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Inventory control with deteriorating items: A state-of-the-art literature review

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C H R O N I C L E

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A B S T R A C T

The present study reviews different studies on inventory control of deteriorating items in chain supply published over the period 1963- 2013. The study investigates supply chain of the items in terms of various perspectives. Finally, the summary of the studies is shown in two tables for one-echelon and multi-echelon supply chain including the main information and assumptions of each paper. In the mentioned tables, the papers were classified in terms of the type of demand rate, deterioration rate, solution procedure and findings. It can be said that no analysis on the results was done in the present study and it can be only used as a good reference in the study field for other researchers.

1. The different inventory models of deteriorating items

In most inventory control models, it is assumed that the goods can be held infinitely for future demand but such assumption does not hold in reality as most items we deal with lose their characteristics overtime and this characteristic is defined as deterioration. For example, the food and drugs or films are deteriorated over time horizon. Most clothes become out of fashion and some goods such as alcohol, petrol and petrochemical industry products must be kept with low inventory echelon. Each of the three states reduces the inventory echelon. Generally, wide range of the goods is put in one classification presented in Table 1 based on the effective parameters on reduction of inventory echelon.

The present study does not consider the supply chain considering the obsolescence of the items. There are a few studies on these items: The main reason is that the perished or outdated goods are not ordered in the next periods by inventory control system. A few issues are mentioned about obsolescence by the researchers. For example, Cobbaert and Oudheusden (1996) presented the inventory model for fast deteriorating items. Various cases of obsolescence risk, with shortage and no shortage in the inventory

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were studied. The charge of obsolescence risk was evaluated in the extended model of Van Beek et al. (1985) by considering lot size and capacity planning as simultaneously in the multiple channels.

Table 1
Classification of different kinds of deterioration

Keyword	**Definition**	**Example**
Perishable, Deterioration	Deterioration is defined as humidity, evaporation, damage, and loss of utility of the product.	Food and medicine, blood, photo film
Obsolescence	Obsolescence refers to the decline in the value of the goods over the time due to some reasons as technology change.	Clothes
Decay	The items with no shelf life and low inventory control.	Chemical products as alcohol and petrol

Many researchers studied the issues on inventory of deteriorating items widely. The study on this topic was first introduced by Whitin (1957). Two studies were accomplishment on deteriorating items (Goyal & Giri, 2001; Bakker et al., 2012). The later study reviewed the literature of the inventory control models in one-echelon and multi-echelon supply chain. A classification of inventory control models of deteriorating items in one-echelon systems based on demand rate was presented. It is attempted to review the most important studies in each classification as briefly. Table 2 demonstrates different states of demand in the literature used for deteriorating items.

Table 2
Different states of demand

Classification	Explanation
Demand-based	Uniform demand
	Time-varying demand
	Inventory-dependent demand
	Price-dependent demand

1.1 Uniform demand

Most of the inventory control models, developed in the past, are based on dynamic demand. The first attempt to describe optimum ordering policies for deteriorating items was made by Ghare and Schrader (1963). Covert and Philip (1973) presented an inventory control model with exponential deterioration rate for deteriorating items and constant demand rate. Later, Philip (1974) derived the inventory control model with deteriorating rate of three-parameter Weibull distribution, no shortage. Shah (1977) developed his model with allowable shortage.

Sarma (1983) developed an inventory control model with two warehouses for deteriorating items. He assumed the transportation cost between the warehouses as constant shortage was forbidden. Goyal (1985) presented the economic order quantity model for deteriorating items to find the optimal order value. In this model, the demand rate is constant, shortage is not allowed and planning horizon is infinite.

Sarma (1987) presented a two-warehouse inventory control model for deteriorating items by adding this assumption that replenishment rate are infinite. Padmanabhan and Vrat (1990) presented the inventory control model in which the deterioration rate of the goods had exponential distribution. The goods ordering cost, deterioration, storage and purchasing of the raw materials are considered in the present study. The replenishment rate was infinite and shortage was not allowed.

Raafat et al. (1991) developed an inventory control model for deteriorating items with constant demand rate and finite replenishment rate. Pakkala and Achary (1992) developed inventory control model for deteriorating items by considering two warehouses. In this model, the replenishment rate was finite, shortage was allowed and demand rate was constant. It was assumed the deteriorating rate in two warehouses is different. Then, for various costs of shortage cost, the changes in the inventory echelon and optimal cost were determined.

Goswami and Chaudhuri (1992) developed an inventory control model for deteriorating items with time-dependent deteriorating rate in shortage and no shortage cases. In this model, the production rate was finite and in accordance with the time-dependent demand rate. Chu et al. (2004) developed a paper with the aim of evaluating the inventory model presented by Padmanabhan and Vrat (1990) with a combination of lost sale costs and backlogging. They considered some criteria for optimal solution of the total cost function. If the criterion does not hold, this model is turned into the inventory cycle model with finite inventory period. This issue refers to the generalization of the shortage period to the long period to create the low cost. If the launching costs and goods cost per unit and inventory transportation costs are increased, the defined criterion is not true. Thus, the inventory model to keep the shortage period to the long period is reduced to once cycle.

Chang (2004) presented the inventory control in which the supplier considered permissible delay in payment for the purchaser if the order quantity is big. The study investigated an inventory control model for deteriorating items under inflation when a permissible delay is provided to the purchaser if the order quantity is greater than or equal to a predetermined quantity. Then, the order amount and optimum replenishment time were determined. Yang (2004) presented two-warehouse inventory control model for deteriorating items with constant demand rate by considering shortage and inflation. Despite the previous two-warehouse models, by assuming shortage at the end of each work cycle, each cycle is started with shortage and is finished without shortage in the present study. Finally, this model was compared with the previous models and it was proved that the presented model was cheaper than the previous models (under inflation conditions).

