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# A multiple-vendor single-buyer integrated inventory model with a variable number of vendors

Christoph H. Glock *

*Chair of Business Management and Industrial Management, University of Wuerzburg, Sanderring 2, 97070 Wuerzburg, Germany*

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ABSTRACT

Supply chain management is concerned with the coordination of material and information flows in multi-stage production systems. A closer look at the literature reveals that previous research on the coordination of multi-stage production systems has predominantly focused on the sales side of the supply chain, whereas problems that arise on the supply side have often been neglected. This article closes this gap by studying the coordination of a supplier network in an integrated inventory model. Specifically, we consider a buyer sourcing a product from heterogeneous suppliers and tackle both the supplier selection and lot size decision with the objective to minimise total system costs. First, we provide mathematical formulations for the problem under study, and then suggest a two-stage solution procedure to derive a solution. Numerical studies indicate that our solution procedure reduces the total number of supplier combinations that have to be tested for optimality, and that it may support initiatives which aim on increasing the efficiency of the supply chain as a heuristic planning tool.



## 1. Introduction

Inventory management has long been treated as an isolated function solely focused on individual entities, taking into account only those cost parameters that could be directly influenced by the planning company. However, companies have realised in the last years that the management of inventories across different echelons in a supply chain is critical to increase profits, as the coordination of inventory directly influences both costs and service. Since demand is almost always uncertain, inventory is required to assure that the demand of the customer can be satisfied without interruption. Increasing inventory levels is thus a popular method to improve customer service, although every unit of a product kept in stock results in inventory holding costs. In this context, some empirical studies suggest that the present value of inventory in the United States is close to $ 1.5 trillion (Neale, Tomlin, & Willems, 2003; US Census Bureau, 2008), which illustrates the importance of efficient inventory management.

Starting with Goyal (1976), a stream of research has emerged in recent years aiming at the coordination of inventory replenishment decisions among individual companies to benefit the entire supply chain, rather than a single company. The consequences of coordinating inventory replenishment decisions are regularly analysed in so-called integrated inventory models, which focus on the total costs of the system in question. So far, research was mainly concerned with single-vendor-single-buyer- and single-vendor-multiple-buyer-models, which does not adequately reflect the importance of the supply side in creating customer value and in improving the overall cost situation of the company. To close this gap, this paper focuses on a single buyer sourcing a single product from multiple suppliers. Specifically, the article analyses a situation where the buyer faces a pool of heterogeneous suppliers, and tackles the supplier selection and lot size decision with the objective to minimise total system costs. The model developed in this article may be used as a heuristic planning tool in practical situations where suppliers have been short-listed after a market study and where it has to be determined how many and which suppliers to select. One area where our model may be applied is the automotive industry, where it has been reported that buyers and vendors engage in strategic partnerships with the intention to create competitive advantages (see for example Dyer, 1996). It is obvious that if buyer and vendors decide to invest in specific assets, it is also necessary to achieve coordination at an operational level. In this case, using an integrated inventory model may help to coordinate material flows in the system. Specifically, the model developed in this article may help to determine the total costs of alternative sourcing agreements and thus provides assistance in finding a setting where a particular product can be produced and distributed at the least total cost. Incentive problems and the question of how to allocate the system profit are not considered in the model, but may be added without altering its core statements.

The remainder of the paper is organised as follows: in the next two sections, the article reviews related literature and outlines the

* Tel.: +49 931 31 82408; fax: +49 931 31 2405.
*E-mail address:* christoph.glock@uni-wuerzburg.de

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assumptions and definitions which are used in Sections 4 and 5. Accordingly, we develop a coordination mechanism and derive a solution for the supplier selection and integrated lot sizing problem. Section 5 presents a numerical example and Section 6 concludes the article.

## 2. Literature review

Integrated inventory models and the supplier selection decision have frequently been discussed in the literature. Glock (2010a), Ben-Daya, Darwish, and Ertogral (2008), and Goyal and Gupta (1989) provide literature reviews on integrated inventory models and Weber, Current, and Benton (1991) and Aissaoui, Haouari, and Hassini (2007) on the supplier selection problem. To position our model in the existing literature, we review both research streams in the following, but restrict our discussion to those works that are important for the development of our model.

### 2.1. Integrated inventory models

One of the first integrated inventory models is due to Goyal (1976), who analyses a system wherein a single vendor delivers a product in equal-sized shipments to a buyer. The vendor is assumed to provide an infinite replenishment rate and is thus modelled as a reseller of the product. To illustrate the advantages of coordinated replenishment decisions, the author derives a solution which is optimal from a systems perspective, and demonstrates that the loss one party incurs if the joint optimal solution is adopted is more than offset by the gain of the other party. Goyal's model is generalised by Banerjee (1986), who considers a finite production rate at the vendor. Thus, in contrast to Goyal (1976), a situation is analysed where the vendor acts as a manufacturer who produces to order for the buyer.

