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Mixed integer and heuristics model for the inventory routing problem in fuel delivery

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ABSTRACT

This paper presents solution approaches for the multi-product multi-period Inventory Routing Problem (IRP) in fuel delivery. A homogeneous fleet of vehicles with compartments is used for fuel distribution from one depot to a set of petrol stations that have deterministic fuel consumption. The IRP consists of two mutually dependent sub-problems, those of inventory and routing, in a Vendor Management Inventory (VMI) environment in which suppliers determine the quantities and time periods of the deliveries. For solving the IRP, we propose a Mixed Integer Programming (MIP) model and a heuristic approach with and without fleet size costs, to observe the impact of these costs on the solutions that are obtained. The heuristics model is based on constructive heuristics with two Variable Neighborhood Descent (VND) search types: a local intra-period search and a large inter-period neighborhood search. Both of these approaches were tested on numerical examples for which the results, together with the performances of the proposed models, are presented. A combination of good computational time and good quality solutions suggests the use of the proposed heuristics on problems with realistic dimensions where the MIP model cannot find an optimal solution in a reasonable amount of time.

1. Introduction

Transportation and inventory costs are the two main components of the supply chain; these factors have the most significant impact on its performance. Although this fact is well known, modeling approaches for supply chain optimization usually consider inventory control and transportation independently, ignoring their interrelationships. However, the interrelationship between the inventory allocation and vehicle routing has recently motivated some authors to model these two activities simultaneously. This practical and challenging logistical problem is known as the integrated Inventory Routing Problem (IRP) (see Moin and Salhi, 2007). The idea of the IRP is to simultaneously solve the problems of choosing the optimal quantity of the goods and the time of delivery as well as the problem of optimal vehicle routing. Therefore, the objective of an IRP is finding a balance between the inventory and routing costs to minimize the total costs that are incurred by these two segments in the supply chain. The IRP assumes the application of the Vendor Management Inventory (VMI) concept, in which suppliers determine the order quantity and the time of delivery. There are many industries using the VMI concept that can benefit from the integrated approach of the IRP, including suppliers and supermarkets, store chains, clothing industries, and automotive industries (Campbell and Savelsbergh, 2004), as well as the petrochemical industry that is studied in this paper. Yu et al. (2012b) presented the most recent paper that describes the VMI concept with deteriorating raw materials and products. These authors developed a model to calculate the total inventory and the deteriorating costs. On the basis of those costs, the replenishment cycle and frequency were obtained.

Inspiration for our paper was found in the practical problem of secondary distribution, for which different fuel types are transported from one depot location to a set of petrol stations by a designated fleet of vehicles, and for which a single oil company has control over all of the managerial decisions over all of the resources. As a consequence, the full VMI concept can be applied, and therefore, the IRP model can be formulated. The IRP studied in this paper can be described as a multi-product multi-period deterministic IRP in fuel delivery. To solve this problem, we propose a Mixed Integer Programming (MIP) model and heuristics for two cases, with and without fleet size costs, to observe the impact of these costs on the solutions that are obtained. A heuristics model is based on constructive heuristics with two improvement techniques: a local intra-period search and a large inter-period neighborhood search. The results of the proposed heuristics are compared with solutions that are obtained from the

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MIP model on the set of small-size test examples, which are used later as benchmarks to estimate the heuristics solution performance. In addition, we have solved moderate-size problems by a heuristic model only, and we have compared the results that were obtained by the models with and without considering the fleet size.

This paper is concerned with the problem of solving IRPs in fuel delivery, which is a well-known research area; however, the proposed approaches offer some innovations in this field. First, the proposed MIP formulation differs from previous models in the formulation of the routing part of the model, which is considered to be the problem of making an optimal assignment of the petrol stations. Second, there are certain advantages to solving this class of problems with the proposed heuristics approach, which includes a relaxed MIP model for obtaining the initial solution, ideas for transferring deliveries over one or more time periods earlier, assigning petrol stations to the vehicle in the same route (represented through the utilities calculation), and a Variable Neighborhood Descent (VND) search.

This paper is organized in the following way. A literature review is presented in Section 2. The model formulation is given in Section 3. Section 4 presents a description of the proposed MIP formulation. A description of the proposed heuristic is given in Section 5, and computational results are presented in Section 6. Finally, Section 7 presents some concluding remarks and directions for further research.

