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INTELLIGENT FREIGHT TRANSPORT SYSTEMS
VISIONS FOR REAL-TIME DISTRIBUTION PLANNING

Helene Martine Overø[1*] **, Allan Larsen**[1] **, Stefan Ropke**[1]

1. Department of Transport, Technical University of Denmark, Denmark
*. Bygningstorvet 115, 2800 Kgs. Lyngby, +45 4525 1522, hmo@transport.dtu.dk

ABSTRACT

The Danish innovation project entitled "Intelligent Freight Transport Systems" aims at developing prototype systems integrating public intelligent transport systems (ITS) with the technology in vehicles and equipment as well as the IT-systems at various transport companies. The objective is to enhance the efficiency and lower the environmental impact in freight transport. In this paper, a pilot project involving real-time waste collection at a Danish waste collection company is described, and a solution approach is proposed. The problem corresponds to the dynamic version of the waste collection problem which can be formulated as a dynamic version of the *vehicle routing problem with time windows* (VRPTW).

KEYWORDS

Real-time planning, freight transport, waste collection, vehicle routing problem with time windows

INTRODUCTION

The Danish innovation project entitled "Intelligent Freight Transport Systems" aims at developing prototype systems integrating public intelligent transport systems (ITS) with the technology in vehicles and equipment as well as the IT-systems at various transport companies. New information and communication technology solutions must be developed which are capable of enhancing the efficiency and lowering the environmental impact in freight transport. Pilot projects involve real-time management and planning of different types of freight transport such as national and international hauler transport, waste collection, packing and also transport of oversize goods. Freight transport operators and system providers are involved in the development and practical testing ensuring realistic and applicable solutions. In the following, a case study based on a pilot project on real-time waste collection is described.

REAL-TIME WASTE COLLECTION – A CASE STUDY

In this case study, the medium sized Danish waste collection company Henrik Tofteng A/S (HT) is considered. HT serves trade clients and public institutions in the Greater Copenhagen area and has around 50 employees including 35 drivers and 4 dispatchers. The main focus of the company is collection, sorting and disposal of all types of waste except residential waste collection.

Secondary, HT performs transport of specific goods for building purposes which require cranes and tippers.

HT owns a fleet of 30-35 vehicles of the following types: container trucks, lift trucks, waste collection trucks and a special truck for washing the containers. In this case study, we are considering the problem involving the waste collection trucks. There are a total of 12 waste collection trucks of which 2 of these are used as reserve.

HT leases out a large number of open and closed containers with sizes ranging from 240L plastic containers to 20 foot ship/chemistry containers. Furthermore, they have approximately 4500 small containers on wheels. The containers are not equipped with RFID tags or other kinds of identification. Thus, the company cannot identify where all the containers are situated at all times. They are, however, testing the durability of specific RFID tags on some of their containers at the present moment.

Customers and restrictions

HT has approximately 1000 customers per month situated in the Greater Copenhagen area. The customers have very diverse visit patterns, depending on their contract with HT. Regarding the washing of the containers, the visit patterns can vary from once every day up to once a year. For the waste collection trucks the variation is not quite as extreme, but the patterns are still very distinct. Hence there is a periodicity in the waste collection so that the customers are served from 1 to t times during a period of t days. When a customer has a collection frequency smaller than the number of days in the period, the collection at that customer must be done using one of the feasible patterns of collection days defined for that customer. This problem is known in the literature as the *periodic vehicle routing problem* (PVRP) [6].

For the waste collection trucks there are between 20-48 visits per day per vehicle. Moreover, there are approximately 20 dynamic customers in total per day. This implies a degree of dynamism of approximately 4-10% if all 10 trucks are used. Furthermore, the trucks have different capacities which constrain the number of customers they can serve before they have to be emptied at a waste disposal site.

Most customers require having their waste collected within a certain time window. These time windows are, however, often quite wide and flexible, especially with respect to the arrival time. The time windows are normally 6-8 hours. Furthermore, the company has access to keys and cards to many of their customers such that they are independent of their working hours. However, the keys and cards are placed in specific vehicles with the result that not all vehicles can visit all customers, i.e. there exist a compatibility relationship between the customers and the vehicles. This problem is known in the literature as the *site-dependent vehicle routing problem* (SDVRP) [7]. This compatibility relationship furthermore restricts the handling of the dynamic customers.

Legislation rules prevent the vehicles from entering the city centre of Copenhagen before 6 am, which complicates the waste collection both regarding accessibility, safety and performance. The vehicles furthermore have to leave the city centre by 11 am which gives them a total of 5 hours to operate in the central part of Copenhagen.

