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Variable Neighborhood Search heuristic for the Inventory Routing Problem in fuel delivery

Dražen Popović [a,*], Milorad Vidović [a], Gordana Radivojević [b]

[a] University of Belgrade, Faculty of Transport and Traffic Engineering, Department of Logistics, Serbia
[b] University of Belgrade, Mihajlo Pupin Institute, Serbia

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ABSTRACT

In this paper we observe the extension of the vehicle routing problem (VRP) in fuel delivery that includes petrol stations inventory management and which can be classified as the Inventory Routing Problem (IRP) in fuel delivery. The objective of the IRP is to minimize the total cost of vehicle routing and inventory management. We developed a Variable Neighborhood Search (VNS) heuristic for solving a multi-product multi-period IRP in fuel delivery with multi-compartment homogeneous vehicles, and deterministic consumption that varies with each petrol station and each fuel type. The stochastic VNS heuristic is compared to a Mixed Integer Linear Programming (MILP) model and the deterministic "compartment transfer" (CT) heuristic. For three different scale problems, with different vehicle types, the developed VNS heuristic outperforms the deterministic CT heuristic. Also, for the smallest scale problem instances, the developed VNS was capable of obtaining the near optimal and optimal solutions (the MILP model was able to solve only the smallest scale problem instances).

1. Introduction

The transportation and inventories management have a decisive influence on the effectiveness of the distribution process. Although this fact is well known, modeling approaches to distribution process optimization usually consider inventory control and transportation independently, neglecting their mutual impact. However, the inter-relationship between the inventory allocation and vehicle routing has recently motivated some authors to model these two activities simultaneously by solving the Inventory Routing Problem (IRP). The objective of the IRP is to minimize the total cost of vehicle routing and inventory management. Regardless of the type and characteristics of the IRP an optimal solution for real life problems is so far unreachable due to the problem complexity which is related to simultaneous resolution of the routing problem and the allocation of deliveries over an observed planning horizon. The IRP assumes application of the VMI concept where suppliers determine an order quantity and the time of delivery. The VMI concept enables the supplier to better utilize the vehicles, but on the other hand it shifts the responsibility of inventory management from clients to the supplier. There are many industries, including the petrochemical industry where the VMI concept is applied, and that can draw benefit from the integrated approach to the IRP (Campbell & Savelsbergh, 2004). Recently, Bersani, Minciardi, and Sacile (2010) discussed the VMI concept in distribution of petrol products to service stations.

The vehicle routing problem (VRP) in fuel delivery is a well known research area (Avella, Boccia, & Sforza, 2004; Boctor, Renaud, & Cornillier, 2011; Brown, Ellis, Graves, & Ronen, 1987; Brown & Graves, 1981; Bruggen, Gruson, & Salomon, 1995; Cornillier, Boctor, Laporte, & Renaud, 2007, 2008; Fallahi, Prins, & Calvo, 2008; Mendoza, Castanier, Gueret, Medaglia, & Velasco, 2010; Uzar & Catay, 2012) where the main objective is to minimize the transportation costs incurred by the delivery of petroleum products to a set of clients, usually trough the use of multi-compartment vehicles. In this paper we observe the extension of the VRP in fuel delivery that includes petrol stations inventory management. Hence, this problem can be classified as the IRP in fuel delivery. More precisely, we observe secondary distribution of different fuel types from one depot location to a set of petrol stations by a designated fleet of multi-compartment vehicles, and for which a single oil company has control over all of the managerial decisions over all of the resources. This enables the VMI concept, and therefore, the application of the IRP.

Bell et al. (1983) were among the first authors to observe the IRP. They considered distribution of liquefied industrial gases and

* Corresponding author. Address: Vojvode Stepe 305, 11000 Belgrade, Serbia. Tel.: +381 011 30 91 273; fax: +381 011 30 96 704.

E-mail addresses: d.popovic@sf.bg.ac.rs (D. Popović), m.vidovic@sf.bg.ac.rs (M. Vidović), gordana.radivojevic@pupin.rs (G. Radivojević).

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used the linear programming model and Lagrangian relaxation to obtain the delivery plan for short-term planning horizon. Recently research efforts on the IRP topic have been intensified (Coehlo, Cordeau, & Laporte, 2012; Li, Chen, & Chu, 2010; Li, Chu, & Chen, 2011; Liu & Chen, 2011; Liu & Chung, 2009; Moin, Salhi, & Aziz, 2011; Shen, Chu, & Chen, 2011; Stalhane et al. 2011; Yu, Chen, & Chu, 2008; Yu, Chu, Chen, & Chu, 2010; Zachariadis, Tarantilis, & Kiranoudis, 2009) where in all of them different heuristic approaches were developed for the purpose of solving the larger scale problems. However, there seems to be a lack of papers that considered the IRP with multi-compartment vehicles, with the exception of papers from the marine transport, for instance Siswanto, Essam, and Sarker (2011). Oppen, Lokketangen, and Desrosiers (2010) solved a multi-compartment vehicle routing and inventory problem in the Livestock Collection Problem (LCP) and Popovic, Bjelic, and Radivojevic (2011) presented a simulation approach to the analysis of the applicability of a deterministic IRP solution to real life stochastic fuel consumption with fuel distribution by multi-compartment vehicles. There are several papers from the IRP research area that have considered Variable Neighborhood Search (VNS) heuristic (Hemmelmayr, Doerner, Hartl, & Savelsbergh, 2009; Hemmelmayr, Doerner, Hartl, & Savelsbergh, 2010; Liu & Chen, 2012; Liu & Lee, 2011; Zao, Chen, & Zang, 2008), which was originally developed by Mladenovic and Hansen (1997).