Yang (2005) presented a model in which maximizing the earnings function is considered as target function to determine the optimal replenishment policy. Many previous studies investigated the inventory control models and applied the minimum costs as target function to find the optimal replenishment policy in finite planning horizon. Compared with other studies, this paper tried to find the optimal replenishment policy considered maximizing the earnings as the target function. In addition, the allowable shortage as partial backlogging for deteriorating items was investigated for four various inventory models. Yang (2006) developed the model of Yang (2004) by considering the partial backlogging. Then, two models of two-warehouse inventory control model based on cost minimizing target function were compared. Lee (2006) first modified two-warehouse inventory control model of LIFO presented by Pakkala and Achary (1992), then proposed a two-warehouse FIFO model. In most two-warehouse inventory control models, LIFO policy was considered while this assumption does not hold in reality; it means that FIFO policy is mostly applied to increase the freshness of the goods. Thus, the study is based on contradiction. By comparing two models, it can be said that if the mixed effects of goods deterioration and holding cost in rented warehouse are less than the owned warehouse, FIFO model is less costly than LIFO model.

Dye et al. (2007) developed inventory control model for two-warehouse deteriorating items. In this study, the rented warehouse is used when the ordered amount is more than the limited capacity of the owned warehouse. It is assumed that deterioration rate in two warehouse is different. The shortage in the main warehouse is allowed and backlogged demand rate is dependent upon the empty space period of the warehouse. The simple solution procedure is presented to find the maximum total earnings per unit. Niu and Xie (2008) showed that the results of the study by Lee (2006) were wrong. In the paper of Lee, different two-house inventory control models were used for deteriorating items in which Pakkala and Achary (1992) model was revised first and then the author concluded that this revised model was less costly than the model of Pakkala and Achary (1992), then the new conditions were presented and proved. The revised model had low cost compared with Pakkala and Achary (1992) model. Hsieh et al. (2008) developed an inventory control model for deteriorating items with two warehouses with the aim of minimizing the current net value of the total cost. The deterioration rate of the items in two warehouses is different and shortage as partial backlogging is allowed. Then, the optimal replenishment policy was obtained under this condition.

Ouyang et al. (2009) developed economic order model of Goyal (1985) with permissible delay in payment to reflect the real world conditions. It means that sale price per unit for the retailer is more than the purchasing price per unit. Obviously, the interest rate of bank is not more than capital return rate of the retailer. Most of the items including fruits and vegetables are deteriorated continually and the manufacturer considers an allowable delay in partial payment, even if the order is less than a definite echelon. Liao et al. (2012) attempted to determine the optimal economic order for deteriorating items by assuming two warehouses, owned and rented. In this paper, the permissible delay in payment was dependent upon the ordered amount, when the ordering amount was less than the case in which the permissible delay was considered. The study emphasized on the fact that how should be the decisions of the retailer for ordering and whether it is necessary to rent warehouse to hold more items or not. Mahata (2012) presented a study with the aim of evaluating the optimal replenishment decisions of the retailer for deteriorating items under trade credit policy. It is assumed that the retailer has high decision making power and can obtain the trade credit proposed by the manufacturer. However, the retailer proposes partial trade credit to the customers and the retailer can achieve high profit under these conditions.

1.2. Times -dependent demand

The constant demand rate is not always used for most of the inventory items (e.g. electronic goods, fashionable clothes, delicious foods, etc.), as these goods experienced some fluctuations in demand rate. Most of the goods experienced the demand increase period during the increase of life. In other words, the demand of some products is reduced due to the introduction of the attractive products affecting the preferences of the customer.

Hollier and Mak (1983) analyzed the declining exponential demand for deteriorating items for the first time to achieve the optimal replenishment policies under constant and variable replenishment distances. Aggarwal and Baharikashani (1991) developed the model presented by Hollier and Mak (1983) by considering the flexible production rate allowable in each period, with no shortage. Goswami and Chaudhuri (1991) presented the inventory replenishment issue on constant planning horizon for a deteriorating good. In this model, the deterioration rate was constant and there was time-dependent rate and shortage was allowed.

Xu and Wang (1992) presented inventory control model for deteriorating items with time-dependent linear demand. They obtained optimal replenishment policy by Wagner- Whitin algorithm. Wee (1993) developed an economic production model for deteriorating items with partial backlogging and obtained time interval and cycle time minimizing the total cost function. Hariga and Benkherouf (1994) revised Hollier and Mak (1983) model by considering the exponential increase or decrease of the market. Wee (1995) presented an inventory control model to obtain the service echelon and the number of optimal replenishments for deteriorating items. In this model, the demand is decreased exponentially in constant time horizon and the timing period was similar and the shortage was allowed except for the first and final period inventory. The inventory control models of deterioration in which both demand and production rate were both time-dependent were considered by Balkhi and Benkherouf (1996). They assumed that deterioration rate of the goods is constant.

Balkhi and Benkherouf (1997) presented an optimal procedure to find the optimal replenishment time in an inventory system in which there was time-varying deterioration rate and demand rate in a finite planning horizon is increased over time. The study completed the previous works by assuming that deterioration rate was with total distribution function, demand rate was time-dependent and planning horizon was finite. Chen (1998) presented a dynamic planning model for the goods with Weibull deterioration rate. By solving time model, the optimal replenishment in finite planning horizon is obtained as the current value of the total cost of this inventory system is minimized. This model considers change allowed in replenishment interval and service echelons between the ordering cycles and this makes better solution compared to the models in which the order intervals or service echelons are constant.

Bhunia and Maity (1998) developed inventory control model by assuming that replenishment rate is finite, demand dependent and inventory is available. In this model, deterioration rate and demand rate were linear-increasing functions of time. Balkhi (1999) presented an inventory control model for integrated manufacturing system and revised solution optimality for the proposed model. He assumed that production rate, demand and deterioration for the final goods and deterioration rate for raw materials were time-dependent. Williams and Patuwo (1999) extracted the required equations to determine the optimal revenue in single-period, continual review inventory control model for the items with two-period life. In this model, lead time was positive and lost sale policy was considered and the optimal order amount was obtained.

