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A combined multistart random constructive heuristic and set partitioning based formulation for the vehicle routing problem with time dependent travel times

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A R T I C L E I N F O

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A B S T R A C T

Although the Vehicle Routing Problem (VRP) has been broadly addressed in the literature, most of the works consider constant travel times. This is a strong simplification that does not allow to correctly model real world applications. In fact, nowadays, travel times sensibly change, across the day, due to congestion phenomena. Therefore, to actually represent the reality, it is necessary to consider time dependent travel times. In this paper, the VRP with Time Dependent Travel Times, service times at nodes, and limit on the maximum route duration, is addressed. The objective function consists into minimizing the total travel time. A Multistart Random Constructive Heuristic, (MRCH), in which congestion level is considered, is proposed. The routes obtained by the MRCH are then used as columns in a Set Partitioning formulation. Computational results, carried out on instances derived by VRP instances taken from the literature, show the efficiency and effectiveness of the proposed approach.

1. Introduction

Due to the growing amount of road traffic and the limited capacity of the road network, traffic congestion has become a daily phenomenon, as stated in Kok et al. (2012). Traffic congestion may be due to different causes. Some of them are predictable and systematically occur, such as the increment of traffic during daily peak hours or during mass events. Others are less predictable, such as road accidents and adverse weather conditions. In this paper we focus only on predictable causes, which have been proved to be major responsible of the travel time fluctuations. (see Skabardonis et al., 2003), and, therefore, need to be taken into account during the vehicle dispatching planning phase. This is not a trivial issue because congestion level does not evolves according to the same law on all the arcs belonging to the same road network. Traffic peaks may be reached in different moments of the day for different arcs, and may last only for few minutes, as for longer periods. Current planning systems simply refer to average estimate travel times, ignoring time-dependent variation of travel times. Therefore, routes planned considering constant travel times may be far from optimality and sometimes even from feasibility, in cases in which tight delivery time windows, and/or maximum route duration are imposed.

The Vehicle Routing Problem (VRP) has been broadly addressed in the literature but in the greatest part of the papers constant travel times on arcs are assumed, ignoring that travel times strongly depends on the time of the day in which the arc is covered, other than on its length. This strong simplification limits the applicability of those models to real world problems. Many algorithms which have been proved to be highly performing on classical VRPs obtain poor performances if applied to Time Dependent VRP (TDVRP), for which ad-hoc suited approaches need to be developed, able to identify the most promising moment, during the day, to traverse an arc, and to exploit this information while performing the routing plan.

The aim of this paper is to propose an efficient method to solve the TDVRP, able to identify the best routes, and the best starting time for each route, taking into account travel times fluctuations over the day. The paper is organized as follows. Section 2 presents a literature review on TDVRP and on travel times representation. The problem statement is reported in Section 3, while in Section 4 the proposed solution approach is described. Computational results are reported and discussed in Section 5. Finally, Section 6 is devoted to conclusions and future development suggestions.

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2. Literature review

Time-dependent vehicle routing problems are harder to model and to solve and have received a limited attention in the literature, respect to their time-invariant counterpart. Taking into account time-dependency is not a trivial issue. Most of available models exploit simple procedures to adjust travel times, like multiplier factors associated with different periods of the day. Unfortunately, these assumptions cannot allow to give an accurate approximations of the real-world conditions where travel times are subject to more complex variations over time, and in which speed variation, and consequently travel time variation, is generally a continuous function. In fact, discontinuous functions implies, that, when crossing the border between two adjacent periods, an infinite acceleration (or deceleration) occurs, which clearly do not correspond to the reality. Another crucial issue is the *First In First Out* property, which imply that, when traveling each arc in the network, given a departure time τ_α, starting at a later time, τ_β, it is not possible to arrive before than if we started at τ_α. This property is always verified in a road network, while it may not hold for a rail network, in which, a traveler, in a railway station, may prefer to wait for the subsequent express train to his destination instead of boarding on the next local train, even if it departs earlier.

Time-dependent problems may be static, if travel times variation functions are known in advance, or dynamic, if those functions evolve during the simulation basing on real-time data on traffic conditions. Another distinction can be applied between deterministic and stochastic information on the travel time variations. Since in this paper, we deal with the static and deterministic version of the problem, the literature review is focused on this type of problems. For a complete survey on the other version of the problem, the reader may refer to Gendreau et al. (2015).

The first to analyze the TDVRP was Beasley (1981), who adapted the savings algorithm, taking into account a planning horizon composed by two periods with different travel times. Malandraki and Daskin (1992), addressed a TDVRP, with time windows and service time at nodes, in which travel times are computed by means of simple step functions. They proposed a mixed integer linear programming formulation, a nearest-neighbor based heuristic and a branch-and-cut algorithm, while in Malandraki and Dial (1996), a dynamic programming algorithm is used to solve the time-dependent traveling salesman problem (TDTSP), a special case of the TDVRP, in which a single vehicle is involved. Hill and Benton (1992), proposed a modeling approach in which time dependent constant pieceweise travel speeds are considered. Horn (2000), proposed a model with linear piecewise travel speed and quadratic piecewise travel times. The major weakness of all the above described models is that they do not satisfy the FIFO property. This issue limits their applicability to real-life problems. In Ichoua et al. (2003), the authors present a time-dependent travel speed model in which time is discretized into time-slots, that could be as small as necessary to correctly describe speed fluctuation, and travel speed is given by a different linear function for each slot, ensuring continuity on the border of adjacent timeslots. In this way, travel speed is defined as a continuous function and could be better represent real cases. Nevertheless, this approach could not correctly represent peaks sharpness because travel speed is supposed to linearly vary. To overcome this limitation, Mancini (2014), modeled travel times as polynomial functions, in order to better represent rush hour peaks and fluctuations. Cordeau et al. (2014), in a study on the TDTSP, have pointed out that the more travel times fluctuation pattern of the arcs are similar among each others, the more the TSP solution obtained considering constant travel times is accurate also for the TDTSP. If all the arcs in the network share exactly the same pattern, the optimal solution for the TSP is equal to the optimal solution for the TDTSP. As observed in Gendreau et al. (2015), results provided by Cordeau et al. (2014) can be extended to a wider class of routing general multiple problems with vehicles where the objective is to minimize the makespan, i.e, the longest route duration.

In Crainic et al. (2012), the authors addressed different scenarios, in each one of which travel times on arcs are different but it is supposed to be constant along all the delivery phase. This approach could be adopted to analyze different periods of the day, as early morning, lunch time, late afternoon, under the assumption that the delivery operations are performed within the same time period. This could hold in some practical application, or when only qualitative responses are needed, (i.e. How much do we gain performing delivery during the afternoon instead to carry out it in the early morning?) while it cannot be applied in cases in which travel times fluctuations are very frequent and/or asynchronous.

From a methodological point of view, several heuristic methods have been proposed to address the static and deterministic TDVRP. In Jung and Haghani (2001), the authors proposed a solution method based on a genetic algorithm. An application to fresh and perishable food delivery has been addressed in Osvald and Stirn (2008). The most innovative aspect of this work concerns the consideration of the perishability of the goods is considered as part of the overall distribution costs. The problem is solved by a Tabu Search (TS) heuristic that, tested on real data coming from the Slovenian food market, shows that, optimizing the routing plan, it is possible to strongly reduce the amount of spoiled goods. In Hashimoto et al. (2008) the author proposed an Iterated Local Search heuristic for the TDVRP with Time Windows. The same problem has been addressed by Maden et al. (2009) in which the authors proposed a TS, and by Balseiro et al. (2011), where an Ant Colony System, (ACS), hybridized with an insertion heuristic, is presented. The authors noted that, at the end of the search, the ACS tends to produce infeasible solutions, which are further repaired by the insertion heuristic. This method has been proved to be very competitive, improving and/or matching the best known solution on different benchmark sets. Figliozzi (2012), proposed a fast iterative route construction and solution improvement method for the TDVRP with Time Windows and investigate the impact of the overlapping of the congested periods distribution and the customer time windows distribution, on the number of vehicles used. In Harwood (2003), the author proposed a quickly travel time estimation technique which results in a neighborhood exploration. The method losses its competitiveness with the increasing of the problem size. Zhang et al. (2012), addressed the TDVRPTW with simultaneous pickup and delivery, proposing an hybrid ACS and TS heuristic. Kuo et al. (2009), studied an interesting variant of the TDVRP in which the goal is to minimize the total fuel consumption. In Jabali et al. (2012), the objective function considers the minimization of fuel consumption, CO_2 emission and travel time. Since all these issues are correlated to the vehicle speed, the authors decided to model the vehicle speeds on arcs, as decision variables. Franceschetti et al. (2013), addressed the CO_2 emission issue, but taking into account, as input data, speed reductions imposed by traffic congestion. Although many heuristic approaches have been proposed across the years, literature review on exact methods is much more limited. Soler et al. (2009), introduced a graph transformation from TDVRPTW to an Asymmetric Capacitated Vehicle Routing Problem, for which several efficient exact and heuristic algorithms, are available in the literature while Dabia et al. (2012), presented an arc-based formulation for the TDVRPTW and developed a Branch-and-Price in which the master problem results to be a Set Partitioning while the pricing problem becomes time-dependent shortest path with resource constraints.

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