2. Literature review

Different types and concepts of the IRP can be found in the literature. Webb and Larson (1995) observed two types of IRP: tactical (TIRP) and strategic (SIRP). TIRP models consider solving routing problems and their impact on inventory, whereas SIRP models address the determination of the fleet size (in cases where the fleet size cannot be determined in a short time period), considering all of the possible TIRP variants. The concept of one-to-many is commonly applied in an IRP in which deliveries are made from one depot to many locations, as is the case with Bertazzi et al. (1997) and Viswanathan and Mathur (1997). Both studies have one depot and many delivery locations, and deliveries can be realized only in defined frequencies (e.g., every two, three, or five days); the former addresses a single product system, whereas the latter addresses a multi-product system. Herer and Levy (1997) also focused on the IRP with a delivery from one location; they use temporal distances between the consumers that represent the cost of moving consumers to a common period. These authors observed a more detailed structure for the inventory costs, which comprise the holding costs, the fixed ordering costs and the shortage costs. Additionally, they considered vehicle outsourcing, which means that each route incurs a fixed cost when hiring a vehicle. The most recent paper in which the authors addressed the concept of many-to-one is published by Moin et al. (2011). They observed IRP in an assembly plant that is supplied by suppliers with multi-products in a multi-period finite horizon via a capacitated homogeneous fleet of vehicles. This problem was solved by a hybrid genetic algorithm in which each chromosome represents the delivery quantities for each supplier for each day of a planning horizon. A double sweep algorithm was used to evaluate the objective function for each chromosome.

Another classification of the IRP model can be made by the length of the planning horizon. Single-period models usually represent a basis for multi-period models, and they are often used in cases in which the demand at each location for a longer period of time is difficult to predict. The main problem with the single-period or short-term models is that they have a tendency to transfer as many deliveries as possible to the next planning period. Therefore, when the demand can be determined for a longer period, it is better to introduce a longer planning horizon, which provides a better solution. A long-term IRP with constant demand rates that are suitable for a cyclic planning approach is considered by Raa and Aghezzaf (2008). A cyclic approach means that customers are repeatedly replenished with the same routes for which the time between consecutive deliveries is constant.

Although the majority of papers from the IRP area consider road transport, there are some papers that observe maritime transportation. A large-scale ship routing and inventory model for liquefied natural gas was developed by Stalhane et al. (2012) to maximize the revenue from selling products on the market while using a heterogeneous fleet of ships; this model considered multiple products as well as inventory and berth capacity. The problem was solved with construction and improvement heuristics. Siswanto et al. (2011) focused on an IRP for maritime oil transport with ships that have undedicated compartments. Four sub-problems were outlined and solved: routing, ship selection, loading, and unloading of ships. This problem was solved by the use of MIP and heuristics. Multi-mode IRP in crude oil transportation is observed by Shen et al. (2011), who evaluated ships and pipelines as possible transportation modes. The objective of that study was to determine the transportation quantities for each mode that generates the minimum logistics costs. For the purpose of solving the problem, an MIP model and Lagrangian relaxation were developed.

In real life, an IRP usually contains stochastic components, especially with respect to the demand, consumption, or production. Nevertheless, in the available literature, the authors mainly observed deterministic models in which they use expected deterministic values for stochastic variables. Huang and Lin (2010) addressed a multi-item IRP with a limited fleet for which the demand is known at the moment of delivery. If the delivery quantity does not satisfy the demand, the unsatisfied quantity can be delivered in another tour that can incur overtime costs. If an unsatisfied quantity is not delivered, then stock-out costs are incurred. Ant colony optimization is used to optimize the tradeoff between stock-out costs and transportation costs. Bertrazzi et al. (2013) considered another typical stochastic IRP with a stock-out and without backlogging, in which an order-up-to level policy is applied. These authors developed a dynamic programming formulation of the problem that was used to design a hybrid rollout algorithm. Yu et al. (2012a) developed a model that observes a single item large-scale IRP with split deliveries, in which unsatisfied demands affect the customer service level and initial stochastic demands are transformed into deterministic demands. This paper presents an extension of Yu et al. (2008) in which they observed an IRP with exclusively deterministic demands. In both of these papers, the authors used a hybrid approach that differs from other papers in the sense that they initially solve only the intensity of the transport between nodes, and in the final step, they assign these arc transportation quantities to vehicles. In this way, the authors could solve larger-scale problems compared with models that incorporate actual routing variables. At the final phase, two local search techniques were applied.

Regardless of the type and characteristics of the IRP, the optimal solution in a real system case study is currently unreachable because of the problem complexity, which is mainly related to the routing segment. Because the routing problem is NP-hard (Bramel and Simchi-Levi, 1997), the IRP is also NP-hard because it includes the routing problem as one segment. A survey paper by Andersson et al. (2010) about the industrial aspects of combined inventory management and routing shows that only small IRP instances can be solved optimally and that almost all authors in the available literature introduce heuristics approaches. Thus, to