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A production–delivery lot sizing policy with stochastic delivery time and in consideration of transportation cost

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ABSTRACT

An extension of the integrated production–delivery lot sizing model under stochastic delivery time with transportation cost is investigated. The delivery time is assumed to be exponentially distributed. The presumption, the optimum delivery quantity determining the minimum of the transportation cost, has been widely adopted in transportation management models. Hence, we model the transportation cost as a function of delivery quantity. We consider comprehensive costs in the optimization problem. The expected total cost per unit of time with respect to the delivery quantity is proved to be a convex function under certain feasible conditions. As a result of computational studies, our proposed production–delivery decision model has shown notably adaptable when the delivery time is random. In particular, when the producer's and retailer's carrying costs are low, and/or mean time of delivery and transportation costs are high, our suggested policy saves more than 9% as opposed to the scheme recommended by prior researches, which manifests highly advanced gains.

1. Introduction

For evaluating prominent joint economic lot-sizing (JELS) inventory problems, Goyal [1] situated that suppliers provided items made from an infinite rate of production and shipped them on the basis of a lot-for-lot policy to meet the demand rate which is finite and constant. While Banerjee [2] loosened the irrational assumption of the infinite production rate, Goyal [3] presented a more reasonable JELS model, where each replenishment cycle consists of two-stage production–delivery operations with the supplier retaining certain inevitable products in stock, allowing the buyer to receive orders at a regular time interval. Implementing the widely used premise of fixed lot-size (FLS) shipment, Lu [4] addressed an integrated production–delivery policy. Moreover, without the assumption of FLS, Hill [5] generalized the coordinated model by making the geometric growth factor a decision variable. Hill [6] contributed an optimal solution for the integrated production–delivery model. Finally, variations of these control policies can be found in Ben-Daya et al. [7], and Glock [8].

Due to fruitfully practical issues posing in the JELS problem, numerous researches have broadened the basic JELS policy to accommodate a wide variety of inventory situations such as (1) stochastic lead time with constant demand, (2) probabilistic lead time and demand, and (3) significant cost caused by transportation. For harboring the first situation, Liao and Shyu [9] developed a single inventory model to discover the length of the lead time by minimizing the expected total relevant cost. Their model was then modified by Ben-Daya and Raouf [10] to simultaneously determine a pair of decision variables, e.g.,

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lead time and order quantities. In the case of consolidated inventory models, Pan and Yang [11] and Hoque and Goyal [12] found optimal values for the triple variables, lead time, order quantity, and the number of deliveries, with the minimum of the total integrated inventory cost.

To adapt the second situation, Ben-Daya and Hariga [13] formed a scheme to allow the lead time to become the function of the lot size and the transportation time. Furthermore, under the allowable shortage of the controllable lead time, the integration of the inventory model advised by Ouyang et al. [14] and Hsu and Huang [15] offered vital information of the reorder point policy for decision makers. Other similar schemes can be referred to Chang et al. [16], Song and Dinwoodie [17], Ho [18], Sajadieh et al. [19], and Sajadieh and Akbari Jokar [20]. Axsäter [21] characterized an excellent review of inventory control when the lead time changes.

For accommodating the last inventory situation, Burns et al. [22] adopted supplier's distribution strategies for customers and brought the sum of the transportation and inventory costs to a minimum. The vendor-managed inventory systems, coordinating stock replenishment and shipment scheduling, were constructed by Çetinkaya and Lee [23], who further proceeded their methodologies to model inventory and cargo capacity of the outbound distribution warehouse, where optimal outbound dispatch policies were further suggested [24]. Furthermore, the vendor–buyer coordinating systems were presented by Toptal et al. [25] to model inbound as well as outbound cargo capacity and their corresponding transportation costs. In addition, Swenseth and Godfrey [26] proved that the complexity arising from incorporating transportation cost into inventory replenishment policies does not affect the accuracy of decisions. The result resembled [27], which conveyed heuristic models for joint decisions in the variables of production, inventory, and transportation. According to this notion, several different schemes and applications were recommended lately. For example, Ertogral et al. [28] considered all-unit-discount structures of the transportation cost. Kang and Kim [29] implemented the methodologies into a two-way supply chain management. Hwang [30,31] changed a dynamic lot-sizing model to a vendor-controlled inventory warehouse under a minimum replenishment policy for the annexed production and inbound transportation. Lee and Fu [32] presented a joint production-and-shipment lot sizing problem for a delivery price-based production facility.

Although there is a substantial amount of studies addressing the joined production and delivery problems, most of them have failed to reflect the inevitable randomness of the delivery time as well as the inherited dynamic characterization of shipping cost, which to a certain extent constrain their adaptation in modern manufacturing and inventory systems. Ertogral et al. [28] first introduced production–shipment lot sizing in a joint single-vendor–single-buyer problem with a deterministic shipment time and in deliberation of transportation cost. They modeled the transportation cost to be an all-unit-discount cost function of the delivery quantity q, meaning the unit transportation cost is a multi-step function jumping down as the delivery quantity q on different ranges of the increased lot size. In other words, the transportation cost function is a discontinuity of the first kind at a certain lot size and linearly increases with a slope of the unit cost charged on that quantity interval. They further developed an overall optimal equal-sized-shipment policy by minimizing cost solutions among the individual optimal results found for all varied shipment numbers. However, there are two shortages that can be found in this research.

First, their policy development is somewhat tedious and ineffectual because of the necessity of cross-reference to realize the discontinuous delivery costs rated for varied quantity intervals, and it will be conceivably worse to reference the cost if there is a complex form of unit transportation cost, which has commonly seen in practice. Moreover, their model is subject to deterministic delivery time, which confines the applicability under currently diverse transport modes or various traffic conditions.

For fulfilling the void, this paper is meant to develop an expansion of the existential production–delivery lot sizing models in a two-stage supply chain. We first introduce stochastic delivery time, which is assumed to be exponentially distributed. The conclusion, the minimum of the delivery or transportation cost determined by the optimization of the delivery quantity, has been widely utilized in logistic or transportation management models. Thus, we then model the transportation cost as a function of delivery quantity. On the basis of actual transportation rate data collected from the professional shipping company, an empirical-fitted proportional-rate functional model (or tapering-rate functional model) is employed to characterize the transportation cost. Comprehensive costs, such as setup cost of the batch production, inventory carrying cost, buyer's handling cost, shortage cost, and transportation cost, are enclosed in the optimization problem. This cost model is different from other existing studies. The expected total cost per unit of time with respect to the number of deliveries or the delivery quantity under certain feasible conditions is proved to be a convex function in one replenishment cycle. It can be noted that this analytical policy development is swift and compelling and eliminates the ineffective procedure used in Ertogral et al. [28]. By comparative studies, our designated production and delivery model has illustrated distinguished applicability when the stochastic delivery time is considered. On average, our proposed policy carries out 6.49% of the savings in cost, which has demonstrated profound advantages in contrast to previous studies. Apparently, the added transportation cost factor in the integrated model can lead to the cost-saving decision with more delivery quantities so as to achieve less numbers of deliveries.

The rest of the paper is organized as follows. In Section 2, we first develop an extension of the production–delivery lot sizing model in the condition of stochastic delivery time and quantity-based transportation cost. The cost function and its expected cost per unit of time are derived for further analysis. Pertaining to the analytic results, a step-by-step procedure is described in Section 3 to efficiently find optimal values of the lot size for production and lot size for shipment along with their corresponding minimal costs. To gain thorough comprehension of our dedicated policy, numerical computations and parametric sensitivity analyses arranged on the basis of a full factorial design are conducted in Section 4. Conclusions are made in the last section.