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Branch-and-price and adaptive large neighborhood search for the truck and trailer routing problem with time windows

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A B S T R A C T

Motivated by a situation faced by infrastructure service providers operating in urban areas with accessibility restrictions, we study the truck and trailer routing problem with time windows (TTRPTW). In this problem the vehicle fleet consists of trucks and trailers which may be decoupled. A set of customers has to be served and some of the customers can only be accessed by the truck without the trailer. This gives rise to the planning of truck-and-trailer routes containing truck-only subroutes, in addition to truck-only routes and truck-and-trailer routes without subroutes. We propose a branch-and-price algorithm for the TTRPTW, using problem specific enhancements in the pricing scheme and alternative lower bound computations. We also tailor an adaptive large neighborhood search algorithm to the TTRPTW in order to obtain good initial columns. When compared to existing metaheuristic algorithms we obtain highly competitive results. Some instances with up to 100 customers are solved to optimality with the proposed branch-and-price algorithm.

1. Introduction

In Austria and many other countries, several infrastructure service pro-viders operate in cities where some areas have accessibility restrictions. These restrictions usually refer to pedestrian zones that cannot be accessed by car and they have to be taken into account in the daily routing and scheduling of field employees providing maintenance and installation services at customer locations. As a result, service providers must often design vehicle routes comprising subroutes that are performed by technicians on foot. In order to better understand the impact of subroute planning from a methodological point of view, this paper develops a branch-and-price algorithm and tailors an adaptive large neighborhood search method for the closely related truck and trailer routing problem with time windows.

The truck and trailer routing problem (TTRP) (Chao, 2002) consists of determining a set of least cost or distance routes visiting a given number of customers with accessibility constraints. The vehicle fleet is composed of trucks which may or may not pull a trailer. One part of the customers can either be visited by a truck pulling a trailer or by a truck alone (denoted as trailer customers). The other part can only be visited by a truck alone (denoted as truck customers). In order to serve these two types of customers, three types of routes can be planned: truck only routes, i.e. routes that are carried out by a truck alone; complete vehicle routes that are carried out by a truck pulling a trailer without any intermediate decoupling; and complete vehicle routes that are carried out by a truck and a trailer containing truck-only subroutes. Each of these subroutes, which may consist of truck customers only or a mix of truck and trailer customers, has to start and end at a given trailer customer where the trailer is decoupled and then re-coupled again at the end of the subroute. Both the trucks and the trailers have a capacity and shifting loads from the trailer to the truck before departing on truck-only subroutes is possible. An important aspect of this problem is that a trailer may not be picked up by a truck different from the one which decoupled it, and each customer may only be visited once. This implies that a decoupling point cannot be used more than once: whenever a customer is used as a decoupling point it has to be served. However, several consecutive subroutes may start and end at the same decoupling point.

The truck and trailer routing problem with time windows (TTRPTW) has first been stated and solved by Lin et al. (2011). The only difference with respect to the TTRP is that customers as well as the depot have time windows. Lin et al. (2011) assume that trailer customers that serve as decoupling points have to be visited before the trailer is decoupled, i.e., before their first

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truck-only subroute starts. Derigs et al. (2013) do not make this restrictive assumption: the customer used to park the trailer may be visited any time the truck returns to the trailer for reloading, i.e., before or after any of its truck-alone subroutes. This allows for more flexibility with respect to the timing of the visit at the trailer customer which serves as decoupling point. Derigs et al. (2013) show that this additional flexibility leads to considerable improvements in terms of solution quality and it is the problem version considered in this paper.

The contribution of this paper is twofold. First, we develop a branch-and-price algorithm for the TTRPTW. The pricing algorithm relies on several problem specific enhancements, such as improved dominance rules and a leveled pricing scheme. In addition, heuristic column generators tailored to the TTRPTW and alternative lower bound computation schemes are applied. Second, we also propose an adaptive large neighborhood search (ALNS) algorithm, relying on known destroy and repair operators. The main purpose of the ALNS is to populate the column pool in our branch-and-price scheme. However, it also achieves highly competitive results when compared to best known results on instances from the literature. To the best of our knowledge, the proposed branch-and-price algorithm provides the first optimal solutions to several benchmark instances with 50 and 100 customers.

In the following, we first give a brief overview of the related literature in Section 2. In Section 3, we define the considered problem in further detail and we propose a path-based model. In Section 4, we describe the column generation scheme to solve its linear programming relaxation, which is embedded into a branch-and-bound tree. The adaptive large neighborhood search algorithm is described in Section 5. The performance of the proposed methods is evaluated in Section 6. Section 7 concludes the paper and provides potential directions for future research.