For an insight in methods and application of VNS we recommend the paper by Hansen, Mladenovic, and Perez (2010). For a detailed review on the IRP we refer the reader to the papers of Moin and Salhi (2007) and Andersson, Hoff, Christiansen, Hasle, and Lokketangen (2010). Also, case studies from the Netherlands (Bruggen et al. 1995) and Hong Kong (Ng, Leung, Lam, & Pan, 2008) can give a detailed insight into the practical issues of the IRP in fuel delivery.

In this paper we developed a Variable Neighborhood Search (VNS) heuristic for solving a multi-product multi-period IRP in fuel delivery with multi-compartment homogeneous vehicles, and deterministic consumption that varies over each petrol station and each fuel type. The local search and the shaking procedure (as two central procedures of the VNS) are based on three neighborhoods that are derived by the following changes of the delivery plan: relocation of individual compartments; relocation of all compartments for the observed station's fuel type; and relocation of all compartments for the observed station. The VNS heuristic is compared to a Mixed Integer Linear Programming (MILP) model and the deterministic "compartment transfer" (CT) heuristic; both models were developed by Vidovic, Popovic, and Ratkovic (2011).

This paper is organized as follows: The mathematical formulation is given in Section 2. Section 3 presents a description of the VNS heuristic. The computational results are presented in Section 4. Finally, conclusions are given in Section 5, together with directions for further research.

2. Mathematical formulation for the IRP in fuel delivery

The model assumptions are as follows:

- The delivery quantities of J fuel types for a given set of I petrol stations must be determined for each day within the planning horizon T;
- Fuel is transported by fleet of homogeneous multi-compartment vehicles of unlimited size. The total number of compartments is denoted as K. Only full compartments are delivered to petrol stations;
- Every petrol station i has a constant consumption q_{ij} of each fuel type j, while the intensity of the consumption varies over different stations and different fuel types;
- Petrol stations are equipped with underground tanks of known capacity Q_{ij} (one for each fuel type).
- Stations can be served only once a day (the observed time period);
- It is not allowed that inventory levels in petrol stations for any fuel type fall below their defined fuel consumption q_{ij};
- The total inventory costs are assumed to be dependent on the sum of the average stock levels in each day of the planning horizon, whereas transport costs depend on a vehicle's travel distance;
- One vehicle can visit up to three stations per route. This constraint is a consequence of the vehicle compartments structure and the total number of different fuel types (Cornillier et al., 2007; Cornillier et al., 2008).

The proposed mathematical formulation can be represented as the MILP model. The objective of the proposed MILP model is to minimize the sum of total inventory (IC) and routing costs (RC). Two types of binary decision variables are used for achieving this objective. The first type of binary decision variable x_{ijtk} defines the delivery quantities of all of the fuel types for all of the petrol stations over the entire planning horizon.

$$x_{ijtk} = \begin{cases} 1 & -\text{if petrol station } i \text{ is supplied with fuel type } j \\ & \text{in time period } t \text{ with } k \text{ compartments} \\ 0 & -\text{otherwise} \end{cases}$$

The second type of binary decision variable includes y_{pqwt}, y_{pqt}, and y_{pt} which are used to define the existence of routes with three, two, and one petrol stations, respectively, during each time period t. Only unique variables are used in the model. For example, variable y_{111t} is not used because the direct delivery for station "*1*" is represented with y_{1t}. Additionally, variable y_{123t} represents all routes visiting stations "*1*", "*2*", and "*3*" (length of this route is determined as the minimum length of all possible visiting orders). Travel costs c_r are calculated by multiplying minimum length and unit costs of the traveled distance for given route.

$$y_{pqwt} = \begin{cases} 1 & -\text{if petrol stations } p, q, \text{ and } w \text{ are supplied in} \\ & \text{the same route in time period } t \\ 0 & -\text{otherwise} \end{cases}$$

$$y_{pqt} = \begin{cases} 1 & -\text{if petrol stations } p \text{ and } q \text{ are supplied in} \\ & \text{the same route in time period } t \\ 0 & -\text{otherwise} \end{cases}$$

$$y_{pt} = \begin{cases} 1 & -\text{if petrol station } p \text{ is supplied} \\ & \text{with direct delivery in time period } t \\ 0 & -\text{otherwise} \end{cases}$$

Because of the mutual dependency between the delivery quantity variables and the routing variables, we have introduced an additional binary variable, H_{it}, that defines whether station i is being served in time period t. The purpose of this variable is to allow only those routes that visit petrol stations to be actually served in an observed time period t.

$$H_{it} = \begin{cases} 1 & -\text{if petrol station } i \text{ is supplied} \\ & \text{in time period } t \\ 0 & -\text{otherwise} \end{cases}$$