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Coordination of inventory and transportation managements in a two-level supply chain

Jae-Hun Kang, Yeong-Dae Kim *

Department of Industrial Engineering, Korea Advanced Institute of Science and Technology, Yusong-gu, Daejon 305-701, Republic of Korea

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ABSTRACT

In this study, we consider a two-level supply chain in which a supplier serves a group of retailers in a given geographic region and determines a replenishment plan for each retailer by using the information on demands of final customers and inventory levels of the retailers. Deliveries are carried out by homogeneous vehicles with a finite capacity, and each vehicle can visit multiple retailers in a single trip. The problem considered here is to determine the replenishment quantities and timing for the retailers as well as the amount of products delivered to the retailers by each vehicle for the objective of minimizing the sum of the fixed vehicle cost, retailer-dependent material handling cost, and inventory holding cost of the whole supply chain. We develop heuristic algorithms by simultaneously considering inventory and transportation decisions. A series of computational tests are performed for evaluation of the performance of the heuristic algorithms, and results show that the heuristic algorithms give good solutions in a reasonably short computation time.

1. Introduction

We consider a supply chain that consists of a single supplier, multiple regional distribution centers, and multiple retailers located in a given geographic region. In the supply chain, distances between the distribution centers are long enough, and each distribution center has its own group of retailers. Also, retailers of the same group are closely located, and a retailer belonging to the retailer group of a regional distribution center cannot receive products from any other distribution center. Because of such independency among the regional distribution centers, we can focus on a two-level supply chain consisting of a single regional distribution center and multiple retailers dedicated to the distribution center.

In the supply chain considered here, deliveries are carried out by homogeneous vehicles with a limited capacity. When a vehicle is dispatched from a regional distribution center to retailers, a fixed vehicle cost (such as the wage of the driver) is incurred. In addition, when a vehicle visits a retailer, there is a retailer-dependent material handling cost for the retailer. Material handling costs for different retailers may be different because the costs for unloading products from vehicles and moving them into storage places may differ for different retailers. Therefore, in order to decrease the transportation cost, one needs to reduce the number of vehicles to be dispatched as well as the frequency the vehicles visit retailers during the planning horizon. On the other hand, the inventory holding costs of the retailers can be increased as the vehicles visit the retailers less frequently and the replenishment quantities become larger. Hence, we need to consider a coordinated inventory and transportation planning problem to reduce the overall cost in the whole supply chain.

Most of recent research articles on supply chain management focus on the coordination and integration issues among members of a supply chain such as

* Corresponding author. Tel.: +82 42 350 3120; fax: +82 42 350 3110.
E-mail address: ydkim@kaist.ac.kr (Y.-D. Kim).

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manufacturers, distributors, wholesalers, and retailers. Arshinder et al. (2008) review research on the importance of supply chain coordination and present various coordination issues and mechanisms. Information sharing among members of a supply chain is considered a useful tool in supply chain management. Lee et al. (2000) and Wu and Cheng (2008) evaluate the benefits of information sharing in a supply chain, i.e., inventory reduction and cost savings, and Sahin and Robinson (2005) show that the overall cost in a supply chain can be reduced by the information sharing, with which the decisions for inventory replenishment and delivery planning can be coordinated. In addition, Ryu et al. (2009) present methods for information sharing in supply chains and analyze the effect on the performance of the supply chains in terms of throughput, inventory and service levels. Development of information and communication technology helps each member of a supply chain to share information with other members, and through such information sharing, one can get opportunities for improving the performance of a supply chain. The vendor-managed inventory (VMI) system is a good example for such opportunities.

In a VMI system, a supplier has the autonomy as well as the responsibility of managing inventory levels of retailers by contracts with the retailers. In other words, the supplier makes decisions on when and how much to deliver to each retailer using the information on demands from final customers and inventory levels of the retailers, which can be obtained through information technology such as electronic data interchange and radio frequency identification. That is, in VMI systems, retailers do not place orders to the supplier, but the supplier makes decisions on replenishment quantities and timing and controls inventory levels of the retailers. Therefore, in order to meet customers' demands with the minimum cost, the supplier needs to solve an integrated inventory and transportation problem in a way that decisions on inventory control and transportation planning are closely coordinated.

Fry et al. (2001), De Toni and Zamolo (2005), Hong and Park (2006), and Southard and Swenseth (2008) show the benefit of a VMI agreement in a supply chain by comparing it with traditional retailer-managed inventory systems. Also, Bertazzi et al. (2005) and Lee et al. (2008) propose decomposition approaches to integrate inventory and transportation planning problems with deterministic demands. On the other hand, for cases of stochastic demands, Çetinkaya and Lee (2000) and Axsäter (2001) present analytical results for the coordination problem between inventory and transportation decisions in VMI systems in which a supplier has the autonomy to hold orders issued by retailers for some time instead of fulfilling them immediately. However, in Çetinkaya and Lee (2000) and Axsäter (2001), only decisions on the inventory replenishment quantity and the delivery frequency are considered, but neither the inventory holding costs at the retailers nor the demands of final customers are included in the models. Meanwhile, Çetinkaya et al. (2008) provide a stochastic model and an approximation method for an integrated inventory replenishment and delivery problem in a supply chain that consists of a supplier and a retailer with compound Poisson demands. Also, Xu and Leung (2009) develop an inventory policy in a supply chain consisting of a vendor and a retailer in which there is a limit on the shelf space.

Inventory routing problems are closely related with VMI systems as well, since inventory and transportation decisions are considered simultaneously, that is, delivery quantities and vehicle routes are determined together. There are a number of research results on the inventory routing problem. For example, Viswanathan and Mathur (1997), Kim and Kim (1999, 2000), Bertazzi et al. (2002), Kim et al. (2002), and Campbell and Savelsbergh (2004) consider inventory routing problems with deterministic demands. On the other hand, Berman and Larson (2001) and Kleywegt et al. (2002, 2004) propose solution methods for stochastic inventory routing problems.

Transportation cost in a supply chain can be reduced by a shipment strategy, such as the one called the *shipment consolidation strategy*, in which multiple shipments of small quantities are combined into a single shipment of a large quantity to be dispatched by a single vehicle (Higginson and Bookbinder, 1994; Rim et al., 2001; Rim and Yoo, 2002). Using the renewal theory, Bookbinder and Higginson (2002) and Çetinkaya and Bookbinder (2003) obtain an optimal consolidation cycle length and an optimal cumulative order quantity, respectively. In addition, Çetinkaya and Lee (2002), Chen et al. (2005), and Çetinkaya et al. (2006) investigate models for joint replenishment and shipment consolidation decisions, while Higginson and Bookbinder (1995) present a method to determine when to deliver consolidated shipments by using a discrete-time Markovian decision process.

In this paper, we present several heuristic algorithms for a coordinated inventory and transportation planning problem, in which the original problem is decomposed into two sub-problems, and the solution for the original problem is obtained by combining the solutions for the sub-problems. This paper is organized as follows. In the next section, the problem considered in this study is described in detail with a mixed integer programming formulation, and Section 3 presents two-phase heuristic algorithms for the problem. For evaluation of the performance of the suggested algorithms, a series of computational experiments are performed and results are reported in Section 4. Section 5 concludes the paper with a short summary and recommendations for further research.

2. The coordinated inventory/transportation planning problem

The inventory and transportation planning problem considered in this study is the problem of determining the replenishment quantities and timing for retailers as well as the amount of products delivered to the retailers by each vehicle for the objective of minimizing the sum of inventory holding costs and transportation costs in a two-level supply chain with a single supplier and multiple