



# Joint production and delivery lot sizing for a make-to-order producer–buyer supply chain with transportation cost



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## ABSTRACT

An integrated production/delivery quantity model in a make-to-order producer–buyer supply chain is analyzed in this paper. The coordinated policy is achieved by scheduling single setup at the producer with multi-delivery to the buyer. We develop two synchronized cost models that include setup cost at the producer, ordering cost at the buyer, inventory carrying cost, and transportation cost that is a fitted power function of delivery quantity, using actual shipping rate data. The mathematical analysis and computational study have demonstrated that significant cost savings can be realized by implementing the proposed approach into the network optimization process.

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## 1. Introduction

In this paper, we consider production and delivery lot sizing policies in a producer–buyer supply chain, where both production and demand rates are finite and constant, rather than instantaneous. More specifically, the production system receives orders from the buyer with custom-made products. Thus, it is infeasible to build up inventory beforehand or use reserved stock to meet the demand; and production must be launched immediately to fill the orders, i.e., a make-to-order production system. Our aim is to determine the integrated production and delivery quantities when delivery or transportation cost plays a key role in the supply chain.

This study is motivated by the following observations. Despite the popularity of many economic order/delivery quantity models in the vendor–buyer supply chain, there is a lack of formal approaches to address the lot sizing problems when production facility is involved in the process. Instead, a sequential decision process is most often observed in the producer–buyer supply chain management. First, an economic production quantity is determined in the production system (at the producer), with the objective to minimize the production–inventory cost to meet the demand. This is often addressed as the well-known economic production quantity models. Second, the optimal shipping quantity to the buyer is determined to minimize the delivery or logistic cost, which can be frequently found in the study of logistic or transportation models. Third, the integration of supply and delivery in these systems is often stressed and discussed in many researches, but there is a lack of a formal methodology to address the coordinated production–replenishment–delivery problem when transportation cost should be considered. The popularity of this decision process suggests that a joint decision model that integrates both production and delivery strategies with transportation cost will be useful.

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The well-known economic production quantity (EPQ) model forms a basis for most of the production lot sizing models, e.g., see [Hadley and Whitin \(1963\)](#) or [Silver et al. \(1998\)](#). Both production and demand rates are assumed finite and constant in EPQ studies. Each replenishment cycle starts when there is no on-hand inventory and a fixed quantity (batch) is launched in the production facility. The inventory is increased during the production stage and then decreased during the depletion stage until it falls to zero, i.e., continuous flow of delivery to meet the demand. The optimal EPQ is determined so that the sum of setup cost and inventory carrying cost is minimized. A major stream of these lot sizing policies has focused on the make-to-order production system. That is, there is no reserved stock to satisfy demands when an order is received. Instead, the production process starts immediately when an order is received, and inventory builds up with finite production rate for later shipment. An integrated cost model with optimal production/delivery quantities under unlimited production rate is presented in [Goyal \(1976\)](#). When the production rate is finite, [Banerjee \(1986\)](#) proposed a lot-for-lot production/delivery policy where the operating cost of the producer and buyer is considered, and the shipment can only be made once when the production has been completed. [Goyal \(1988\)](#) extended the above model to allow for multiple deliveries. Via a numerical example, he showed that the total cost could be reduced under single-setup multi-delivery strategy. Later, [Atkins et al. \(1992\)](#) considered the EPQ problem in a supply chain that includes the procurement of raw material and the production of finished goods. [Golhar and Sarker \(1992\)](#) studied a similar problem where ordering cost of raw material, setup cost for production, and inventory carrying cost are considered. When the delivery quantity is fixed or known, they show that the total cost function is convex, and an optimum production quantity exists for the extended EPQ problem. [Sarker and Parija \(1994\)](#) extended this study to determine both the order quantity of raw material and the economic production quantity. This model is further enhanced in [Sarker and Parija \(1996\)](#) by installing a periodic ordering (delivery) policy to avoid stock shortage. More recently, [Mungan et al. \(2010\)](#) considered a dynamic delivery policy in a similar production/delivery problem with finite planning horizon. These works have focused on either the optimal EPQ policy or the joint production/delivery policy without explicitly considering the transportation or delivery cost of goods.