Papachristos and Skouri (2000) presented an inventory control model in finite planning horizon where deterioration rate was assumed constant, demand time was time dependent, and allowable shortage was as partial backlogging. The backlogging rate was varied over time and was increased exponentially as the expectation time for the next replenishment was decreased. Chung et al. (2000) presented the required conditions for the uniqueness of the optimal profit solution per unit in the study done by Padmanabhan and Vrat (1990) for total backlogging and no backlogging. Then, it was explained that to solve the optimal solution of profit function per unit in no-backlogging and total backlogging, it is better to use Newton-Raphson method. Giri et al. (2000) presented an innovative procedure for an inventory control model of the deteriorating items to find the optimal lot size. In the study, the demand rate was time dependent and was considered as both linear and exponential. In the previous similar studies, the shortage in all cycles except the final cycle was allowed while in this model, the shortage was allowed for all cycles and was considered as total backlogging.

Teng et al. (2002) presented optimal replenishment policy for deteriorating items. In this model, the demand rate was time dependent and shortage was allowed as partial backlogging and deterioration rate was constant. They completed the shortage of the model presented by Papachristos and Skouri (2000) by adding not only the lost sale but also the varied purchasing cost. Wang (2002) completed the model of Giri et al. (2000) with suitable definition of partial time-dependent backlogging rate and introduction of the lost sale opportunity cost. Giri et al. (2000) did not consider opportunity cost or lost sale. The study aimed to have logical discussion on inventory control of the deteriorating items with time-dependent demand and allowed shortage in finite planning horizon. Wu (2002) presented economic order quantity (EOQ) with time dependent demand (Weibull distribution). In this model, the shortage was allowed as partial backlogging and backlogging rate was dependent upon waiting time for the next replenishment.

Giri and Goyal (2003) considered an inventory-production model where demand, production and deterioration rates were time dependent. Shortage in each period was allowed as partial backlogging. They explained two approaches of Balkhi and Benkherouf (1996) and Goyal (1985) model to determine the economical operational policies. Teng and Yang (2004) presented economic order quantity where the shortage was allowed as partial backlogging. They evaluated economic order quantity model in the study in which not only the demand was time-dependent but also the cost per unit was varied over time. Sana et al. (2004) considered an inventory-production model for deteriorating items in finite planning horizon. In this model, the demand rate was time-dependent, production rate was finite and constant and shortage was allowed as total backlogging. The problem was solved by Box

Complex algorithm and finally the optimal numbers of production cycles minimizing the total cost of the system were obtained.

Chern et al. (2005) considered the models (4 models with different assumptions) reflecting that the longer the waiting time, the lower the backlogging rate. In a finite planning horizon, 4 different inventory control models were considered and then maximum profit was considered as target function to have a good comparison among 4 cases under different conditions. The first model started with an immediate replenishment and finished with zero inventories (Chaudhuri & Goswami, 1992). The second model was started with an immediate replenishment and was finished with shortage (Hariga, 1994). The third model was started with shortage and finished with zero inventories (Goyal et al., 1992). The fourth model was started with shortage and finished with shortage (Teng et al., 1997). Yang (2005) presented a comparison between the different inventory control models for deteriorating items based on maximum profit and in these models, the shortage was allowed as partial backlogging. He applied profit maximum to find the optimal replenishment policy.

Moon et al. (2005) developed inventory control model for revised deteriorating items with time-dependent demand in a finite planning horizon by considering the inflation effect and time value of money. They assumed that the demand rate was time-dependent and then, optimal replenishment policy was determined. The present study attempted to present a similar definition of two opposite characteristics (modification and deteriorating) in an inventory control model. Modified items were the ones their values were increased over time while the quality or quantity of deteriorating items was eliminated over time. Ouyang et al. (2005) proposed inventory control model for deteriorating items with exponential decreasing demand in which the shortage was allowed as partial backlogging and backlogging rate was dependent upon waiting time for the next replenishment. The aim was to minimize the total cost by optimizing the shortage and cycle length at the same time.

Chaudhuri and Ghosh (2005) presented economic order quantity model in finite planning horizon. In this model, deteriorating rate was time-dependent, backlogging rate was dependent upon waiting time for the next replenishment, and replenishment cycle was varied with infinite replenishment rate. They tried to determine the optimal replenishment cycle. Dye et al. (2006) completed the model presented by Chu et al. (2004) and Padmanabhan and Vrat (1990) by considering purchasing cost and lost sale cost and varied purchasing cost. It can be said that Chu et al. (2004) presented the required conditions for the uniqueness of the optimal solution of Padmanabhan and Vrat (1990) study.

Chern et al. (2008) developed inventory control model with the shortage and inflation assumption. In this model, it was assumed to consider the cycle's length equal and the length of shortage interval as constant. Then, by assuming shortage as partial backlogging, the deterioration rate was inventory dependent and time-price dependent demand, the optimal replenishment time was determined. Singh et al. (2009) developed an inventory control model for deteriorating items with two separate warehouses, one owned with finite capacity and the other rented with infinite capacity under inflation and time value of money. The deterioration rate in both warehouses was different while it was time dependent. Shortage as total backlogging was allowed and holding cost in both warehouses was different. Lee and Hsu (2009) developed two-warehouse inventory control for deteriorating items with time-dependent demand. Compared with the previous articles, in this model, the demand rate was time dependent. The replenishment rate and planning horizon were finite. Singth et al. (2009) presented inventory control model in which the shortage was allowed as partial backlogging and backlogging rate was consistent with the waiting time for the next replenishment. It was assumed the deterioration rate is time dependent with the concept of life time of the items. In other words, the deterioration of the items is considered after the end of their time.

Skouri et al. (2011) developed inventory control model with time-dependent demand under permissible delay in payment. In this model, the shortage as partial backlogging was allowed and backlogging rate depends upon the waiting time for the next replenishment.

1.3 Inventory-dependent demand

Inventory dependent demand is a common phenomenon in supermarkets. As more goods attract many customers and a retailer can display his goods for more demands. Thus, the space dedicated for each good and investment on demand being achieved as the result of increase of the inventory echelon is created. This condition is complicated when a creature is decayed naturally. This complication affected most of the researchers of the market and involved them to the analysis of the deteriorating inventory control models with inventory -dependent demand rate. The inventory models for deteriorating gods with inventory dependent demand rate were studied widely in the past.

