of primary and secondary supply chain systems, and preservation policies for deteriorating products. His research has been published in famous journals of Industrial Engineering. His areas of interest include, Supply Chain Management, Operations Research, Non-linear programming, Optimization, Inventory Management, Production Planning and Control, Reverse Logistics, and Preservation Policies in supply chains.