Another stream of production lot sizing policies has focused on the make-to-stock production system, which is applicable for managing most of standard products. That is, reserved on-hand stock is immediately available to meet demand when an order is received. In this case, the production process may start immediately or later when customers place their orders. Clearly, it is infeasible to utilize such a production policy for custom-made products. A non-delayed production policy is proposed in [Lu \(1995\)](#) if the shipment lot size is known or fixed beforehand. [Hill \(1997, 1999\)](#) extended these studies to consider both the optimal production and shipment quantities. More recently, an optimization model of [Chan and Kingsman \(2007\)](#) considered both production and delivery schedule for a single-vendor multi-buyer supply chain, which improved the solution procedure given in [Lu \(1995\)](#). Note that the transportation cost has not been considered in these works. Toward this end, [Ertogral et al. \(2007\)](#) considered the optimal production/delivery strategy for a one-for-one (one supplier and one vendor) supply chain with transportation cost, extending [Lu's \(1995\)](#) non-delayed policy. Using a rate table to model the transportation cost, an enumerative search procedure is developed to determine the optimal policy where the cost to ship a given delivery quantity is determined by accessing the rate data in the constructed table. Variations of these policies can also be found in [Ben-Daya et al. \(2008\)](#), and [Glock \(2012\)](#).

A parallel stream of research works focuses on delivery or shipping strategies in the production/procurement system, without explicitly considering production or order quantity optimization. [Hoque and Goyal \(2000\)](#) considered the optimal delivery policy for capacitated shipment. [Çetinkaya and Lee \(2002\)](#) developed an optimal delivery policy when the delivery cost for an order is a fixed constant, i.e., the delivery cost is independent of the order quantity. [Swenseth and Godfrey \(2002\)](#) and [Abad and Aggarwal \(2005\)](#) considered the optimal order quantity problem where the buyer or the vendor is charged with the shipping cost. [Toptal et al. \(2003\)](#) studied a similar policy where both parties share transportation cost. More recently, [Hwang \(2009, 2010\)](#) addressed an EPQ model with delivery strategy, when demand of customer is dependent on production and delivery quantities, and shipping cost is a function of the shipping capacity. Production and inventory costs are assumed to be convex functions of the production quantity; and setup cost for production is excluded in the analysis. Under these restricted assumptions, the optimal production quantity can be determined by classical EPQ model. Note that the popular vendor/buyer studies in supply chain have focused on the EOQ (economic order quantity) models with infinite production rate and/or instantaneous delivery. These works can be found in, e.g., [Goyal and Gupta \(1989\)](#), [Viswanathan \(1998\)](#), [Benkherouf and Omar \(2010\)](#), among others, which are beyond the scope of this study. Based on production strategies, decision scopes, delivery frequency, and delivery cost, these studies are summarized in [Table 1](#).

The position of this work can be examined from the table presented above. This study focuses on the joint production and delivery policy with transportation cost for a make-to-order production facility in the supply chain. In particular, real shipping rate data from the shipper is used to fit a regression model, and a power function is selected to model the most popular transportation rate data, i.e., both proportional and tapering rates. Existing works such as [Hill \(1997, 1999\)](#), [Chan and Kingsman \(2007\)](#), and [Ben-Daya et al. \(2008\)](#) also considered the joint policy, while delivery or transportation cost is excluded in these models. The joint production–delivery quantity model with transportation cost in [Ertogral et al. \(2007\)](#) can only be applied for make-to-stock production (non-delayed policy, i.e., shipment can be made immediately when an order is received), while the proposed study focuses on make-to-order production. As a summary, the proposed study is developed over the bedrock of existing studies such as [Banerjee \(1986\)](#), [Goyal \(1988\)](#), and [Mungan et al. \(2010\)](#), which are applicable for make-to-order production in the supply chain. Note that delivery or transportation cost has not been incorporated in these studies.

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