Datta and Pal (1990) considered the inventory control model with finite planning horizon, no shortage with inventory-dependent demand rate. In this model, demand rate was decreased until the inventory echelon is reached definite echelon and it was constant for the residual cycles. In this study, the optimal order quantity was obtained. Hariga (1993) presented inventory control model for deteriorating items to find the optimal replenishment timing. He put away in this model the constant demand rate being considered in most of the inventory models and regarded demand rate as varied with inventory echelon. In this model, replenishment rate is infinite, shortage is not allowed and planning horizon is finite.

Padmanabhan and Vrat (1995) presented inventory control model for deteriorating items with inventory dependent demand rate in which the profit function for without backlogging and total backlogging was achieved. They assumed that demand rate is a function of current inventory rate and deterioration rate is constant. Giri et al. (1996) investigated the model presented by Datta and Pal (1990) for deteriorating items. Giri and Chaudhuri (1998) developed Giri et al. (1996) model by assuming non-linear holding cost. Roy and Maiti (1998) developed inventory control model for deteriorating items with inventory-dependent demand rate in a fuzzy environment. Mandal and Maiti (1999) raised inventory control model for deteriorating items with varied replenishment rate and inventory-dependent demand rate. Items made of glass, ceramics break/get damaged during the storage due to the accumulated stress of heaped stock. For the first time, an inventory model of such a damageable item was developed with variable replenishment when both demand and damage rates are stock-dependent.

Chung et al. (2000) considered the problem presented by Padmanabhan and Vrat (1995) and obtained the adequate conditions for the uniqueness of the optimal solution of profit per unit. Liao et al. (2000) presented inventory control model with demand dependent rate to the initial inventory under inflation condition. When the delay in payment is allowed and shortage is not allowed, this issue was investigated under different environmental conditions: 1- Credit period is smaller or equal to cycle time for payment clearing. 2- Credit period is bigger or equal to cycle period for payment clearing. Then, the total cost, optimal order quantity and optimal cycle time for both models were obtained. Benkherouf and Balkhi (2004) considered an inventory control model for deteriorating items with time-dependent demand rate and inventory on finite planning horizon. Then, a procedure to determine the optimal replenishment time was presented. The paper generalized the previous works Hariga (1993) and Hariga and Benkherouf (1994).

Teng and Chang (2005) presented the inventory control model for deteriorating items with sale price-dependent and inventory echelon-dependent demand. In the study, a maximum value was considered for the number of the displayed goods and a limited space to show the goods, if the inventory is displayed more, there will be negative effect on the buyer. Then, by considering constant deterioration rate, optimal price and time of production were obtained. Maiti (2005) developed inventory control model in which replenishment rate and production cost per varied unit (demand-dependent production cost), demand-dependent replenishment rate, demand rate and deterioration were dependent upon stock echelon. In the study by using Simulated Annealing based on maximizing the profit, the optimal inventory echelon was obtained. Dye and Ouyang (2005) developed the model presented by padmanabhan and Vrat by adding time-dependent backlogging rate to be more applicable. Chang et al. (2006) developed the model presented by Dye and Ouyang (2005).

Dye and Ouyang (2005) considered the economic order quantity model for deteriorating items under the inventory-dependent demand rate and time-dependent backlogging rate and obtained the optimal solution for the case where the warehousing of the goods was not beneficial. They did not consider optimal solution when the warehousing was profitable. In the present study, the model was raised in which the warehousing was profitable. Uthayakumar et al. (2006) developed economic order quantity under permissible delay in payment. In most of the inventory models, the manufacturer proposed fixed periods of credit for the retailer to clear the payment of the items. This study presented inventory control model for deteriorating items with time-dependent demand and inventory as the supplier considers the fixed period of trade credit was allowed.

Hou (2006) presented an inventory control model for deteriorating items where there was inventory-dependent demand rate, constant deterioration rate, and permission of shortage without partial backlogging and planning horizon is finite. He considered inflation in the development of this model and showed that total cost function was convex, which helped create a simple solution algorithm to determine the optimal order quantity and optimal interval between the orders. Jolai et al. (2006) presented the model of determining the economic lot size to obtain the optimized production amount under inflation for deteriorating items. In this model, demand rate was inventory dependent, deterioration rate had Weibull two-parameter distribution, and shortage was allowed as partial backlogging with constant rate. They considered the effect of time value of money and inflation on each cost.

Alfares (2007) considered an inventory control model with inventory dependent demand and variable holding cost where the holding cost was dependent upon shortage time. You and Hsieh (2007) presented an inventory control model of economic order quantity to find the strategy for the company selling the seasonal deteriorating items on finite planning horizon. The aim of the company was to maximize the profit by determining the optimal order quantity. In this model, the demand rate was dependent upon inventory and price echelon. Roy et al. (2009) developed inventory control model with inventory-dependent linear demand under inflation and time value of money. They assumed that the planning horizon was stochastic with exponential distribution and used genetic algorithm to solve the resulted model. Valliathal and Uthayakumar (2009) studied inventory control model in which partial backlogging was dependent on time and demand rate were dependent on inventory and time. To make this theory realistic, the demand rate was considered as mentioned. Then, optimal replenishment time was determined. Gayen and Pal (2009) developed a two-warehouse inventory control model to handle deteriorating items. The cost per unit of each item and replenishment cost were constant but holding cost dependent upon available stock. Planning horizon was finite, demand rate was dependent upon inventory and deterioration rate was constant. They tried to determine the optimal replenishment time. Arya et al. (2009) presented an optimal framework to find the optimal replenishment policy for deteriorating items with inventory dependent demand rate. Deterioration rate was time-dependent with three-parameter Weibull distribution. The shortage was allowed as partial backlogging and backlogging rate was dependent upon the waiting time to the next replenishment.

