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Discrete Optimization

A variable neighborhood search for the multi-period collection of recyclable materials

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ABSTRACT

We consider an approach for scheduling the multi-period collection of recyclable materials. Citizens can deposit glass and paper for recycling in small cubes located at several collection points. The cubes are emptied by a vehicle that carries two containers and the material is transported to two treatment facilities. We investigate how the scheduling of emptying and transportation should be done in order to minimize the operation cost, while providing a high service level and ensuring that capacity constraints are not violated. We develop a heuristic solution method for solving the daily planning problem with uncertain accretion rate for materials by considering a rolling time horizon of a few days. We apply a construction heuristic in the first period and re-optimize the solution every subsequent period with a variable neighborhood search. Computational experiments are conducted on real life data.

1. Introduction

Modern society generates ever-increasing amounts of waste and for environmental and sustainability reasons the public authorities naturally focus on increasing the amount of recycling. Recycling and recycling costs have thus become issues of vital importance for both society and environment.

Research in collection and handling of waste and reusable material is therefore a matter of large practical relevance. Beullens, Oudheuseden, and Wassenhove (2010) give an overview of transportation of waste and reusable material from an Operations Research point of view. They argue that research in reverse logistics systems is very inadequate and sparse compared to that of (normal) forward logistics, and that more research needs to be conducted with the goal of making reverse logistics systems efficient.

Our project focuses on the transportation related to collection of two recyclable materials generated by households. The aim of this project is to find improved scheduling procedures for collection of materials for recycling and the related transportation to the treatment facilities with the goal of minimizing cost while ensuring efficient flow and high service levels.

From a theoretical point of view, the problem under consideration is a multi-period inventory routing problem with two commodities and the addition of transportation to treatment facilities. To the best of our knowledge, the special capacity constraints related to the problem have not been discussed in existing literature. Bogh, Mikkelsen, and Wøhlk (2014) do, however, study another aspect of the same problem.

In the following, we shortly describe the real life case used for our study of the problem. An illustration of the case setup is provided in Fig. 1 and a more thorough description of the details is given in Section 3.

So-called *cubes* which can hold approximately 1.6 cubic meter of material, are scattered around at locations in Denmark and are used for collection of paper and glass for recycling. This paper focuses on the case in Djursland where 211 locations are available, holding a total of 240 cubes for glass and 198 cubes for paper. The majority of the locations have one cube for each type of material, but some of them have up to six cubes located together. The quantity of material deposited by the citizens in the cubes on a given day is unknown. Therefore, the fill level of a cube is not known until the location is visited. The need for service varies between every second week and every second month depending on location.

The collection is performed with a vehicle carrying two 36 cubic meter containers, one for glass and one for paper. Hence glass and paper are collected from the cubes simultaneously and the vehicle can be viewed as a multi-compartment vehicle. The vehicle is equipped with a crane that makes it possible to lift up the cube and remove the bottom of the cube. In this way the material in the cube can be emptied into the proper container before the cube is restored to its place.

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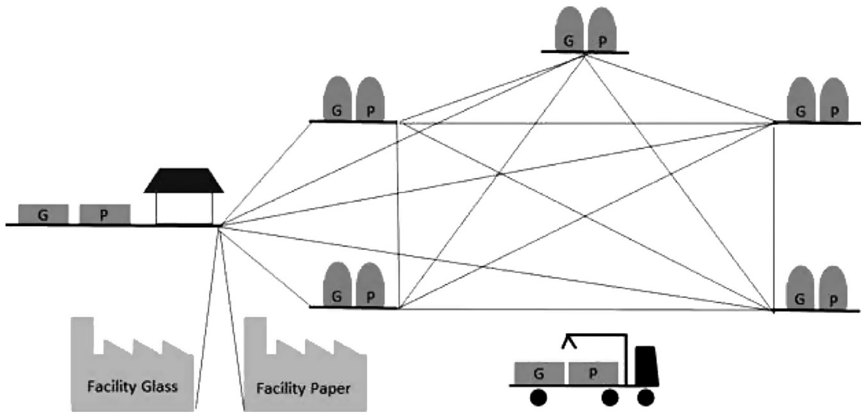

Fig. 1. Setup of the case. Illustration of principle with only five locations, each with two cubes.

It takes 3 minutes to empty the first cube, 2 minutes for the first cube of the other type, and 1 minute for any additional cube.

