European Journal of Operational Research 236 (2014) 936–945

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

An inventory–routing problem with the objective of travel time minimization

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ARTICLE INFO

Article history:
Available online 30 July 2013

Keywords:
Logistics
Distribution
Inventory routing
Tabu search
Lagrangian relaxation

ABSTRACT

In this paper, we consider an inventory–routing problem (IRP) in a large petroleum and petrochemical enterprise group. Compared to many other IRPs, the problem in this paper includes some special aspects due to the operational constraints, such as hours-of-service regulations of the company and the industry. Also, in some cases, it is more important to avoid stock out for any station, rather than purely focusing on transportation cost minimization. The objective is to minimize the maximum of the route travel time, which is not addressed in the literature so far. We present a tabu search algorithm to tackle the problem, which builds in an efficient and effective procedure to improve the search quality in each iteration. Moreover, lower bounds of reasonable sized problems, which are intractable in the formulated mathematical model by existing optimization software, are obtained via Lagrangian relaxation technique. Computational results indicate that the lower bounds are tight and the tabu search is capable of providing near optimal, close-to-lower-bound solutions in a computational time effective manner.

1. Introduction

This paper studies a problem which is observed in a large petroleum and petrochemical enterprise group in China. The company relies on the product of gasoline for the majority of its sales and owns almost 40,000 gas stations spread all over China. Hundreds of oil depots are also maintained to replenish gasoline to the gas stations. Considering the number of depots and gas stations involved, the daily operations of gasoline distribution within this network is particularly complex. Generally, the problem can be formulated as an inventory–routing problem (IRP) with the following features:

1. The distribution of gasoline to gas stations is operated independently by each province. Therefore, the overall network is divided into sub-networks. For each province, there might be dozens of oil depots and thousands of gas stations. The network within each province is further divided into different districts according to the current company policy. Normally, each district has several oil depots and hundreds of gas stations. This is the basic operating unit for gasoline distribution within the company.
2. For each operating unit, the depots are regularly replenished to maintain a proper level of inventory to avoid stock outs. A central scheduling office determines the time and the amount to be delivered to each gas station, which has limited storage capacity with the daily demand represented by a consumption rate.
3. The product is distributed by a fleet of tank trucks, which belongs to a third party logistics (3PL) service provider. The 3PL previously belonged to the enterprise but now operates as an independent company to serve the function of transportation department of the enterprise.
4. When a truck arrives at a gas station, the gasoline is delivered at a delivery rate, i.e., the delivery cannot be instantaneous. An order up to level policy is applied to each gas station for inventory replenishment. Therefore, the maximum inventory level will be reached once the gas station is visited by a truck.
5. In order to improve the utilization of transportation resources, a minimum delivery quantity (Campbell & Savelsbergh, 2004a) is specified for each station. The inventory level in the gas station declines as the time elapses. Thus, this minimum delivery quantity specifies the earliest time that the station should be visited. Moreover, the central scheduling office should guarantee that each gas station will not run out of stock, which specifies the latest time that the station should be visited. These two constraints naturally pose a delivery time window for each gas station.

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http://dx.doi.org/10.1016/j.ejor.2013.07.034

Each day, a fleet of vehicles depart from the oil depot and visit the gas stations following the routes designated by the central scheduling office. At the end of the day, the fleet returns to the depot or a specified parking area. For IRPs, one objective is to minimize the total transportation cost, which has received much attention in the literature (Andersson, Hoff, Christiansen, Hasle, & Løkketangen, 2010). However, the consideration of time is also very important in this problem.

In this paper, we address the IRPs from the perspective of travel time minimization. The objective is to minimize the maximum route travel time among all vehicles due to two reasons. Firstly, each vehicle should deliver products to each gas station earlier than the latest allowable visiting time. If a gas station runs out of stock, it might not only be viewed as a business problem, but also a social problem by the local community. Therefore, it can be argued that in some cases, it is more important to avoid stocking outs, rather than purely focusing on transportation cost minimization. The similar priority rule is also applicable to the distribution of some scarce resource such as blood, and critical resources stored for use in emergencies. The delivery of these resources has a strong focus on speed of delivery. Secondly, in the petrol delivery network, all vehicles should return to the depot within the work shift so that the total driving hours are maintained at a safe level and workers' preference on getting off duty on time are catered for. Furthermore, the maximum amount of accumulated driving time is limited by the regulations of the company. Similar regulations can be observed in the US, Europe and many other countries (Goel, 2009, 2010; Goel & Kok, 2012). Hence, the hours-of-service of each vehicle should be leveraged so that each driver has similar working hours, while the hours-of-service regulation is complied with at the same time. Although there is a large body of research addressing IRPs with objective of transportation cost minimization (Coelho, Cordeau, & Laporte, 2012a; Ng, Leung, Lam, & Pan, 2008), there is almost no work considering time in the objective function.