Yang et al. (2010) presented an inventory control model for deteriorating items under inflation. In this model, the demand rate was dependent upon inventory, shortage was allowed as partial backlogging and deterioration rate was constant. Min et al. (2010) presented the model of determining lot size for deteriorating items with inventory dependent demand and permissible delay in payment. In their study, the retailer buying the goods is enjoying the constant credit period from the supplier. The retailer also considered such a case for his customer. Khanlarzade et al. (2011) developed the model presented by Chang et al. (2006) by adding active package parameters and explained that using active packing instead of ordinary packing could have considerable effect on increasing profit. Chung et al. (2013) developed solution procedure presented by Min et al. (2010) and simplified it.

1.4. Price-dependent demand

There are many real-world cases where determining the lot size of retailer is influenced by demand and demand depends on price. Thus, determining price and lot size of the retailer are correlated. Wee (1995) in an inventory control model studied the replenishment and pricing policy for deteriorating items where demand rate was dependent upon price decreasing over time.

Kim et al. (1995) studied the determination of the pricing and lot size for deteriorating items with constant deterioration rate and Wee (1997) repeated the study for varied deterioration rate. Abad (1996) considered pricing issue and determining lot size as dynamic for deteriorating items where the shortage as partial backlogging was allowed. Wee (1999) developed inventory control model with quantity discount and partial backlogging. It was assumed that by the increase of the goods price, the demand rate was reduced. Despite the previous models based on minimizing the cost, the present study aimed to maximize the profit.

Abad (2001) presented an inventory control model where the lot size and optimal price for a retailer were obtained under the partial backlogging. It is assumed in this model that the demand was backlogged and the sale price was constant in inventory cycle. In this study, the backlogging phenomenon was modeled without considering backlogging cost and lost sale cost. Papachristos and Skouri (2003) developed the study done by Wee (1999) where he presented inventory control model with quantity discount conditions per unit of goods, partial backlogging with constant rate and price-dependent demand rate. In the extended model, demand rate was concave function of sale price and backlogging rate was dependent upon time. As waiting time for the next replenishment was reduced, the backlogged demand rate was increased. Abad (2003) presented determining the lot size and pricing for the deteriorating goods in which the deterioration rate was exponentially allowable and shortage was allowable as partial backlogging. In this study, it was assumed that the customers were less patient and backlogging is considered when it is economical.

Shinn and Hwang (2003) evaluated optimal pricing and lot sizing of the retailer at the same time. This model was solved under permissible delay conditions in payment while this delay depends upon the order size and amount. In addition, it was assumed that the credit period was dependent upon the order size of the retailer and demand rate was dependent upon sale price. Yang (2004) developed optimal pricing and ordering policy for deteriorating items with price-dependent demand. If the seller profit is more than the profit of the buyer when the buyer and seller are considered as integrated. Thus, a discount strategy is required to attract the attention of the buyer to accept the integration. Therefore, establishment in profit of two parties was considered as agreement factor in the present study. Pal et al. (2006) presented determination of lot size for deteriorating items with inventory dependent demand rate and sale price. The shortage as partial backlogging was allowed and backlogging rate was dependent upon the waiting time to achieve the next replenishment.

It is assumed that storage capacity of the goods was limited. Chang et al. (2006) established economic order quantity for a retailer with where the sale price and the number of replenishment and optimal replenishment timing for the retailer were determined by considering the shortage as partial backlogging. Teng et al. (2007) made a comparison between two models of determining the lot size and pricing for deteriorating items and permissible shortage as partial backlogging. In this paper, they not only developed Abad (2003) model by adding shortage cost and lost sale cost, but also he compared his method with the method of Goyal and Giri (2003). Dye et al. (2007) developed inventory control model for deteriorating items with price-dependent demand rate. In this model, deterioration rate was dependent upon time and shortage was allowed as partial backlogging. In addition, the backlogging rate had negative exponential function with the waiting time. Then, in this model, the optimal replenishment timing model was determined.

Rong et al. (2008) presented an optimal inventory control policy for deteriorating items where the lead-time was fuzzy, shortage was allowed as partial and total backlogging and price was demand dependent. The retailer had two warehouses, one was owned with finite capacity and the other was rented in a far place with more capacity. Holding cost in rented warehouse was reduced by far distance from the market. The study aimed to find the optimal decisions of the retailer to maximize the profit. Abad (2008) considered pricing and determined the lot size for deteriorating items. In this model, it was assumed that demand rate was declining function of price and profit was a non-decreasing function of it. By assuming the partial backlogging in an infinite planning horizon, three types of lost sale cost, shortage and holding were considered.

Tsao and Sheen (2008) studied dynamic pricing issues and replenishment for deteriorating items by considering the effect of trade credit of the manufacturer and advertising effect of the retailer. In this model, the demand was dependent upon time and price and planning horizon was finite. The study aimed to determine the optimal values of the retailer and replenishment price. Hsieh and Dye (2010) presented the inventory control model for deteriorating items under inflation on finite planning horizon. This model was solved by descending cash flow method. Demand rate was dependent upon time and price and shortage was as partial backlogging. The present model aimed to find the lot size and sale price and the number of optimal replenishment as the current net value of the total profit is maximized. Maihami and Nakhai (2012) developed an inventory control model and pricing for deteriorating items with allowable shortage as backlogging. The study aimed to determine the optimal values for sale price, timing the replenishment and determining order quantity with the aim of maximizing total profit.

2. Review of literature of deteriorating items in multi-echelon supply chain

The manufacturers acquire the raw materials from the suppliers and by some processes change the raw materials into goods sold to the distributer and then it is delivered to the retailer or the final customer. When goods took the above stages before it is delivered to the customer, a multi-echelon inventory system is created. Most of the inventory control models are extracted from the view of the buyer and optimal decisions of the buyer is not the most economical case for the seller. In the competitive markets, the buyer is entitled to make decision on the number of replenishments during ordering. The optimal number of the orders delivered to the buyer is not optimal for the seller. It is required to extract the common policy following win-win strategy (for all components of supply chain). If the number of deliveries is determined in accordance with the two parties' collaboration, then their integration cost is minimized.