The basic integrated inventory models introduced by Goyal (1976) and Banerjee (1986) have frequently been extended in recent years. For example, Lu (1995), Agrawal and Raju (1996), and Hill (1997, 1999) assume that the vendor is able to deliver an integral number of batch shipments per production cycle to the buyer. Thus, the buyer may initiate consumption of a lot earlier, which reduces minimum inventory in the system and consequently leads to lower inventory carrying costs. Further extensions of the single-vendor-single-buyer case include stochastic demand (Ben-Daya & Hariga, 2004; Glock, 2009), product quality (Huang, 2002, 2004), product deterioration (Wee, Jong, & Jiang, 2007; Yang & Wee, 2002), variable selling prices (Hsu, Teng, Jou, & Wee, 2008) and learning effects (Nanda & Nam, 1992), among others.

The first integrated inventory model that considers multiple buyers is offered by Joglekar and Tharthare (1990), who study a vendor supplying a product to a group of identical buyers. The model is extended by Banerjee and Burton (1994), who consider heterogeneous buyers and use a delivery cycle at whose beginning the vendor supplies to all buyers to coordinate the system. With the help of a common delivery cycle, discrete and unequally spaced depletions from the vendor's inventory which might result in shortages at the vendor's side can be avoided. Further models that consider a single vendor and multiple buyers are proposed by Siajadi, Ibrahim, and Lochert (2006), Hoque (2008), and Bylka (1999), who study the impact of alternative shipment policies or dynamic model parameters on the total costs of the system.

One of the few integrated inventory models that consider more than one supplier is due to Kim and Goyal (2009), who study a system with a single buyer and multiple suppliers. The authors compare two different delivery structures – one model where all suppliers deliver their respective production lots simultaneously and one model where the suppliers deliver successively, i.e. supplier 1 delivers after the lot of supplier 2 has been used up etc. – and study the impact of different parameter values on the allocation of the order quantity on the suppliers and on the total cost of the system. Another model is proposed by Jaber and Goyal (2008), who consider a system with multiple suppliers, a single manufacturer, and multiple buyers. The authors assume an identical order cycle for the buyers and propose an algorithm to derive the optimal solution. A similar model is developed by Sarker and Diponegoro (2009), who consider a system with multiple suppliers, a single manufacturer, and multiple buyers as well, but who assume that successive production cycles do not necessarily need to be of the same length. The authors formulate the problem as a network and use a shortest-path method to derive the optimal solution.

### 2.2. Supplier selection

Concerning the supplier selection problem, quantitative models mainly focus on the questions of which vendors to select and how to allocate the order quantity to the suppliers. Since we consider a lot size problem in this article, we will only review supplier selection models that take the lot size decision and corresponding costs, such as ordering costs or inventory carrying charges, explicitly into account. For an overview of further quantitative models on supplier selection, the reader is referred to the review papers mentioned above.

A supplier selection model which explicitly considers stock-keeping is due to Benton (1991), who offers a heuristic programming procedure to select one vendor under conditions of multiple items, multiple suppliers, and quantity discounts. The procedure developed by the author in principle relies on calculating an optimal order policy for all items for each vendor and selecting the supplier that causes the lowest total costs at the buyer.

Another supplier selection model is proposed by Hong and Hayya (1992), who consider a JIT scenario wherein the buyer intends to reduce his lot size, either by splitting a larger order into multiple deliveries or by allocating the order quantity to multiple suppliers. The authors formulate a total cost function for the buyer, which is minimised under the constraint that both product quality and delivery costs have to meet a pre-determined level.

Ghodsypour and O'Brian (2001) develop a model for supplier selection under multiple sourcing and formulate a mixed-integer non-linear programming problem that explicitly considers material costs, ordering and inventory carrying costs, and constraints at the buyer and the vendors. The mixed-integer non-linear programming problem is then transformed into a pure non-linear programming problem by solving the model for a pre-defined set of suppliers. To reduce the number of sets which have to be tested for optimality, the authors exclude all sets which cannot guarantee an uninterrupted supply of materials to the buyer.

### 2.3. Synthesis of both research streams

To the best of our knowledge, previous work has not addressed the problem of selecting suppliers in the context of an integrated inventory model. This is insufficient inasmuch as various interdependencies exist between the supplier selection decision and the coordination of material flows in a production system, wherefore both decisions should not be studied independently. Considering the selection of suppliers in production planning gives the manufacturing system additional flexibility to react to changes in its environment, and may thus lead to planning results that help to increase the competitiveness of the whole supply chain. To close this gap, this article develops an integrated inventory model which considers supplier selection.