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An adaptive large neighborhood search algorithm for a selective and periodic inventory routing problem

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ABSTRACT

We study a selective and periodic inventory routing problem (SPIRP) and develop an Adaptive Large Neighborhood Search (ALNS) algorithm for its solution. The problem concerns a biodiesel production facility collecting used vegetable oil from sources, such as restaurants, catering companies and hotels that produce waste vegetable oil in considerable amounts. The facility reuses the collected waste oil as raw material to produce biodiesel. It has to meet certain raw material requirements either from daily collection, or from its inventory, or by purchasing virgin oil. SPIRP involves decisions about which of the present source nodes to include in the collection program, and which periodic (weekly) routing schedule to repeat over an infinite planning horizon. The objective is to minimize the total collection, inventory and purchasing costs while meeting the raw material requirements and operational constraints. A single-commodity flow-based mixed integer linear programming (MILP) model was proposed for this problem in an earlier study. The model was solved with 25 source nodes on a 7-day cyclic planning horizon. In order to tackle larger instances, we develop an ALNS algorithm that is based on a rich neighborhood structure with 11 distinct moves tailored to this problem. We demonstrate the performance of the ALNS, and compare it with the MILP model on test instances containing up to 100 source nodes.

1. Introduction

Recovery and reuse of waste and end-of-life products provide significant environmental and economic benefits. While collection of recoverable material from various sources can be costly for a processing facility, efficient management of the collection operations may determine the economic viability of the recovery operations. In this study, we consider a facility that collects and processes waste vegetable oil for reuse as raw material, and thus needs an effective periodic collection plan. The problem originates from a case study about a company in Istanbul that collects waste vegetable oil from different locations in the city to use the oil in biodiesel production (see Aksen, Kaya, Salman, & Akça (2012)). Biodiesel, which is a nontoxic and biodegradable alternative fuel, is a substitute for petroleum. While the cost of virgin oil used in the production of biodiesel constitutes 85% of the total production cost, Gonzalez, Encinar, and Rodriguez-Reinares (2005) and Predojević (2008) state that collecting and using waste vegetable oil costs almost half the price of using virgin vegetable oil.

The source nodes for the collection of waste vegetable oil include businesses that consume cooking oil in large volumes, such as restaurants, hotels, and catering companies. The biodiesel production facility makes an agreement with the selected source nodes, and specifies on which days of the week their accumulated waste oil will be collected. Waste oil accumulates with different rates at source nodes, and the uncollected amount is stored until the next visit of the collection vehicle. The facility has a predetermined daily production plan, and needs to procure vegetable oil as raw material input to follow the plan. This creates the daily input requirements. The facility can satisfy its vegetable oil need either by waste vegetable oil collection or by purchasing virgin oil. The latter has a much higher marginal cost, but also the former has a significant cost due to vehicle dispatching, driver wages, fuel consumption, etc. Daily vehicle routes should be determined to realize the collection at the minimum possible cost. Moreover, the amount of waste vegetable oil accumulating at the source nodes might be more than the capacity of the collection vehicle or the amount needed for production. In such cases visiting all source nodes is not necessary or not feasible. Hence, the facility manager is faced with the following threefold decision problem:

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1. Which of the source nodes to select for the collection program.
2. How many vehicles to use each day and which periodic (weekly) routing schedule to repeat over an infinite planning horizon so as to collect the waste oil accumulating at the selected source nodes.
3. How much virgin oil to purchase on each day in order to meet the daily input requirements for biodiesel production.

The objective is to minimize the total collection, inventory and purchasing costs while meeting the production requirements and operational constraints. This considerably hard routing and scheduling problem has been recently defined as the *S*elective and *P*eriodic *I*nventory *R*outing *P*roblem (SPIRP) by Aksen et al. (2012) in 2012. The authors introduced a commodity flow-based mixed integer linear programming (MILP) formulation, and solved it on a real-world case with 25 hospitals treated as waste oil accumulation nodes. In this paper, we propose an *A*daptive *L*arge *N*eighborhood *S*earch (ALNS) method to solve large size SPIRP instances in less than one hour. It includes a variety of move operators that are adapted to the characteristics of SPIRP. To the best of our knowledge, this is the first metaheuristic algorithm developed for SPIRP.

The rest of the paper is organized as follows. Section 2 reviews the existing literature on periodic, inventory, and selective vehicle routing problems. The definition of SPIRP and its MILP model are given in Section 3. In Section 4, we elaborate the proposed ALNS method. In Section 5, we test the ALNS method and compare its performance with that of the exact solution of the MILP model. Finally, Section 6 provides concluding remarks and discusses possible directions for future work.

