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Integrated inventory-transportation model by synchronizing delivery and production cycles

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This paper develops an integrated single-vendor multi-buyer inventory-transportation synchronized supply chain model. In this paper, the decisions of truck assignment and routing are also considered and as a result, a series of vehicle routing problems (VRP) are required to be solved. Due to the highly complicated objective function and the *NP*-hard VRP problems, the problem cannot be solved analytically. Hence, meta-heuristics are proposed. By means of the numerical examples and a case study, the meta-heuristics developed are shown to be very effective in solving such comprehensive supply chain models, and the results so obtained are promising.

1. Introduction

Supply chain management has become a critical issue in nowadays business environments. Numerous published studies have established the fact that co-ordination between buyers and vendor reduces the total system cost in a supply chain network. During the last three decades, various integrated replenishment co-ordinated models have been established. See Sarmah et al. (2006) and Khouja and Goyal (2008) for recent reviews of those models. Chan et al. (2003) developed a model to reduce buyers' costs by coordinating the replenishments of multiple items among a group of heterogeneous buyers. In response to the coordinated replenishments of buyers, a supplier faces a problem of how to schedule its deliveries so as to minimize its costs. Chan and Kingsman (2007) developed a synchronized cycles model that allows each buyer to choose its ordering cycle, while the length of the cycle should be kept as a factor of the vendor's production cycle. In order to further minimize the total cost, under the synchronized cycle the vendor may schedule the time of the delivery within an ordering cycle, and this delivery time may be different from buyer to buyer. It has been shown, by many numerical experiments, that the synchronized cycles model can significantly reduce the total system cost and make a significant reduction in vendor's cost compared to the independent policy. As an extension, Chan et al. (2010) developed a delayed payment method and Chan and Lee (2012) developed a quantity discount scheme to ensure that all of the buyers and vendor are not worse off. The two mechanisms used in the two extensions can be achieved without requiring any cost information from the buyers. The above mentioned synchronized cycles model considers the order processing and shipment cost on a number-of-order

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basis. This cost only takes into account those activities such as order processing, loading and unloading of each order. In real-life situations, goods are delivered by trucks and therefore this delivery cost has to be reflected in the model.

There are numerous researches on incorporating transportation costs in supply chain inventory models. Lippman (1971) and Aucamp (1982) considered transportation cost with a constant cost per truckload. Tersine et al. (1989) formulated an economic inventory-transportation model with freight discounts. Tersine and Barman (1991, 1994) combined incremental quantity discount and transportation discounts in a single inventory model. Arcelus and Rowcroft (1991) proposed incremental quantity discounts and three different freight structures. Carter and Ferrin (1996) demonstrated that a small improvement in transportation cost may lead to a significant improvement in the profit of the whole supply chain. Swenseth and Godfrey (2002) proposed a method to approximate the actual transportation cost with truckload freight rates. Abad and Aggarwal (2005) incorporated transportation cost in lot-size and pricing decision with downward sloping demand. Ben-Daya et al. (2008) presented a comprehensive summary on different shipment policies for joint economic lot sizing problems. Rieksts and Ventura (2008, 2010) considered a combination of two different modes of transportation, the less-than-truckload mode (LTL) and the full-truckload mode (FTL). In the field of supply chain co-ordination, researches such as Viau et al. (2009) and Kim and Goyal (2009) focused on the integration of inventory control and transportation decisions. Yildirmaz et al. (2009) considered joint pricing and lot-sizing decision with transportation. In the existing literature, co-ordination of single-vendor multiple-buyer model is still in its infancy stage and very little work is available considering vendor as a manufacturer producing the items to supply multiple heterogeneous buyers. In addition, there are increasing focuses on transportation/freight schedule in order to enhance supply chain co-ordination. The objective of this paper is to address these issues by proposing an inventory-transportation supply chain model. In this paper, the overall distance traveled and the overall truck cost are also considered in the objective function. The truck used for delivering is assumed to be capacitated and therefore, the number of trucks required is also a decision variable.

Vehicle routing problem (VRP) has been a topic of intense investigation for decades. It can be described as the problem of delivering goods from a depot to satisfy the demand of the customers scattered in different location. The main objectives are to minimize the traveling time, cost or distance. VRP is an NP-hard problem. As a result, most VRP are solved by heuristics so as to obtain a near-optimal solution. There exist numerous variants of VRP in the literature. Solomon (1987) considered a VRP with time windows constraints and presented four heuristics to get near optimal solutions. Laporte et al. (2000) carried out a survey on the heuristics for the vehicle routing problems. Nagy and Salhi (2005) proposed a number of heuristics for the vehicle routing problem with pickups and deliveries. Archetti et al. (2006) proposed several variants of tabu search algorithm to obtain solutions for the VRP that allowed split delivery. Ropke and Pisinger (2006a, 2006b) considered five different variants of the VRP with pickup and delivery models and solved using the ALNS approach. Bianchessi and Righini (2007) carried out a variable neighborhood search algorithm and a tabu search algorithm to solve the VRP that allowed simultaneous pick-up and delivery. Crevier et al. (2007) considered a multi-depot VRP with replenishment in intermediate depots and solved by an adaptative memory principles and tabu search. Nagy and Salhi (2007) conducted a survey of papers related to location-routing problem, taken into consideration of vehicle routings. Ombuki-Berman and Hanshar (2009) developed a GA to solve for the multi-depot VRP. Sbihi and Eglese (2010) discussed the use of combinatorial optimization in green supply chain, in the areas of reverse logistics, waste management and vehicle routing and scheduling. Laporte et al. (2010) and Ribeiro and Laporte (2012) adopted ALNS to solve a series of capacitated vehicle routing problems. Korsvik et al. (2011) developed a ship routing and scheduling model using a case study from a chemical shipping company. Azi et al. (2014) and Salazar-Aguilar et al. (2014) considered problems involving a series of vehicle routing problems which are required to be considered for each operation day. However, most of the literature on vehicle-routing problems only consider problems with a fix number of buyers and a fix number of intermediate stops for the whole planning horizon. In this paper, the number of buyers and the number of stops may vary along each time point over the whole production period. As a result, the existing VRP-heuristics may need to be applied at every time point and as the VRP problem is NP-hard, the time required to solve the whole supply chain model may be very time-consuming. Hence, simple heuristics are developed in this paper to solve the truck-assignment and route-sequence problems so as to speed up the solution procedure. The problem addressed here consists of finding the length of the vendor's production cycle, the cycles of replenishment of each buyer, the time of the delivery (within each replenishment cycle), the truck allocation of the delivery and the determination of the route sequences in order to minimize the sum of the set-up and ordering cost, the inventory holding cost, and the transportation cost. It is assumed that there is at most one delivery per replenishment period to each buyer, and initial inventories are considered to ensure no stockout.

The remaining of the paper is organized as follows: Section 2 states the assumptions and notations. Sections 3 and 4 provide a brief background on the independent policy model and the synchronized cycles model, respectively. Section 5 introduces the synchronized cycles inventory-transportation models. Section 6 describes the heuristics applied followed by the numerical examples and a case study, and discussions in Section 7. Finally, conclusions are drawn in Section 8.

2. Assumptions and notations

2.1. Assumptions

Throughout the paper, the following assumptions are imposed: