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Inventory systems with deterioration: A literature review up to 2005

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Abstract
This paper presents up-to-date review of advances made in the field of Inventory control of perishable items. Contributions are highlighted by discussing main system characteristics including backordering, one or two warehouses and delay in payments.

Keywords: Inventory systems, organization, deterioration

Introduction
Inventory control is very developed field of Operations Research. “Monks (1987) defined inventory as idle resources that posses economic value”. It is very common to keep an inventory, for future sales or use in business e.g. blood banks, and retail firms etc. generally have a stock of goods on hand. Insufficient stock is a negative aspect because in this situation customers may prefer some other brands hence it will create a loss to the producers. In other words shortage or stock out cost can be defined as a penalty imposed for being unable to meet the internal and external shortage. Internal shortage incur when an order of a group or department within the organization is not filled. External shortages incur when demands of customer are not fulfilled. It can results into backorder cost, present profit loss and future profit loss. Internal shortages incur lost production and delay in a completion date. Further deterioration is very important natural phenomenon. The study in this direction began with the research of, Whitin (1957). This chapter presents the complete survey of published literature in mathematical modeling of deteriorating items and shortages.

Analysis
Ghare, and Schrader (1963), developed the classical no-shortage inventory model with a constant rate of decay Empirically it has been observed that failure and life expectancy of many items can be expressed in terms of Weibull distribution. This important observation has prompted researchers to represent the time to deterioration of a product by a Weibull distribution. Covert, and, Philip (1973) generalized Ghare, and Schraders(1963) model and obtain a perishable Economic Order Quantity model with variable decay rate by taking this rate as two parameter Weibull distribution Zangwill, (1966) discussed an inventory model with scheduling of production as multi -period with backlogging. Pierskalla and Roach (1972) developed optimal issuing policies for perishable inventory. Montgomery *et al.* (1972) formulated a mixture inventory model. Philip (1974) derived an EOQ model by taking deterioration rate as Weibull distribution. Misra (1975) proposed a perishable production inventory model with variable decay rate and rate of production was taken as finite. Hartely (1976) first discussed the basic two warehouse inventory model. It was generally considered that the inventory costs including holding cost and deterioration cost in the RW are usually higher than the same in the OW because of additional cost of maintenance, material handling etc. Shah and Jaiswal (1977) discussed an inventory model for decaying items with constant rate of deterioration. Aggarwal (1978) derived inventory ordering policies for deterio- rating items. Rosenberg (1979) formulated a lot-size inventory model with partial backlogging.

