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Technical Paper

A lot sizing model with partial downstream delayed payment, partial upstream advance payment, and partial backordering for deteriorating items

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ABSTRACT

In practice, installment of cost of lots is very common between manufacturers and distributors, and many distributors pay the purchasing cost in equal installments (i.e., an upstream partial prepayment). In a similar fashion, distributors allow retailers to pay the cost of purchased goods after such goods are received (i.e., a downstream partial delay payment). In this research we apply a model of economic order quantity (EOQ) in supply chains with partial downstream delayed payment and partial upstream advance payment for a deteriorating item under three conditions: 1) shortage is not allowed, 2) full back ordering is allowed, and 3) partial back ordering is allowed. We prove the convexity of the cost functions and derive closed form global optimal solutions for the decision variables of all models. Eventually, to demonstrate the theoretical results and managerial options, we perform some computational examples.

1. Introduction and literature review

Harris [1] first presented the EOQ model to help organizations make decisions concerning the optimal number of units they should demand from suppliers when receiving stock. Many scholars adopted the EOQ model, and each one advanced the classical EOQ model by relaxing assumptions to render the model closer to reality.

One of the hypotheses considered in the EOQ model is the storage of goods for unlimited periods of time in order to respond to future demands. However, in reality, many commodities (such as medications, food, blood, volatile fluids) are perishable and will deteriorate as they near their expiration date. Ghare and Schrader [2] developed a model for perishable goods in which they assumed a fixed decay rate and calculated a purchasing cost paid upon receipt of goods. Several years later, Skouri and Papachristos [3] presented an inventory control model in which ordering, product deterioration, maintenance, shortage, and capital costs are considered when deterioration rates are constant and shortage is backordered. An EOQ model with partial backordering for a deteriorating item was studied by Skouri et al. [4]. The demand was a quadratic function and deterioration rate was defined as a time-dependent Weibull function. This specific model was then extended by Hung [5], who used arbitrary demand and arbitrary deterioration rates instead of considering a ramp-type demand rate and a Weibull deterioration rate; he modeled the problem again and solved an extended version. Valliathal and Uthayakumar [6] developed a model with definite inventory control for a corruption product under time-dependent partial backordering shortage and an exponential rate of perishability. Sarkar et al. [7] worked on an inventory control model for perishable products during constant horizon planning with a time-dependent deterioration rate. Annual demand is a quadratic function of time, and shortage is partially backordered in their model. Soni and Shah [8] proposed a model of inventory control with a three-stage payment with delay. In fact, the delayed payment time involves one interest-free period and two periods with different interests charged in stocks. Chung and Huang [9] researched an inventory control model while delay is allowed in payments where shortage is permitted. Jiangtao et al. [10] proposed a model under a stock-dependent demand rate and a two-level trade credit proposed by both the manufacturer and the retailer under inventory capacity restrictions. Li et al. [11] did a comprehensive review of all inventory control models researched on deteriorated goods. Another literature

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review was performed by Bakker et al. [12] who focused on articles related to the topic of perishable goods from 2001 to 2011 concerned with assumptions such as backordering shortage, lost sales, single-product or multiple products, and delay payment policy.

In the traditional EOQ model, purchases are paid for when products are delivered. However, it is common for retailers to give buyers the opportunity to pay for their purchases a few days after delivery. It increases buyer satisfaction and enhances demand for their services; that approach is called delayed payment. Similarly, Goyal [13] modeled an inventory control problem with delayed payment; this model was subsequently adopted by other researchers. Huang [66] developed an inventory model in which delayed payment was allowed; the method excited clients to enhance the quantities of their order because the retailer permitted them to forego payment for some days after gaining the goods. Liao and Chen [15] proposed a model of EOQ with delayed payment; they also considered inflation for a deteriorating item. In this research, deficiency is not permitted while demand, deterioration, and inflation rates all are constant.

On the other hand, there are cases where the cost is paid in advance, rather than upon delivery or days later. The first relevant research on this topic was performed by Maiti et al. [16] who researched the effect of prepayment strategy on the total profit and assumed that the fixed ordering, holding, advertising, and purchasing expenditures are constant. Thereafter, Taleizadeh et al. [17] researched on partial prepayment's influence in a constrained joint replenishment inventory management model where shortage is not permitted. Taleizadeh and Pentico [18] proposed a model of EOQ by considering partial backordering and several equal-sized prepayments. Next, Taleizadeh [19] studied an inventory control model for perishable products where shortage is permitted and equal-sized prepayment is considered.

