Traffic Information and Dynamic Vehicle Routing in Forwarding Agencies

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Abstract. This paper considers a routing and scheduling problem of forwarding agencies handling less-than-truckload (LTL) freight. On the one hand, the performance of these companies is influenced by unknown customer orders, increasingly received shortly before the actual pickup. On the other hand, the transport times between two consecutive points in a tour sometimes vary significantly. The objective is to avoid lateness of orders and increase equipment utilization. In the following we present the basic ideas of modeling a look ahead capability for travel times and an anticipation of customer orders.

Keywords. dynamic vehicle routing, pickup and delivery problem, forwarding agency, less-than-truckload freight, varying travel times, clustering, tabu search

1 Introduction and Problem Description

The worldwide transportation of cargo is steadily growing and forwarding agencies handling less-than-truckload freight are no exception. The performance of these companies is strongly influenced by varying transport times between two consecutive points due to traffic jams. Surprisingly, traffic information is hardly used within the forwarding industry, even though vehicle location is available in real-time. Numerous unknown customer orders, increasingly received shortly before the actual pickup, are impacting the performance, too.

Typical forwarding agencies perform the pickups and the deliveries conjoined. They have to cope with hundreds of pickups and deliveries each day and a few tens of vehicles are necessary to service the customers in the short-distance traffic region. Furthermore, inquiries of business customers cannot be neglected. In the following we focus on the integration of varying travel times, which are often responsible for late deliveries and penalties. Especially in urban areas for many roads rush hour traffic jams are common, but this information is hardly used within forwarding agencies.

In particular, real-time approaches solving pickup and delivery problems (PDP) with inhomogeneous goods, capacities of general cargo, time windows, varying travel times, and unknown customer orders, which cannot be neglected, are missing. Thus, the objective is to develop a customized dynamic routing model capable of handling all requirements and assisting forwarding agencies in routing vehicles efficiently in real-time.

2   Literature Review

Malandraki and Daskin distinguish two types of variations in travel time, because often the assumption of constant travel times is unrealistic [1]. The first type compromises stochastic and unforeseen events like, accidents, weather conditions, vehicle break-downs, or other random events. The second type compromises temporal events like hourly, daily, weekly, or seasonal variations (e.g., heavy traffic during rush hours). Only these temporal events can be included by using time dependent functions.

Several papers deal with average speeds for specific areas, a method similar to directly assign a travel time to a link. Therefore, often the FIFO ("first-in-first-out") property does not apply ([2], [3]). Ichoua et al. work with travel speeds and ensure the FIFO property, but they do not assume constant travel speeds over the entire length of a link [4]. The time spent in an interval is calculated by dividing the speed of that interval by the distance covered during the interval. If the planning horizon is divided into three time intervals with different speeds, the entire travel time for one edge is the sum of the time spent in each interval. This is one of the first approaches to use time dependent travel speeds which satisfy the FIFO property. The time windows in this approach, that does not consider any capacities, are soft ones, except for the depot.

Fleischmann et al. criticize Ichoua et al., because the drawback of models with varying speeds and constant distances is that they do not pay attention to potential changes of the shortest paths, which might change the distances [5]. Besides, the forward and backward algorithms go through all time slots. With constant travel times the direct link between each pair of visits is taken as the shortest path, but with time varying speeds it might happen that taking other links requires less travel time. Therefore, an approach using Euclidean distances and no real roads is only valid, if the speed distribution preserves the triangle inequality. Fleischmann et al. describe the derivation of travel time data and built a vehicle routing model working with time-varying travel times. The problem is solved using a savings heuristic and insertion heuristics and a 2-opt improvement heuristic.

Dynamic models can be differentiated in models which anticipate and consider possible incoming orders and models which simply start a recalculation, if new information becomes available. In the following the time dependent modeling is depicted, thus only a small overview of dynamic approaches is given. Fu, for example, analyzes scheduling a dial-a-ride paratransit with tight service time windows and time-varying, stochastic congestion and applies successfully a par-

allel insertion algorithm [6]. Several other authors analyze time dependent routing problems and consider different solution techniques (e.g., [7]). Fleischmann et al. also consider a dynamic routing system using forecasted data, where customer orders arrive at random during the planning period [8]. Rarely approaches dealing with dynamic or varying travel times consider all relevant requirements of forwarding agencies, which motivated us to develop an integrative approach suited to these requirements.