2. Related work

Truck and trailer routing problems have only recently received more attention in the literature. From a methodological point of view, most of the works published on the TTRP are metaheuristic algorithms. Chao (2002) and Scheuerer (2006) propose tabu search algorithms, Lin et al. (2009) a simulated annealing based method, Villegas et al. (2011) a greedy randomized adaptive search procedure combined with path relinking, and Derigs et al. (2013) apply their metaheuristic solution framework, combining attribute based hill climber and record-to-record travel with large neighborhood search and local search. Two groups of authors combine heuristic and exact ideas in the form of so-called matheuristics: Caramia and Guerriero (2010) combine mathematical programming with a local search algorithm and Villegas et al. (2013) use heuristic column generation. A multi-objective version has been addressed by Tan et al. (2006) with a hybrid multi-objective evolutionary algorithm.

Until very recently, the TTRPTW had only been addressed by Lin et al. (2011), who proposed a simulated annealing algorithm, and by Derigs et al. (2013) who applied their solution framework not only to the TTRP but also to the TTRPTW and to a problem version in which load transfers are not allowed. Much earlier, a real-world inspired problem involving trucks, trailers, time windows and a heterogeneous vehicle fleet had been addressed by Semet and Taillard (1993).

The generalized truck and trailer routing problem (GTTRP) has been introduced by Drexl (2011). In this variant, additional decoupling (so-called transshipment) locations, time windows and a heterogeneous vehicle fleet are considered. Trucks and truck-and-trailer combinations do not only differ in terms of their capacities but also in terms of their fixed and distance-dependent costs. Drexl (2011) proposes a branch-and-price algorithm to solve the GTTRP. The pricing subproblems are solved by a labeling algorithm based on dynamic programming, considering the following resources: cost, collected load, transferred load, time, visited locations and trailer in use; and a label may only dominate another label residing at the same node if the current trailer parking positions are equal. We will show that, in our case, dominance is also possible under different circumstances. Drexl (2011) solves instances with up to 10 truck customers, 10 trailer customers and 10 transshipment locations to optimality with a time limit of 11,100 s. He also derives a heuristic algorithm from the proposed branch-and-price framework and solves some of the TTRP instances of Chao (2002).

Belenguer et al. (2015) have solved the single truck and trailer routing problem with satellite depots by branch-and-cut. In this problem, a single truck towing a detachable trailer has to serve a given set of customers only accessible by truck. Appropriate satellite depots or transshipment locations have to be selected and are used to park the trailer and transfer load from the trailer to the truck. Several families of valid inequalities are proposed. The largest instance solved has 100 customers and 10 satellite depots.

Very recently, Rothenbächer et al. (2016) have introduced a branch-and-price-and-cut algorithm for the TTRPTW and two real-world extensions: 1) a two-day planning horizon during which each customer can be visited once or twice and 2) load transfer times that depend on the amount moved from a truck to the associated trailer. The model also considers a heterogeneous fleet of vehicles. In contrast to the algorithm introduced here, Rothenbächer et al. (2016) use a bidirectional labeling algorithm to solve the pricing problem and they generate subset-row inequalities (Jepsen et al., 2008) during the branch-and-price process to strengthen the LP relaxation of the problem. Computational experiments performed on single-day instances without load transfer times show that this algorithm is faster than ours and was able to solve a number of additional instances to optimality.

Truck and trailer routing problems are also related to two-echelon VRPs (2E-VRPs). In the 2E-VRP goods are delivered from a depot to satellite facilities and from the satellite facilities they are distributed to the actual customers. Direct shipping from the depot to a customer is not possible. Split deliveries to satellite facilities are allowed but not to the customers. The number of customers that can be served by a satellite facility depends on the amount of goods shipped from the depot to this facility. The best performing exact algorithm is the method of Baldacci et al. (2013) in which the problem is decomposed into several multi-depot VRPs with side-constraints. They solve almost all instances from the literature with 50 customers and up to 5 satellites.

In Drexl (2013) a modeling framework is introduced for the vehicle routing problem with trailers and transshipments (VRPTT). No fixed assignment of trailers to trucks is considered and load transfers between vehicles are allowed. The author explains how, for example, the 2E-VRP can be modeled as a VRPTT. Drexl (2014) proposes branch-and-cut algorithms for the VRPTT, considering several families of valid inequalities. Instances with up to 8 customers, 8 potential transshipment locations and 8 vehicles are solved.

Finally, both the 2E-VRP and the TTRP are related to the location routing problem. Recent surveys covering these problem classes can be found in Cuda et al. (2015); Drexl and Schneider (2015) and Prodhon and Prins (2014).

3. Problem formulation

The TTRPTW can be modeled on a complete directed graph $G(V, A)$ where V is the set of all vertices which contains the origin depot d^+, the destination depot d^-, and the set of customers N; and A denotes the set of arcs. Each arc $(i, j) \in A$ is associated with a travel cost c_{ij} and a travel time t_{ij}. There is a fleet of m