The vehicle starts and ends each collection route at a depot, where an extra container for each type of material is located. When the vehicle returns to the depot, the crane unloads the paper from the vehicle to the extra paper container, while, due to shattering, this is not possible for glass. Instead, when the glass container of the vehicle is sufficiently full, it is swapped with the extra glass container.

Once two containers of the same type are filled, they are transported to the proper treatment facility, where the materials will be processed for recycling. The time for offloading at the treatment facility is 15 minutes for two containers. Due to the limited amount of material, such trips to the treatment facilities are not needed on a daily basis. Therefore, the available capacity in the glass container of the vehicle each day depends heavily on the work carried out during the previous days. Likewise, once the extra paper container is full, the capacity available in the paper container of the vehicle also depends on the work completed during the previous days.

The collection of waste and recyclable material in Djursland is handled by a semi public company, Reno Djurs. Their responsibility is to provide a high service level for the citizens, which is equivalent to ensuring that the cubes are emptied before being overfilled. In practice, the work is outsourced to a third party logistics provider, but in this paper we consider the problem as if they provide the service themselves. They seek to minimize their cost, which is composed of cost of driving on the routes and to the treatment facilities and a cost of service for the cubes and at the treatment facilities.

In this paper, we define the problem based on the Reno Djurs case. The aim is to create a multi-period schedule for combined collection of paper and glass that minimizes the total cost, while ensuring that the cubes are not overfilled and that capacity constraints of the containers are not violated. We treat the problem as an inventory routing problem where two commodities must be collected jointly but handled separately and transported to separate treatment facilities. The daily filling at each location is stochastic and will be assumed to follow a normal distribution. The service is carried out by a single multi-compartment vehicle, where the available container capacity can vary from day to day.

The remainder of the paper is organized as follows. In Section 2, we present the related literature and in Section 3, we provide a description of the problem and the related notation. We give a detailed description of our solution approach in Section 4 and provide the results of our computational experiments in Section 5. Conclusions and directions for further research are given in Section 6. Finally Appendix A, we offer a mathematical model of a deterministic version of the problem, i.e. a model based on the assumption that the daily input is known for all cubes.

2. Related literature

A number of studies on waste management are available in the literature. According to Golden, Assad, and Wasil (2002) the waste collection business can be divided into three major areas: commercial, residential, and roll-on-roll-off. The collection of residential waste is often dealt with as an arc routing problem because of the large number of households that typically have to be visited and the small distances between them. Collection of recyclable materials from cubes is a special case of residential waste management since the waste is generated by households. However, the materials are not collected directly from the households, but from separate locations and it is most naturally modeled as a node routing problem. In the following we present a brief overview of node routing problems with characteristics that are similar to our problem.

Within the field of waste management, Angelelli and Speranza (2002) consider two case studies. They suggest a deterministic model for estimating the cost of three waste collection systems and present a solution method based on the Periodic Vehicle Routing Problem (PVRP) with intermediate facilities. Since they did not have access to data concerning distance between every given collection point, they group the locations that are geographically close to each other, hold the same type of waste, have the same daily accretion rate of waste, and share the same visiting schedules. They implement a Tabu Search heuristic for solving the problem.

Kim, Kim, and Sahoo (2006) address a real life waste collection vehicle routing problem with driver's rest periods, multiple final destinations for each type of waste, and time windows associated with commercial customers, final destinations, and the depot. Since the commercial customers do not change the frequency of service very often, the weekly service schedule is fairly static and assumed to be predetermined. Each vehicle can, and typically does, make multiple trips to the final destinations per day. They develop an algorithm for a capacitated clustering-based waste collection vehicle routing problem with time windows.

Real world constraints such as drivers' rest periods, multiple facilities, and time windows are also studied by Benjamin and Beasley (2010). However, they only consider the problem for a single period. They solve the problem with three metaheuristics: Tabu Search, Variable Neighborhood Search, and Variable Neighborhood Tabu Search. In the latter heuristic, the variable neighborhood is searched via Tabu Search. The VNS provides the best results.

Teixeira, Antunes, and de Sousa (2004) study vehicle route planning for a separate collection of three types of materials. Glass, paper and plastic/metal must be collected separately from locations scattered around the country by several vehicles. The vehicle capacity is fixed, but differs according to material type. They create static routes for every day of the month. These routes are repeated every month in