The integrated policy compared with the independent decisions of the seller and buyer can lead to the reduction of costs (Wee & Yang, 2002). Clark and Scarf (1970) raised the integration of the seller-buyer for the first time. Yang and Wee (2000) considered economic order policy for deteriorating items for the seller and buyer as integrated approach. This study developed an economic ordering policy for deteriorating goods with constant production and demand rate. By considering both the buyer and seller, a mathematical model with one buyer and one seller and multiple deliveries per order was developed. They showed that integrated approach compared with the independent decision by the buyer decreased the costs, considerably. Huang (2002) presented a model to determine an optimal integrated policy of production-inventory with one buyer and one seller for deteriorating goods in JIT production environment. Yang and Wee (2002) presented a production-inventory policy for a seller and some buyers with constant production and demand rate. The cost of both buyer and seller was calculated separately and it was shown that integrated approach was better than their autonomy approach from each other in terms of cost.

Rau et al. (2003) developed multi-echelon inventory model for deteriorating items and total common optimal costs by integrating the buyer, producer and supplier. They showed that the results of integration method had the lowest cost compared to the independent decisions method. Sarmah et al. (2007) developed a coordination mechanism via credit choice as after both parties were satisfied with their profit share, they could divide the extra profit equally among each other. In the present study, two cases were defined:

1- The case in which no one achieves profit as individually;
2- The case in which achieving profit is possible individually. The aim of the study was to determine suitable mechanism for coordination;

Mahapatra et al. (2007) developed inventory-production model for deteriorating goods in a system with one seller and one buyer where the demand and production rates were constant. Lin and Lin (2007) developed an integrated inventory policy for deteriorating items for two-echelon model. This is similar to the study of Balkhi (1999) but the authors of this study assumed that the supplier besides supplying the materials is a manufacturer and the buyer is a retailer, buyer and whole-seller besides being the manufacturer. Wee et al. (2008) presented integrated ordering policy for a buyer and a seller for deteriorating items. They developed the analysis raised by Yang and Wee (2000) for integrated production-inventory model for a buyer and a seller with the assumption of stock echelon –dependent deterioration rate. Yang and Wee (2008) investigated integrated inventory model with a buyer and a seller in which the product demand rate was decreased exponentially. Some products as computer, house appliances with their new technology in the market are some examples of this classification.

Shah et al. (2008) developed integrated optimal inventory strategy for both the buyer and seller, if the goods deterioration rate was constant. It was shown that the integrated approach compared with the independent decisions of the buyer reduced the total cost of the chain, considerably. Although the chain cost was reduced by integration, the buyer cost was increased due to the big ordering. Thus, to encourage the buyer to continue the ordering of the great replenishment values, a permissible delay in payment was proposed from the seller to the buyer. Wee et al. (2008) considered a three-echelon inventory control for deteriorating items integrating the middle, upper and lower echelons of the supply chain. They assumed that deterioration was dependent upon the in hand inventory in total chain. In the present study, the inventory of multi-echelon supply chain inventory was solved for the first time by Simulated Annealing algorithm guaranteeing the achievement of the global optimality.

Nagaraju et al. (2010) investigated the inflation and price decreasing effect on optimal values of replenishment and total cost of supply chain. The paper studied the type of behavior of replenishment quantity and total cost of supply chain to the changes in inflation rate and decline of price in each of the supply chain elements. In the presented model, the current value of the total cost for each period was considered and then the order quantity, the optimal cycle period and the total cost were obtained. Wang et al. (2011) investigated the optimal inventory policy for the items where the deterioration rate was dependent upon time in a multi-echelon supply chain. This case is common in most of the industries as manufacturers of LCD and agricultural industry. They investigated three-echelon supply chain including the manufacturer, distributer and retailer.

Lee et al. (2012) developed the study of Rau et al. (2003) by dynamic models of the system. It can be said that Rau et al. in the studied three-echelon supply chain did not consider dynamic complex relations and only by optimization classic models, computed the number of replenishments and optimal lot size. Khanlarzade et al. (2012) presented inventory control policy for a two-echelon inventory control with one buyer and one purchaser. They developed the model presented by Lin and Lin (2007) by considering active packaging (instead of using ordinary packaging) for deteriorating items. Then, it was shown that by using this type of package, total cost of supply chain is more economical.

Sarkar (2013) considered three types of probable deterioration functions to find the system costs and the study aimed to find the cost minimum in three models and determined the optimal value of the number of replenishments. Das et al. (2013) presented an integrated model of retailer and supplier as a permissible delay in payment was proposed from the supplier to the retailer. In this model, the deterioration rate was constant and shortage was not allowed and the retailer providing cost linearly was dependent upon the credit period. In addition, the cost of this process for the supplier was a linear function of the amount purchased by the retailer. The study aimed to make decision about the credit period and the number of replenishment of retailer on finite time horizon as the integrated system reaches the optimal cost. Table 3 and Table 4 summarize the literature review of this paper.

Table 3
Classification of deteriorating inventory control for one-echelon supply chain