The planning setting today

The planning of the orders is carried out manually by the dispatchers. The waste collection trucks are handled by 1 dispatcher. Approximately 80% of the known orders are planned a long time in advance, and the remaining 20% are planned the day before operation. The dynamic customers are evaluated on the day of operation as they arrive. The drivers have a large influence on the planning, especially regarding the dynamic customers or ad hoc orders arriving on the day of operation.

THE DYNAMIC WASTE COLLECTION VEHICLE ROUTING PROBLEM WITH TIME WINDOWS

The waste collection *vehicle routing problem with time windows* (VRPTW) is illustrated in Figure 1 for a single vehicle and multiple disposal sites.
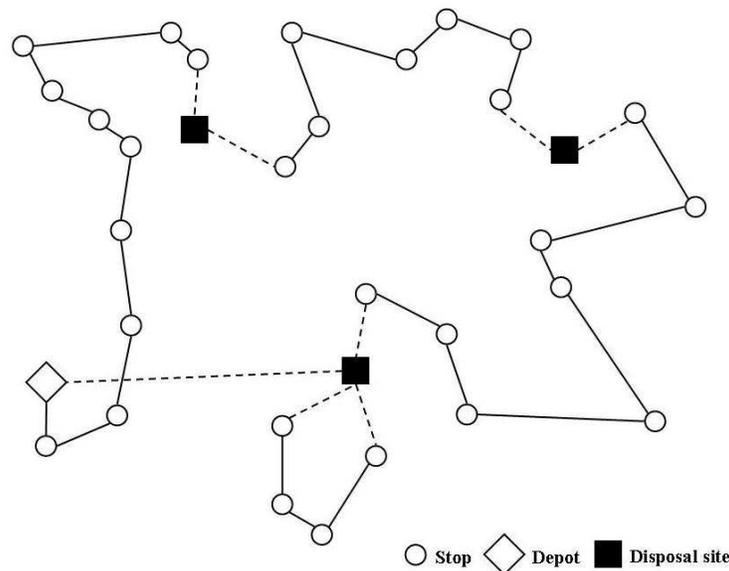

Figure 1 – A route sequence of one vehicle considering disposal operations with multiple disposal sites

The vehicle must visit a number of customers on a given day respecting their demands and time windows. The vehicle has a certain capacity and must be emptied at a waste disposal site when that capacity is met. After the vehicle is emptied, it can carry on collecting waste. Hence a vehicle can make multiple disposal trips per day. At the end of the day, the vehicle returns to the depot. A mathematical programming model for a simplified version of the problem is presented by Sahoo et al. [22].

In this case study we are considering the *dynamic* version of the waste collection VRPTW. Incoming customer requests, information about delays, actual order sizes, the spare capacity of the vehicles, drivers' working hours etc. affects the planning and causes the current routes to be

either infeasible or possibly far from optimal. Hence the routes must be reoptimized whenever new information becomes available which has an effect on the optimality or feasibility of the current plan. This complicates the solution procedure and sets high demands on speed and efficiency of the algorithms.

The waste collection VRPTW, and especially the dynamic case, is not well documented in the literature. It has, however, received more attention in recent years. Kim et al. [12] address a real life waste collection VRPTW with consideration of multiple disposal trips and drivers' lunch breaks. They address the problem by using an extension of Solomon's well-known insertion approach [23], and a clustering-based algorithm. Ombuki-Berman et al. [18] address the same problem by using a multi-objective genetic algorithm on a set of benchmark data from real-world problems obtained by Kim et al. A very similar problem, with only one disposal site, is addressed by Tung & Pinnoi [25], where they modify Solomon's insertion algorithm and apply it to a waste collection problem in Hanoi, Vietnam.

Teixeira et al. [24] apply a heuristic approach for a PVRP for the separate collection of three types of waste: glass, paper, and plastic/metal. The approach has three phases: define a zone for each vehicle, define the waste type to collect on each day, and select the sites to visit and sequence them. Angelelli & Speranza [2] study the PVRP with *intermediate facilities* (PVRP-IF). When a vehicle visits an intermediate facility, its capacity will be renewed. They propose a tabu search algorithm for the problem which they apply for estimating the operating cost of different waste-collection systems [3]. The main difference between their problem and ours is the time window constraints, which must be explicitly considered in our problem. Tabu search algorithms are also proposed by Cordeau et al. [6] for the multi-depot PVRP, by Brandão & Mercer [4] for the multi-trip vehicle routing and scheduling problem, and by Alonso et al. [1] for the PVRP with multiple vehicle trips and accessibility restrictions. Alonso et al. refer to their problem as the *site-dependent multi-trip* PVRP (SDMTPVRP), which is very similar to our problem with the exception of the time window constraints. The time windows are considered by Brandão & Mercer along with different capacities of the vehicles and the drivers' working hours in addition to the other constraints. The vehicle routing problem with multiple trips is studied by Petch & Salhi [20].