Dave (1986) discussed a perishable inventory model with time dependent demand and decay rate as constant while lead time was zero Model was discussed as continuous in units but allowed discrete opportunities for replenishment. Sarma, (1987) generalized his earlier model to a deterministic single item with two warehouse facilities model by taking the case of infinite replenishment rate and allowing shortages. Mak (1987) derived an inventory model in which shortages allowed and partially backlogged. Aggarwal and Jaggi (1989) discussed inventory ordering policies for deteriorating items. A perishable inventory model concerning a single item was proposed by Mandal, and Phaujdar, (1989) with a variable rate of deterioration. Shortage was allowed and the excess demand was backlogged. The rate of deterioration was taken first as constant and then variable. Pakkala and Achary (1992) derived a discrete time inventory model for deteriorating items with two warehouses. Bhunia and Maiti (1994) derived a single item deterministic model with two warehouse facilities item with linear trend in demand One warehouse owned by management and the other, the rented warehouse. The replenishment rate is finite and the model is constructed with shortages, which are fully backlogged Abad (1996) developed a generalized perishable inventory model with shortages allowed and partially backlogged. Benkherouf, (1997) presented a perishable inventory model with two storage facilities. The lost sales effects on composite lot sizing were analyzed by Sharma and Sadiwala (1997). Rao *et al.* (1997) has formulated a deterministic order level inventory model for deteriorating items with two levels of storage and power pattern demand. The model with deterministic demand is studied in detail and the behavior of various parameters of the system is discussed. One practical situation is that in many cases, extra storage space can be acquired in the form of rented warehouse (RW) if the own warehouse (OW) is insufficient to accommodate the received lot. The model aptly suits real life situations where there is high demand in the beginning of the period when single storage facility is insufficient to accommodate the order level. A perishable inventory model with partial backordering was formulated by Wee (1999). Demand was taken to be inversely proportional with the price of the product. Abad (2000-a) formulated a perishable inventory model in which shortage was allowed and partially backlogged The finite production perishable inventory model was developed by Abad (2000-b).In this model a mixture inventory was discussed by taking shortage as partial backlogged. Wu (2000) formulated a perishable inventory model with partially backlogged by taking demand as time dependent and decay rate as a Weibull distribution Wu (2001) formulated a perishable inventory model for decaying items with ramp type demand and decay rate as Weibull distribution Shortages were allowed and partially backlogged. Kar *et al.* (2001) discussed a non-probabilistic inventory model with storage capacity at two levels. In this model demand was taken as linear over fixed time horizon. The model is discussed by assuming that the rate of replenishment is infinite and the successive replenishment cycle lengths are in arithmetic progression. Shortages were allowed and fully backlogged. Manna, and Chaudhuri (2001) developed an economic order quantity model for deteriorating items with time-dependent deterioration rate, demand rate, unit production cost and shortages. Chung *et al.* (2001) [60, 61, 62] developed a perishable, time discount inventory model. Shanthi, and Kalpakam (2001) discussed a deteriorating inventory model with arbitrary processing time and modified (S-I,S) policy Chang and Dye (2001) [39, 40] formulated a perishable inventory model with permissible delay in payments. Shortages were allowed with partial backlogging. Abad, (2001) [2], developed an inventory model in which shortages were allowed and partial backordered. Chung, and Tsai, (2001) [61] formulated a perishable inventory model with time value of money Demand was taken as linear and shortages were allowed. Chung *et al.* (2001) [60, 61, 62] calculated the optimal cycle time for exponentially deteriorating products under the environment of trade credit financing. Balkhi (2001) [14] derive a perishable finite horizon production inventory model. Chang *et al.* (2001) [39, 40, 62] developed a perishable inventory with permissible delay in payments and demand was taken as linear. Chang. *et al.* (2002) [41] formulated a perishable finite time horizon inventory model by taking under consideration the time-value of money and permissible delay in payments. Chen, and, Lin (2002) [46], discussed an inventory model for decaying items with normally distributed decay. Chu, and, Chen (2002) [66, 46] developed replenish inventory model for decaying items. Skouri and Papachristos (2002a) discussed a perishable inventory model. In this model demand was taken as time dependent while replenishment cost was taken as linear. Shortages were allowed and partially backlogged Decay rate was time dependent. Skouri and Papachristos (2002b) formulated a non probabilistic inventory model for decaying items with shortages. Ouyang and Chang (2002) [41] discussed stochastic inventory model with variable lead time and partial backorders to capture the reality of uncertain backorders. Dye and Chang (2003) [75, 32] derive an inventory model for decaying with shortages In this model demand was taken as linear. Das and Maiti (2003) established a differential item inventory model. In this model shortages were allowed with variable demand. Khanra and Chaudhuri (2003) [95] developed a perishable inventory model with demand taken as quadratic function of time. Abad (2003) [3] formulated a finite production perishable inventory model Shortages were allowed and taken as partial backlogging with lost sale. Benkherouf *et al.* (2003) [19] discussed a diffusion inventory model for deteriorating items. A perishable inventory model for decaying items in which demand was dependent on time with partial backlogging was formulated by Teng *et al.* (2003) [32]. Giri *et al.* (2003) [95], developed an economic order quantity model with shortages Deterioration was assumed as Weibull distribution, and ramp-type demand. Papachristos, and Skouri, (2003) derived a perishable inventory model for decaying items. Shortages were allowed with partial backlogging. Goyal and Giri (2003) [95] formulated a perishable inventory model for decaying items In this model the demand and production both taken as a function of time. Arcelus *et al.* (2003) [5] formulated a perishable inventory model for decaying items. Kumar et. al. (2003) formulated a perishable production quantity inventory model In this model demand rate and decay rate was taken as fuzzy Ouyang *et al.* (2003) [32] formulated a perishable inventory model for decaying items. In this model demand was taken as stock-dependent along with the condition of inflation and time-value of money. Chang *et al.* (2003) [32] developed an inventory model for decaying items. Rau *et al.* (2003) established a perishable inventory model for decaying items under a multi-echelon supply chain environment. Zhou *et al.* (2004) developed a perishable inventory model. In this model shortages were allowed with time dependent backlogging and demand was taken as time dependent. C.Y. Dye (2004) [73] developed a perishable inventory model with shortages In this model deterioration was distributed as Weibull distribution. Rau *et al.* (2004) discussed a decaying item inventory model. Shortages because of supplier were allowed. Hwang (2004) formulated a probabilistic decaying inventory model. Balkhi and Benkherouf (2004) [15, 18] developed a perishable inventory model for decaying items In this model demand rate was taken as dependent on time and stock. Balkhi (2004) [15, 18] formulated a perishable inventory model with decaying and imperfect items with inflation and time value of money. Sana *et al.* (2004a) discussed a production inventory model for decaying items. In this model demand was taken as a function of time with shortages. Sana *et al.* (2004b) discussed a perishable inventory model for a decaying item with shortages. *et al.* (2004) derived a perishable inventory model for decaying items. Chakravarthy and Daniel (2004) [67] developed a Markovian inventory system with random shelf time and backorders. Chang (2004) formulated an inventory model with decaying items under inflation. Mukhopadhyay *et al.* (2005) discussed a perishable inventory model In this model deterioration was defined as a two parameter Weibull distribution. Demand was taken as price-dependent. A perishable finite horizon inventory model with deterioration as time dependent and demand as a linear function of time was discussed by Ghosh and Chaudhuri (2005). Dye, and Ouyang, (2005) [76] developed a deteriorating inventory model with shortages. In this model shortages were partially backlogged which was taken as dependent on time. Selling price was taken as stock dependent. Moon (2005) formulated a perishable inventory model for decaying items with inflationary condition. Chen and Chen (2005) [26] discussed a finite horizon production inventory model for decaying item. Ouyang *et al.* (2005) [76] formulated a perishable inventory model for decaying items. Demand in this model was decreasing exponentially, shortages were allowed and partially backlogged.

Conclusion

In this paper we have provided an up to date review of deteriorating inventory literature up to 2005. In this paper it is important to notice that most of the models assumed deterministic setting. Future research should emphasis on these complex and very poorly covered aspect of deteriorating inventory control.

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