Reference	Demand Rate	Replenishment Rate	Planning Horizon	Deterioration Rate	Lead Time	partial backlogging	Complete backlogging	Inflation	Permissible in payment	solving Procedure	Findings
Ghare & Schrader,1963	F	I	I	TDE	zero					D	EOQ
Covert & Philip,1973	F	I	I	TDW2	zero					D	EOQ
Philip,1974	F	I	Fn	TDW3	zero					D	EOQ
Shah,1977	F	I	Fn	TDW3	zero	✓				D	EOQ
Sarma,1983	F	F	Fn	F	zero					D	EOQ
Hollier & Mak,1983	TD	F	Fn	F	F					D	EOQ
Goyal,1985	F	I	I	F	zero					D	EOQ
Sarma,1987	F	I	I	F	zero	✓				D	EOQ
Padmanabhan & Vrat,1990	SD	I	I	TD	F					D	EOQ
Datta & Pal, 1990	SD	I	I	F	zero					D	EOQ
Raafat et al., 1991	F	F	Fn	F	zero					D	Replenishment
Aggarwal & Bahari-kashani,1991	TD	F	Fn	F	zero					D	EOQ
Goswami & Chaudhuri,1991	TD	F	Fn	F	zero	✓				D	Replenishment
Pakkala & Achary,1992	F	F	Fn	F	zero	✓				D	Replenishment
Goswami& Chaudhuri,1992	F	F	Fn	TD	zero	✓				D	EOQ
Xu & Wang, 1992	TD	I	Fn	F	zero					D	EOQ
Wee, 1993	TD	I	I	F	F	✓				D	Replenishment
Hariga, 1993	TD	I	Fn	F	zero					D	Replenishment
Hariga & Benkherouf, 1994	TD	I	I	F	zero					D	EOQ
Wee, 1995	TD	F	Fn	F	zero	✓				D	Number of replenishment
Padmanabhan & Vrat, 1995	SD	I	I	F	zero		✓			D	Replenishment
Kim et al., 1995	PD	I	I	F	F					D	Pricing & inventory control policy
Abad, 1996	PD	I	I	F	zero	✓				D	Pricing & inventory control policy
Balkhi & Benkherouf, 1996	TD	F	Fn	F	F					D	Replenishment
Giri et al., 1996	SD	I	I	F	zero					D	EOQ
Benkherouf & Balkhi, 1997	TD	I	Fn	TD	zero					D	Replenishment
Wee, 1997	PD	F	Fn	TD	zero					D	Pricing & inventory control policy
Giri & Chaudhuri, 1998	SD	I	I	F	zero					D	EOQ
Bhunia & Maity, 1998	TD	I	I	TD	zero	✓				D	Replenishment
Roy & Maity, 1998	SD	F	Fn	F	zero					D	Replenishment
Chen, 1998	TD	I	Fn	TD	F		✓		✓	D	Replenishment
Wee, 1999	PD	I	Fn	TD	zero	✓				D	Replenishment
Balkhi, 1999	TD	I	I	TD	zero					D	Replenishment
Mandal & Maiti, 1999	SD	D	Fn	SD	zero					D	Inventory control policy
Williams & Patuwo, 1999	TD	F	Fn	F	F		✓			D	EOQ
Giri et al., 2000	TD	I	Fn	F	zero	✓				H	Inventory control policy
Papachristos & Skouri, 2000	TD	I	Fn	F	zero	✓				D	Replenishment
Chung et al., 2000	SD	F	Fn	TD	zero	✓				D	Replenishment
Liao et al., 2000	SD	I	I	F	zero			✓	✓	D	Replenishment-EOQ
Abad, 2001	PD	I	I	TD	zero	✓				D	Replenishment-Pricing policy
Wu, 2002	TD	I	Fn	TDW2	zero	✓				D	Replenishment-EOQ
Wang, 2002	TD	I	Fn	F	zero	✓				D	Replenishment
Teng et al., 2002	TD	I	Fn	F	F	✓				D	Replenishment
Yang & Wee, 2002	F	I	I	F	zero					D	Number of replenishment-Replenishment
Goyal & Giri, 2003	TD	I	I	TD	zero	✓				D	Replenishment
Shinn & Hwang, 2003	PD	I	I	F	F				✓	D	Pricing & inventory control policy
Papachristos & Skouri, 2003	PD	I	I	TDW2	zero	✓				D	Replenishment-EOQ
Abad, 2003	PD	I	I	TD	zero	✓				D	Replenishment

D: Deterministic, H: Heuristics, M: Metaheuristics, F: Fix, TD: Time dependent, DD: Demand dependent, DDE: Demand dependent (Exponential), SD: Stock dependent, TDW2: Time dependent weibull-2, TDW3: Time dependent weibull-3, PD: Price dependent, PSD: Price and Stock dependent, I: Infinite, Fn: Finite

Table 3
Classification of deteriorating inventory control for one-echelon supply chain (Cont.)