Nuortio et al. [17] present a guided variable neighbourhood thresholding metaheuristic for the problem of optimizing the vehicle routes and schedules for collecting municipal solid waste in Eastern Finland. Solid waste collection is furthermore considered by Li et al. [13] for the City of Porto Alegre, Brazil. Their problem consists of designing daily truck schedules over a set of previously defined collection trips, on which the trucks collect solid waste in fixed routes and empty loads in one of several operational recycling facilities in the system. They use a heuristic approach to solve the problem.

As mentioned, the literature on the dynamic version of the waste collection VRPTW is quite limited. Johansson [11] investigate and analyse the effects of dynamic scheduling and routing in a solid waste management system. In the analysis, the real-time information on the status of 3300 Swedish recycling containers, equipped with level sensors and wireless communication equipment, is used. In the study, analytical modelling and discrete-event simulation have been used to evaluate different scheduling and routing policies utilizing the real-time data. The *dynamic* version of the classical VRPTW (DVRPTW), motivated from courier service

applications, is investigated by Gendreau et al. [9]. A tabu search heuristic has been adapted to the dynamic case and implemented on a parallel platform to increase the computational effort. A more recent contribution on the DVRPTW is by Housroum et al. [10], where an original resolution approach, based on a genetic algorithm adapted to the dynamic optimization context, is proposed. Li et al. [14] studies real-time vehicle rerouting problems with time windows applicable to delivery and/or pickup services that undergo service disruptions due to vehicle breakdowns. The dynamic *pickup and delivery problem with time windows* (PDPTW) is furthermore studied by Mitrovic-Minic et al. [15], and solved using a double-horizon based heuristic.

The VRPTW without considering multiple disposal trips is NP-hard [8], and finding a feasible solution with a fixed fleet size is an NP-complete problem [5]. Thus, a heuristic solution approach [19] seems like a natural choice.

INTELLIGENT REAL-TIME WASTE COLLECTION

In this section, we propose a solution approach for the real-time waste collection VRPTW. A flowchart of the solution approach is shown in Figure 2. The data from HT is given as input to a waste collection VRPTW solver, for which we consider the adaptive *large neighbourhood search* (LNS) heuristic developed by Ropke & Pisinger [21]. Large neighbourhood search has previously been suggested to solve the VRPTW, and Ropke & Pisinger's extended approach has shown very powerful for the PDPTW. It is expected that since the algorithm is so robust, it will be able to adapt to various instance characteristics, and hence we will try to solve the waste collection VRPTW using a variant of the approach.

After the waste collection VRPTW is solved for the given data, a continuous monitoring of real-time information is performed until a certain time threshold, T_{MAX}, is reached. Typically, this would be the end of the working day. In idle periods, a continuous improvement of the solution by LNS is performed.

There are basically three types of real-time information to monitor; information on orders, vehicles and infrastructure. For the orders, there can either be changes in the existing orders or a new order can arrive. For the vehicles, various status updates are relevant, such as the residual capacity of the vehicles. For the infrastructure, changes in the estimated travel time due to congestions, road work etc. will be monitored. If there are changes with respect to the existing data, it is checked whether these changes are significant or not. If the changes are not significant with respect to some predefined thresholds for travel time, residual vehicle capacity etc., they are disregarded, and the real-time monitoring is continued. If they are significant, the problem is reoptimized by LNS. If the reoptimization results in any changes in the vehicle routes, the new routes are sent to the vehicles. If the time threshold, T_{MAX}, is not reached, the real-time monitoring is continued.

If a new order arrives, it must be decided whether to handle the order immediately or whether to postpone it. The best waiting strategy is thus determined. Mitrovic-Minic et al. [16] describe and compare various waiting strategies for the dynamic PDPTW. A very simple waiting strategy could be to require a vehicle to depart as soon as it is feasible, i.e., to leave from its current