The IRPs are difficult to solve (Campbell & Savelsbergh, 2004a). According to the published work, it is not easy to develop an exact algorithm for solving IRP with reasonable sizes (Archetti, Bertazzi, Laporte, & Speranza, 2007; Engineer, Furman, Nemhauser, Savelsbergh, & Song, 2012). In practice, the tank of the gas station in urban area is relatively small due to limited space within the city and safety requirements. Thus, the delivery quantity for the gas station in the urban area is relatively small compared to vehicle capacity. As a first step, we concentrate on a simplified version of the problem, assuming that the vehicle capacity is un-constrained, which is similar to the uncapacitated assumption in Valle, Martinez, da Cunha, and Mateus (2011). However, we are well aware that in practice, more often than not, vehicles have limited capacity. We believe that our contribution will serve as a basis for solving more realistic cases.

The remainder of this paper is organized as follows. We review the related literature in Section 2. The problem definition and the mathematical model are presented in Section 3 and a tabu search algorithm is proposed in Section 4. Section 5 employs the Lagrangian relaxation technique to obtain the lower bound for the problem. Section 6 presents computational results of the tabu search algorithm and the lower bounds, followed by the concluding Section 7.

2. Literature review

The IRPs are observed in various industries and have received the attention of the academic communities since 1980, such as supermarket chains (Gaur & Fisher, 2004), industrial gas industry (Bell et al., 1983; Campbell & Savelsbergh, 2004a, 2004b), vending machine chain (Huang & Lin, 2010), automobile industries (Alegre, Laguna, & Pacheco, 2007; Blumenfeld, Burns, Daganzo, Frick, & Hall, 1987; Ohlmann, Fry, & Thomas, 2008), meat industry (Oppen, Løkketangen, & Desrosiers, 2010), oil refineries (Persson & Göthe-Lundgren, 2005), frozen food distribution companies (Custódio & Oliveira, 2006), blood distribution (Hemmelmayr, Doerner, Hartl, & Savelsbergh, 2009) and maritime transportation industry (Al-Khayyal & Hwang, 2007; Dauzère-Pérès et al., 2007). Recently, Andersson et al. (2010) reviewed related literature published until 2008, where more than 100 papers or book chapters are classified accordingly to three types of planning horizon: instant time horizon, finite time horizon, and infinite planning horizon. IRPs are solved exactly by Archetti et al. (2007), Solyali and Süral (2011), Ceolho and Laporte (2012), Adulyasak, Cordeau, and Jans (2012), etc. Also, efficient heuristic algorithms are proposed by Bertazzi, Paletta, and Speranza (2002), Zhao, Wang, and Lai (2007), Campbell and Savelsbergh (2004), Archetti, Bertazzi, Paletta, and Speranza (2011), Coelho, Cordeau, and Laporte (2012b, 2012c), Michel and Vanderbeck (2012), Archetti, Bertazzi, Hertz, and Speranza (2012), etc. In this paper, we only review the work published after 2008, which is not covered by the survey of Andersson et al. (2010).

Considering the infinite planning horizon, Bertazzi (2008) determines shipping policies that minimize the sum of transportation cost and inventory cost at both the supplier and the retailers. The bounds of direct shipping over shipping with routing are developed subject to given conditions. Archibald, Black, and Glazebrook (2009) also considers direct deliveries. In the work of Li, Chen, and Chu (2010), the effectiveness of the direct shipping strategy is evaluated. Raa and Aghezzaf (2008, 2009) assume that the demand rate is constant.

The IRPs with finite planning periods are addressed by Bard and Nananukul (2009a, 2009b), Kang and Kim (2010), Toriello, Nemhauser, and Savelsbergh (2011), Solyali and Süral (2011), etc., where both exact and heuristic algorithms are presented.

There is a set of work which considers different network structures in the IRPs as well. For example, Ohlmann et al. (2008) address the inbound vehicle routing problem, with the constraints that limit the amount of inventory in the logistical network and present a two phase solution procedure. Moin, Salhi, and Aziz (2011) address the multi-product IRP in a many-to-one distribution network with finite planning periods. Zhao, Chen, and Zang (2008) and Li, Chu, and Chen (2011a) address an integrated IRP in a three-echelon logistics system, which consists of a supplier, a central warehouse and a group of retailers.

Variations of IRPs can be found in the literature by considering different constraints or assumptions. Abdelmaguid, Dessouky, and Ordóñez (2009) investigate the IRP with backlogging. Stochastic IRPs are considered by Chen and Lin (2009), Hvattum, Løkketangen, and Laporte (2009) and Hvattum and Løkketangen (2009). Grønhaug and Christiansen (2010) address a maritime IRP in the liquefied natural gas business. Huang and Lin (2010) study the multi-item IRPs with demand uncertainty. Benoist, Gardi, and Jeanjean (2011) present a randomized local search method for real-life IRP, which takes into account pickups, time windows, drivers' safety regulations, and orders. Li, Chu, and Chen (2011b) consider the IRPs with split deliveries while Liu and Lee (2011) address the IRP with time windows.

Recently, there emerged a set of work, which focuses on the petrol delivery problems. Various formulations and solution methodologies are proposed. Avella, Boccia, and Sforza (2004) study the case of a company that delivers different types of fuel to a set of fuel pumps. The objective is to minimize total travel cost. A branch-and-price algorithm is proposed. Cornillier, Boctor, Laporte, and Renaud (2008) investigate a multi-period petrol station replenishment problem with the objective to maximize the total profit which equals to the revenue minus the sum of routing costs