Reference	Demand Rate	Replenishment Rate	Planning Horizon	Deterioration Rate	Lead Time	partial backlogging	Complete backlogging	Inflation	Permissible in payment	solving Procedure	Findings
Yang, 2004	PD	I	Fn	F	zero	✓		✓		D	Replenishment
Teng & Yang, 2004	TD	F	Fn	F	zero	✓				D	Replenishment
Chang, 2004	F	I	Fn	F				✓	✓	D	Replenishment -EOQ
Yang, 2004	F	F	Fn	F	zero		✓	✓		D	Replenishment
Chu et al., 2004	F	I	Fn	F	zero	✓				D	EOQ
Sana et al., 2004	TD	F	Fn	F	zero		✓			H	Replenishment
Balkhi & Benkherouf, 2004	TD	I	Fn	F	F					D	Replenishment
Chern et al., 2005	TD	I	Fn	F	zero	✓				D	Replenishment
Yang, 2005	F	I	Fn	F	zero	✓				D	Replenishment
Dye & Ouyang, 2005	SD	I	Fn	F	zero	✓				D	Replenishment
Ouyang et al., 2005	TD	I	I	F	zero	✓				D	Replenishment
Maiti & Maiti, 2005	SD	D	Fn	SD	F					SA	Inventory control policy
Moon et al., 2005	TD	I	Fn	F	zero	✓		✓		D	Replenishment
Ghosh & Chaudhuri, 2005	TD	I	Fn	TD	zero	✓				D	Replenishment
Teng & Chang, 2005	PS	I	I	F	zero					D	EOQ
Hou, 2006	SD	I	Fn	F	zero		✓	✓		D	EOQ
Jolai et al., 2006	SD	I	Fn	TDW	zero	✓		✓		D	EOQ
Chang et al., 2006	PD	F	Fn	F	zero	✓				D	Replenishment-Pricing policy
Yang, 2006	F	F	Fn	F	zero	✓			✓	D	Replenishment
Lee, 2006	F	F	Fn	F	zero	✓				D	Replenishment
Dye et al., 2006	TD	I	Fn	F	zero	✓				D	Replenishment
Chang et al., 2006	SD	I	I	F	zero	✓				D	Replenishment
Uthayakumar & Parvathi, 2006	SD	I	Fn	SD	zero	✓			✓	D	Replenishment
Pal et al., 2006	SD	I	I	F	F	✓				D	Inventory control policy
Alfares, 2007	SD	I	I	SD	zero					D	EOQ
You & Hsieh, 2007	SD	F	Fn	F	zero					D	EOQ
Teng et al., 2007	PD	I	I	F		✓				D	Pricing & inventory control policy
Dye et al., 2007	PD	I	I	TD	zero	✓				D	Replenishment
Tsao & Sheen, 2008	PD	I	Fn	F	zero				✓	D	Replenishment-Pricing policy
Chern et al., 2008	TD	I	Fn	TD	zero	✓		✓	✓	D	Replenishment
Hsieh et al., 2008	F	I	I	F	zero		✓			D	Replenishment
Rong et al., 2008	PD	I	I	F	fuzzy	✓	✓			D	Inventory control policy
Niu & Xie, 2008	F	F	Fn	F	zero	✓				D	The comparison of LIFO model by cost
Abad, 2008	PD	I	I	TD	zero	✓				D	Replenishment
Roy et al., 2009	SD	I	Fn	F	zero			✓		GA	Inventory control policy
Lee & Hsu, 2009	TD	F	Fn	F	zero					VPC	Replenishment-Number of replenishment
Valliathal & Uthayakumar, 2009	SD	I	I	F	zero	✓				D	Replenishment
Gayen & Pal, 2009	SD	I	Fn	F	F					D	Inventory control policy
Ouyang et al., 2009	F	I	I	F	zero				✓	D	Replenishment
Singh & Singh, 2009	TD	I	Fn	TD	zero	✓				D	Replenishment
Singh & Kumar, 2009	TD	I	I	TDW2	zero		✓	✓		D	Replenishment
Arya et al., 2009	SD	I	Fn	TDW2	zero	✓				D	Replenishment
Yang et al., 2010	SD	I	Fn	F	zero	✓		✓		D	Replenishment
Min et al., 2010	SD	I	I	F	zero				✓	D	Replenishment
Hsieh & Dye, 2010	PD	I	Fn	F	zero	✓		✓		DCF	Pricing & inventory control policy
Khanlarzade et al., 2011	SD	I	I	F	zero	✓				D	Replenishment
Skouri et al., 2011	TD	I	I	F	zero	✓			✓	D	Replenishment-EOQ
Maihami & Nakhai, 2012	PD	F	Fn	F	zero	✓				D	Replenishment-Pricing policy
Liao et al., 2012	F	I	Fn	F	F				✓	D	EOQ
Mahata, 2012	F	F	I	F	zero					D	Replenishment
Chung & Cardenas-Barrron, 2013	SD	F	Fn	F	zero				✓	D	Simple procedure for replenishment

D: Deterministic, H: Heuristics, M: Metaheuristics, F: Fix, TD: Time dependent, DD: Demand dependent, DDE: Demand dependent (Exponential), SD: Stock dependent, TDW2: Time dependent weibull-2, TDW3: Time dependent weibull-3, PD: Price dependent, PSD: Price and Stock dependent, I: Infinite, Fn: Finite

Table 4
Classification of deteriorating inventory control for multi-echelon supply chain

Reference	demand rate	production rate	deteriorating rate	shortage	model	solving procedure	findings	other properties
Yang & Wee,2000	F	F	F		2E	D	EOQ	Zero lead time
Yang & Wee,2002	F	F	F		3E	D	Number of replenishment	
Huang,2002	F	F	F		2E	D	Integrated policy	JIT
Rau et al,2003	F	F	F		3E	D	Number of replenishment-EOQ	Zero lead time
Sarmah et al,2007	F	F	no		2E	D	Integrated policy	Credit-infinite replenishment rate
Mahapatra et al,2007	F	F	F	✓	2E	GA	Integrated policy	infinite replenishment rate for buyer-TD shortage rate
Lin & Lin,2007	F	F	F	✓	2E	D	Number of replenishment	Allowable shortage for buyer except for the last period
Yang et al,2008	F	F	F		2E	D	Integrated policy	TD demand rate
Shah et al,2008	F	F	F		2E	D	Integrated policy	infinite replenishment rate-zero lead time
Wee & Yu et al,2008	F	F	F	✓	3E	SA	Integrated policy	infinite replenishment rate-two warehouse
Wee & Chung et al,2008	F	F	SD		2E	D	EOQ	-
Nagaraju et al,2010	F	F	F		2E	D	Number of replenishment-EOQ	Inflation for buyer
Wang et al,2011	F	TD	TD		3E	D	Integrated policy	TD deterioration rate
Lee & Chung,2012	F	F	F		3E	DP	Number of replenishment-EOQ	Dynamic systems
Khanlarzade et al,2012	F	F	F	✓		GA	Replenishment	Using active packaging
Sarkar,2013	F	F	Not-Fed		2E	D	Number of replenishment-EOQ	-
Das et al,2013	F	F	F		2E	D	Number of replenishment	Permissible in payment for retailer-finite planning horizon

D: Deterministic, F: Fix, TD: Time dependent, DP: Dynamic programming, SD: Stock dependent, 2E: Two Echelon, 3E: Three Echelon

3. Conclusion

Deteriorating inventory models have so far been developed and analyzed extensively in terms of deterministic approaches or based on stochastic techniques. In deterministic approach, the parameters are assumed to be known; the objective is formulated under fixed constraints. In the real world inventory of deteriorating items, the information available is not always well defined or precise; it is rather vague, imprecise or insufficient. Consequently, mathematical modeling of such an inventory system with specific precision is not always straightforward. In this regard, the probability theory has performed a good job in making decisions under the conditions of risk and uncertainty. The imprecisions or uncertainties can also be interpreted efficiently, in some cases, through fuzzy set concepts.

In this study, we have investigated the studies on supply chain of the items from various perspectives based on demand. Finally, the summary of the papers has been presented in two tables for one-echelon and multi-echelon supply chain including the main information and assumptions of each paper. It should be noted that this study is continuing the Goyal and Giri (2001) and provided an up to date review of deteriorating inventory literature after their study.

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