Pure recalculation or iterative planning might be to find tours of a pure static problem and with each new information available the generated routes are updated. Savelsberg and Sol applied a branch-and-price approach on such a problem, where each new information triggers recalculation of previous results [9]. Nonetheless, the results of such approaches are limited, because possible benefits of anticipating events are not used.

Powell was one of the first to review the idea of forecasting uncertainties within dynamic routing, though the focus is on job assignment to maintain a steady flow of work [10]. Van Hemert and La Poutré try a new approach [11]. The authors do not consider the distances traveled or the number of vehicles, instead they solely try to cover the expected workload of the area. They try to use the fact that the number of service requests from different regions might vary. Therefore, it might be beneficial to service regions with high probability of customer requests (i.e., service fruitful regions). The authors conclude that, if the time restriction to deliver loads is beyond a certain point, it is best to perform routing for pickup and delivery only. This assumption might hold for other pickup and delivery tasks, but does not fit with forwarding agencies, because it is absolutely necessary to pickup all available orders.

Jaillet and Wagner consider online routing problems and analyze the value of advanced information using competitive ratios [12]. The work is dedicated to online traveling salesman and traveling repairman problems and show improved competitiveness results for both. Promising results motivate to extend the multiple scenario approach suggested by Bent and van Hentenryck [13], which permanently generates routing plans considering known and future requests. According to a consensus function the plan which offers the best flexibility at the actual point in time is chosen.

Branke et al. instead derive theoretical results about the best waiting strategies for the one and the two vehicle case [14]. Some deterministic waiting strategies and an evolutionary algorithm for waiting strategies are presented. The results show that a proper waiting strategy reduces detours and allows to service additional customers. They state that, if only few customer orders are unknown, it is better to use preplanned routes and insert new customers. On the other hand, if requests are expected customer orders should be anticipated.

The list of related approaches is not nearly complete, but most approaches are dealing either with varying travel times or dynamic customers, some also consider both but rarely PDPs including both are analyzed. In particular, the special requirements of forwarding agencies are not considered.

3   Optimization Approach

The objective within a first step was to determine how far and under what premises freight forwarding agencies might benefit (i.e., reduction of expenses) from a real-time intelligent planning system, due to the fact that within the freight transportation industry enlarging the low profit margins becomes increasingly important (e.g., [15]).

A mixed integer problem developed earlier is modified to account for time dependent travel times. Besides other modifications, the travel time matrix associated with E is modified according to different time zones (z), which give the corresponding travel times tt_{ij}^z, where $z \in Z$ and $Z = \{1, 2, 3\}$. That is an arc has not only one travel time, instead the travel time depends on the time of the day ($T(0)$, $T(1)$, ..., $T(n)$), resulting in a step function. Hence, each vehicle k travels a link (i, j) in a certain time zone z: x_{ijk}^z, but still has to comply with all other restrictions. In this context the FIFO ("first-in-first-out") property, a method originally applied in inventory management, is important. In vehicle routing it means a vehicle entering a road first, will leave the road first. The FIFO property is violated by using a step function, but not by working with a non step function with a slope of at most minus one. We maintain FIFO in allowing vehicles to wait (cf. [1]); accepting the disadvantage of unnecessary waiting.

In the state of North Rhine-Westphalia (NRW) numerous sensors are constantly recording traffic data on the interstates. The regional authorities for central police services provided us with data for one year for detailed analyzes and testing. Time zones valid for all interstates are established to reduce computational complexity, increase reliability and preserve the triangle inequality for all time zones ($d_{i,j} \leq d_{i,p} + d_{p,j} \ \forall \ i, j, p \in N$). Fig. 1 visualizes the three groups of travel times our analysis yielded. In the morning, after 6 am, the average travel time increases on most interstates. Around 7 am the zone with the slowest average travel time is reached, but after 9 am it drops already back to the intermediate zone. Similar characteristics can be observed in the afternoon.
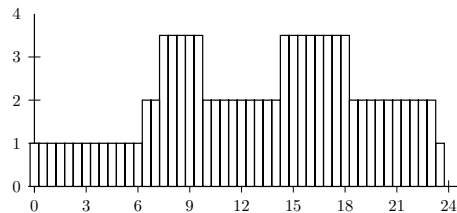
Fig. 1. Travel times zones in North Rhine-Westphalia over 24 hours

The objective is to find a set of routes with minimal total travel time using the previously derived travel time zones, starting and ending at a single depot

and serving demands of all customers. Furthermore, vehicle capacity, driving time restrictions and time windows are considered. In addition, the number of vehicles used is minimized, because this is a crucial cost driver. Due to the complexity of the model even an explicit column generation approach could not improve computational times for industrial size scenarios requiring a quick response.