Many research studies are allocated to the subject of inventory control models of perishable goods. Goyal's [13] work had been extended by Aggarwal and Jaggi [20] by accommodating deterioration, and the shortage model included in Goyal's [13] work is further explored by Jamal et al. [21]. Sarker et al. [22] and Chang et al. [23] generalized the above models and added inflation rate and linear demand functions to them. Yang [24] developed a model for a deteriorating product in which shortage, inflation, and two levels of storage are simultaneously assumed. This work is extended by Zhou and Yang [25] and Min et al. [26] by assuming stock-dependent demand as well as transportation costs. Liao [27] studied a two-level warehouse and an economic production quantity model in which deterioration has been considered by exponential function. An optimal approach for dynamic pricing and inventory control of perishable goods in the delayed payment strategy is established by Tsao and Sheen [28]. Le et al. [29] and Diabat et al. [30] integrated inventory and routing problems for decaying items. Diabat et al. [31], Diabat and Richard [32], and Diabat et al. [33] used Lagrangian relaxation-based heuristics to solve different joint location inventory problems. Diabat and Theodorou [34] solved an uncapacitated joint location inventory problem using piecewise linearization based approximation, and Diabat [35] studied the capacitated version of the same problem. Beranek [36] developed a model with two levels of storage in which deterioration rates are different in two warehouses. Deterioration rates follow an exponential distribution and leakage is unallowable. Many researchers, like Diabat et al. [37], Diabat and Al-Salem [38], Diabat and Deskoores [39], Hiassat et al. [40], and Alshamsi and Diabat [41] have widely used Genetic Algorithms (GA) to solve difficult combinatorial optimization problems. Some researchers, such as Santibanez-Gonzalez and Diabat [42] and Alshamsi and Diabat [43], studied reverse logistics optimization problems. Others, including Diabat et al. [31], Diabat et al. [33], and Al-Salem et al. [44], studied closed loop integrated supply chain optimization problems. Lashgari et al. [45] proposed an EOQ model for a supply chain in three different states, consisting of various customers, a supplier, and a retailer. This model assumes, at the time of ordering, that the retailer pays a fraction of the buying cost. On the other hand, customers are permitted to pay a fraction of the cost in a predetermined time period.

In addition to the described literature review, Table 1 offers a compact illustration that provides a brief review of the topics mentioned in this paper.

The current paper is an extension of the work presented by Lashgari et al. [45] and Taleizadeh [19], in which the products start to deteriorate from the delivery moment and demand depends on the inventory level. On the other hand, Lashgari et al. [45] consider the demand rate fixed and did not account for the deterioration rate.

In this paper, the retailer receives a portion of the purchase price from customers when the goods are delivered. Then, the remainder is paid by the customers in a given period defined by the retailer. In fact, a partial delayed payment schedule is adopted here, while Taleizadeh [19] only considered prepayment and did not account for partially delayed payment.

Despite the fact that the current literature review does not include all works, it is generally accepted and verifiable through Table 1 that there is a gap in terms of developing an inventory control model with partial upstream prepayment, partial downstream delayed payment, and partial backordering for deteriorating items. This problem is investigated and modeled for the first time, as research thus far has not accounted for both advance and delayed payment policies together. Within these parameters, the developed model has enough flexibility to generate different models under full delayed payment, partial delayed payment, no delayed payment, full advance payment, partial advance payment, no advance payment, full backordering, partial backordering, and no shortage, while it even allows for combinations of these cases. Therefore, another contribution of the current work is that it allows for adopting any of these assumptions, which is not the case in other works found in the literature.

The remainder of this paper is presented as follows. The problem is defined and formulated in Section 2, and numerical examples are provided in Section 3 to clarify the problem. Subsequently, the results of the model's sensitivity analysis are presented in Section 4, and the managerial options are summarized. Finally, the conclusion and future research fields on the topic are presented in Section 5.

2. Problem definition and formulation

Assume a condition where a manufacturer demands that a distributor prepays a portion of the purchase price of an order, at a fixed time before the delivery of goods. The manufacturer may want to receive the prepayment in equal or multiple allotments. In a system of prepayment, the distributor's capital cost will be enhanced since he/she was subjected to an interest cost of α % of the buying cost of products which have not yet been received.

It is deemed that n is the number of prepayments the manufacturer requires. Secondly, to set practical assumptions, the distributor permits the customer to spend a portion of the purchasing expenditure by a delayed period of Z. In reality, both cases of partial prepayment from the distributor to the manufacturer (upstream fraction prepayment) and fraction delayed payment from the distributor to the retailer (downstream delayed payment) exist. The described problem may occur under three different scenarios, in which 1) backordering is impermissible, 2) total backordering is permitted, or 3) partial backordering is allowed. All scenarios are modeled in the current paper.