2. Literature review

The economic and environmental impact of recycling and remanufacturing of end-of-life products has led to a number of studies in the OR literature (see e.g. Van Wassenhove, Beullens, & Van Oudheusde (2004), Bloemhof-Ruwaard, Fleischmann, Beullens, & Van Wassenhove (2001), Antunes, de Souza, & Teixeira (2004), Zobolas, Tarantilis, Ioannou, Repoussis, & Paraskevopoulos (2009), Benjamin & Beasley (2010)). Belien, De Boeck, and Van Ackere (2011) reviewed solid waste collection problem types with a particular focus on vehicle routing problems in the literature, and give a classification of the solution methods proposed for each problem type. The periodic vehicle routing problem (PVRP) (see Francis, Smilowitz, & Tzur (2008), Christofides & Beasley (1984) and Baldacci, Bartolini, Mingozzi, & Valletta (2011)) and the inventory routing problem (IRP) (see Dror & Ball (1987), Campbell, Clarke, Kleywegt, & Savelsbergh (1998)) are two of the most related research streams to our study. The first formal definition of PVRP was made by Russell and Igo (1979) in 1979 as the "Assignment Routing Problem". They introduced a MILP model for this problem. Christofides and Beasley (1984) defined PVRP as the generalization of vehicle routing problems over a planning horizon where each customer has a number of visit requirements over the horizon. In the literature, several variants of the PVRP have been analyzed and solved (see, among others, Cordeau, Gendreau, & Laporte (1997) for the PVRP with time windows, Hadjiconstantinou & Baldacci (1998) and Vidal, Crainic, Gendreau, Lahrichi, & Rei (2012) for the multi-depot PVRP, Angelelli & Speranza (2002) for the PVRP with intermediate facilities). Francis, Smilowitz, and Tzur (2006) extended the PVRP to make the visit frequency a decision of the problem and call it the PVRP with Service Choice (PVRP-SC). Gulczynski, Golden, and Wasil (2011) introduce practical real-world variants of the PVRP. They handle these variants with a hybrid heuristic which joins a mixed integer programming (MIP) based improvement heuristic with a modified record-to-record travel algorithm. PVRP literature admits that the problem is computationally hard. Research in this area has favored metaheuristics and mathematical programming based approaches, recognizing the need to adopt an integrated approach to the PVRP. We refer the reader to a literature review of the PVRP and its extensions which has been published in 2008 by Francis et al. (2008).

On the other hand, the IRP combines the periodic routing problem with inventory control such that customers have a daily usage rate of a product and the product must be supplied on a periodic basis before its stock depletes. In their review paper which presents the state of the art of the IRP as of 2006, Moin and Salhi (2007) explained that the inventory allocation and vehicle routing decisions are interrelated. This means that the marginal profit (revenue minus delivery cost) for each customer can be computed only if the routing cost information is available. Marginal profit information helps decide which customers to supply by how much (the inventory allocation decision). Then again, the delivery cost for each customer depends on the vehicle routes, which in turn requires information about customer selection. Hence, inventory and routing activities should be modeled simultaneously.

Heuristics have been traditionally the main tool applied in solving the IRP since the solution of moderately sized problems have been so far beyond the capability of exact methods. Earlier, Dror and Levy (1986) had adapted VRP heuristics to the solution of a weekly IRP. Anily and Federgruen (1990) had proposed the first clustering algorithm for the IRP. Clustering heuristics have been proposed more recently also by Campbell and Savelsbergh (2004). Bertazzi (2008) dealt with direct deliveries to simplify the problem. The first branch-and-cut algorithm for a single-vehicle IRP was proposed in Archetti, Bertazzi, Laporte, and Speranza (2007). Solyalı and Süral (2011) provided a stronger formulation for the problem in Archetti et al. (2007) by using shortest path networks to represent customer replenishments. Abdelmaguid, Dessouky, and Ordonez (2009) considered an IRP in which demand backlogging decisions are either unavoidable or more economical, and they have to be coordinated with other inventory holding and vehicle routing decisions over a specific planning horizon. The authors introduced constructive and improvement heuristics for solving this type of IRPs. Raa and Aghezzaf (2009) considered an IRP with deterministic constant demand rates where backlogging is prohibited. This leads to a long-term cyclic IRP involving limited storage capacities, driving time restrictions, and constant inventory replenishment intervals. The solution approach proposed for this particular IRP combines several heuristic procedures within a column generation framework. Yu, Chen, and Chu (2008) studied a multi-period IRP with split delivery, where the delivery of each customer in each period over a given planning horizon can be split and performed by multiple vehicles to reduce transportation costs. The authors worked on an approximate mathematical model of the problem whose solution only defines the quantity delivered to each customer, the quantity transported through each directed arc of the given network, and the number of times each directed arc is visited by a vehicle. This approximate model is solved using a Lagrangian relaxation method embedded in surrogate subgradient optimization procedure. Recently, Coelho and Laporte (2013) obtained the exact solution of multi-period IRPs with multiple products and multiple vehicles using a branch-and-cut algorithm.

At this point we would like to refer the interested reader to a very recent comprehensive review of the IRP literature composed by Coelho, Cordeau, and Laporte (2014). The review which covers the IRP literature from 1983 through 2013 categorizes IRPs with respect to their structural variants and with respect to the certainty regarding customer demand information. The presented classification scheme of the problem involves 34 papers on the basic versions of the IRP, 29 papers on extensions of the basic versions, and 20 papers on one or another version of the stochastic IRP.