Considering objective function, degree of dynamism, and demand rate, we develop a modified tabu search. A tabu search explores only parts of the solution space by moving at each iteration to the most promising neighbor of the current solution, even if this requires a decrease of the objective function. The objective function $z(x^\eta)$ associated with a particular solution η of an iteration is characterized by the vector $x^\eta = x_{ijk}^{z;\eta}$, denoting the used edges (i,j) for every vehicle k and time zone z. Cycling is avoided by using a tabu list, where recently considered solutions are blocked out for a number of iterations. The initial solution is made up by an insertion algorithm inserting all $n-1$ customers according to their proximity. The neighborhood $N(i,j,\eta)$ of a solution η contains only solutions, where the removed customer j can be inserted approximately to customer i complying all restrictions under time dependent travel times. For a moved vertex a reinsertion or displacement is tabu until the iteration $\eta + \theta$.

The tabu search should also have a look ahead capability, because approaches using anticipation perform in general better than real-time adjustments, which, for instance, require additional vehicles. The objective in a dynamic rescheduling problem is a formulation that allows servicing all customers during the planned routes without or nearly without extra tours. Prerequisite of such smooth tour changes is that, among other things, the customer alterations are known in time, the orders are pickup orders and the remaining capacity is sufficient. The approach should be able to plan routes in real-time during the tour execution, but also use anticipation to avoid or minimize sudden rescheduling. The concept for forwarding agencies is developed, because solutions proposed so far are not feasible in practice or are too specific for this setting (cf. [16]). The approach will consider time windows, capacities and varying travel times. Furthermore, the routes should include customer clusters with potential orders. The computed clusters should be constructed from historical data and serve as placeholder for possible service requests. An implicit tour structure should enable the assignment of later pickup orders in the most efficient way.

Figure 2 illustrates the idea of an implicit tour structure. Three tours are planned including the known customer orders (black nodes). Based on experience, historical data, or demand density and customer dispersion for different regions possible or expected orders can be computed. These are compared with actual orders of the region before the tour start. In a static planning one vehicle would service the two customers in the lower left corner only and would return to the depot from the customer nearest to the depot. Opposed to that an anticipatory strategy includes the possible orders into the planning. For example, the region in the bottom right corner is likely to experience two orders (colored nodes), but right now no vehicle is traveling there. An anticipating algorithm

reserves the necessary travel time and capacity (e.g., via a cluster (rectangle)), to service the customers in the lower right corner, if that seems favorable. These orders are then assigned to the vehicle servicing the customers in the lower left corner. In that way the original static tour is traveled in the reversed way, if possible. After the service of the known customer orders, the service of additional orders emanating in the neighborhood is feasible. In this manner all expected, but unknown, orders will be considered.
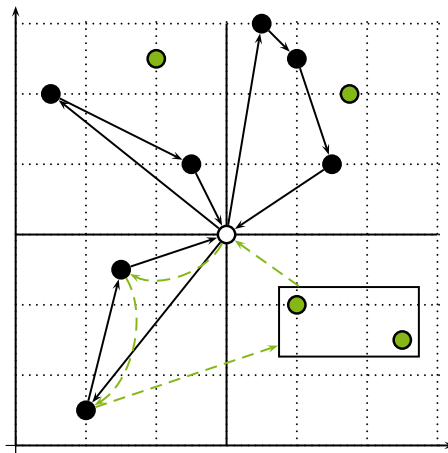

Fig. 2. Customer clustering and implicit tour structure

4   Outlook

This paper shows the successfully derived travel time zones for a PDP incorporating practical complexities which received only little attention in literature. The presented tabu search seems to be capable of industrial size problems and to perform well with time dependent travel times, which is very helpful in decreasing the probability of lateness due to rush hours slow downs within PDPs customized for forwarding agencies. The ongoing research will focus on the refinement and testing of the described customer clusters and the anticipation of both travel times and customer clusters.

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