location at the earliest departure time (the *drive-first* waiting strategy). Another strategy could be to require a vehicle to wait at its current location for as long as it is feasible, i.e., the vehicle leaves its current location at the latest possible departure time (the *wait-first* waiting strategy). If the order should be handled immediately, the problem is reoptimized by LNS. If the handling of the order should be postponed, the real-time monitoring is continued.
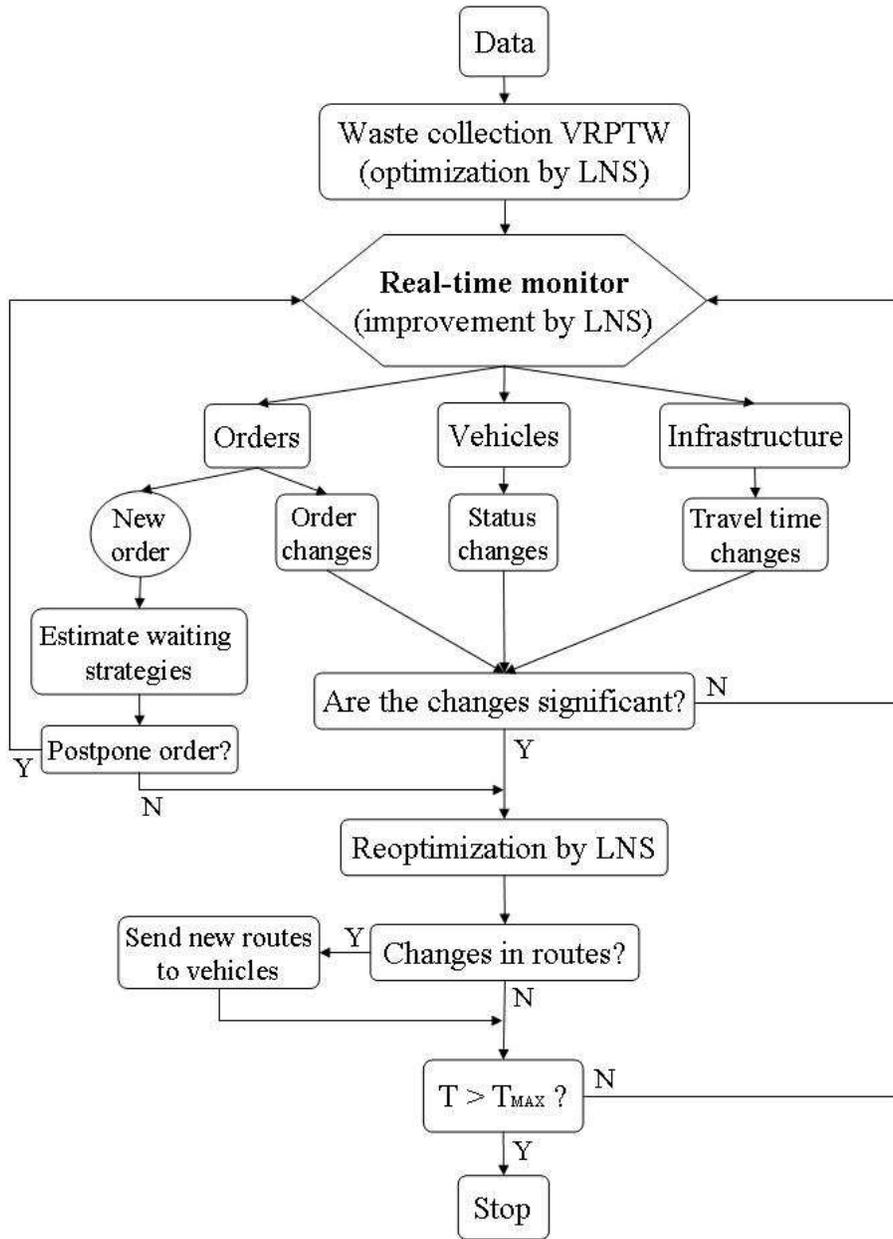

Figure 2 – Flowchart of the proposed solution approach

The implementation of the solution approach and the practical testing on real-life data from HT is ongoing work and will not be presented in this paper.

CONCLUSION AND PERSPECTIVES

The waste collection problem at the Danish waste collection company Henrik Tofteng A/S was described and formalised to the dynamic waste collection VRPTW. A brief literature survey was presented with focus on waste collection and relevant variants of the vehicle routing problem. The survey showed that primarily heuristic approaches have been employed for these types of problems. Furthermore, a heuristic solution approach for the real-time waste collection VRPTW was proposed and described.

An interesting problem left for future work is the synchronization of the waste collection trucks with a container washing truck. After the containers are emptied at a given customer, they may need to be washed. It is important that the washing truck arrives *after* the containers are emptied and *after* the waste collection truck has left to visit another customer or a waste disposal site. This is in order to avoid waiting time at the customers. Hence the routing of the washing truck depends on the routing of the waste collection trucks and on changes/delays on their routes. This makes the waste collection problem even more dynamic, since the routing of the washing truck must be updated each time the other routes are changed. The handling of the washing truck must be incorporated in the solution algorithm presented in Figure 2 in order not to make sub-optimal planning.

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