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Real-time multi-depot vehicle type rescheduling problem

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ABSTRACT

The multiple-depot vehicle type rescheduling problem (MDVTRSP) is a dynamic extension of the classic multiple-depot vehicle scheduling problem (MDVSP), where a heterogeneous fleet is considered. The MDVTRSP consists of finding a new schedule given that a severe disruption occurred in previously scheduled trips very quickly, simultaneously minimizing the transportation costs and the deviations from the original plan. Although several mathematical formulations and solution methods have been developed for the robust MDVTRSP, the real time MDVTRSP is still unexplored. In this paper, we introduce a formulation of the problem and develop a heuristic solution method, employing time-space network, truncated column generation, and preprocessing procedures. The solution method has been implemented in several algorithm variants, combining different developed preprocessing methods. Computational experiments on randomly generated instances were performed to evaluate the performance of the developed algorithms. The best solutions concerning efficiency and efficacy were obtained by the variants considering state space reductions to accelerate the convergence process of the column generation. Solutions were obtained very quickly (in less than 150 seconds for large instances, considering up to 2500 trips, eight depots, and one breakdown. The developed heuristics also presented a good behavior for several simultaneous disruptions, solving the problem with a little increase (less than 8.5%, on average) in the required CPU time. A case study using data from a real-life small instance in Brazil also demonstrated the efficiency and efficacy of the approach when compared with manual planning strategies.

1. Introduction

Public transportation systems are susceptible to disruptions such as vehicle breakdowns, staff problems, and traffic accidents. For example, in London Buses, the subsidiary of Transport for London that manages bus services within Greater London, 2.4% of the scheduled mileage was lost due to a serious vehicle breakdown, traffic or staff problems in 2016/2017 (https://tfl.gov.uk/corporate/publications-and-reports/buses-performance-data), representing 13.2 million km. While minor vehicle failures can be repaired quickly, serious failures require long repair times and in general, results in towing the disabled vehicle for lengthy repairs or long-term maintenance.

This paper is focused on the real-time schedule recovery for the case of serious staff problems or vehicle failures — generalized in this article as “vehicle breakdowns”. Such problems require that the passengers from the disabled vehicle

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and those expected on the remaining part of the trip are to be picked up. Also, since the vehicle serving the disrupted trip may have future trips assigned to it, the given schedule may be deteriorated to the extent that the off-line plan may need to be adjusted in real-time, depending on the current state of what is certainly a dynamic system. Usually, without the help of a rescheduling algorithm, the dispatcher either cancels the trips that are initially scheduled to be covered by the disabled vehicle (when there are upcoming planned future trips that could serve the expected demand for the canceled trips) or simply dispatches an extra available vehicle from a depot. In both cases, there may be considerable delays introduced. This manual approach may result in a weak solution. The implementation of new vehicle communication technologies in public transit systems makes it possible to implement real-time vehicle recovery algorithms at a low cost.

In some sense, the vehicle rescheduling problem (VRSP) can be viewed as a dynamic version of the classic vehicle scheduling problem (VSP) where assignments are dynamically generated (Li et al., 2007). Although the VSP is a well-studied problem, the VRSP and its variants present peculiarities and a diversity of situations that make the problems very difficult to model and solve. The rescheduling problem must be solved in short computational times so that the disruption is controlled as soon as possible. Another issue for developing a new schedule is the associated crew scheduling problem. If the new plan is very different from the current one, then it might be difficult to assign crews to trips with which they are unfamiliar. Thus, having minimal changes to the current schedule should be a consideration in rescheduling. Finally, note that a vehicle breakdown could lead to delays of multiple trips. The current trip that is directly affected by the breakdown is indeed delayed. The vehicle breakdown may also delay other trips. Usually, the nominal time describing a scheduled trip includes some slack times to allow for small delays so that small variations in starting times can be easily tolerated. However, large delays are usually not acceptable by both potential passengers and transit system regulators. It is also worth mentioning that multiple vehicles can break down simultaneously, for example, during poor weather conditions; the recovery method should account for these extreme, but frequent situations to be useful in real-world applications.

Although there are some modeling tools to deal with the real-time vehicle recovery problem (Visentini et al., 2014), the existing formulations do not recognize important aspects related to the problem addressed in this paper. Some of them limit the disruptions only to delays; others apply algorithms and heuristics whose performances are incompatible with the dimensions of real-world problems (involving thousands of trips and vehicles), while some neglect schedule disruption costs and the impact of extreme changes in the off-line scheduling. Under these approaches, the vehicle rescheduling is only applied to very limited real-world situations.

This paper proposes a formulation for the multi-depot vehicle type rescheduling problem (MDVTRSP) and a heuristic framework for solving the problem; incorporating truncated column generation (CG) and state space reduction techniques. We address the real-time MDVTRSP not only with a focus on providing real plans for the transit operator in a very efficient way, but also accounting for passenger demand and introducing the minimum delay in the involved trips to be serviced. In our solution method, we reschedule the whole disrupted transit network, considering the set of occurred disruptions. The vehicle rescheduling network is rebuilt and resolved — allowing the disrupted trip and all non-initiated trips to be rescheduled to a new vehicle route. The developed algorithms include the consideration of schedule disruption costs and the minimization of the number of changes in the initial off-line scheduling. They are also capable of handling simultaneous multiple trip interruptions and deal with thousands of trips. The performance of the heuristic algorithms is assessed on randomly-generated instances up to 2500 trips, eight depots, and three vehicle types, and in a real-life case of the transit network of Santa Maria, Brazil. The obtained results show that the developed algorithm has a potential to be used in real-world applications, requiring low CPU times to obtain acceptable solutions.

The contributions of this paper are as follows: (i) to introduce a formulation for the real-time MDVTRSP; (ii) to develop an integrated heuristic framework, combining several modeling and solution techniques capable of offering very quick solutions to the problem; (iii) to analyze the performance of the developed algorithm variants that compose the heuristic framework, offering some guidance of the best option for different circumstances; (iv) to take into account a heterogeneous fleet, a common characteristic of transit networks of most large size cities around the world (Roman, 2016), but neglected in the VSP literature, with the exception of Ceder (2011), Hassold and Ceder (2014), and Guedes and Borenstein (2015); and (v) to demonstrate through a case study that the approach can be used with benefits to handling serious disruptions in real world transit systems. To the best of our knowledge, the developed approach is the only alternative to solve the real time MDVTRSP, without considering strong assumptions such as a depot per vehicle type.

The paper is organized as follows. Section 2 reviews the literature on the MDVTRSP. Section 3 introduces the problem, explicitly defining our assumptions to model and solve it. The developed mathematical formulation of the problem is presented in Section 4. The solution method is described in detail in Section 5. Section 6 describes the computational experiments carried out to evaluate the performance of the developed solution method. A case study using a small instance is discussed in Section 7. Finally, a summary of the results and areas of future research are provided in Section 8.

2. Literature review

The interest in the automatic recovery of public transportation systems has followed the development of new information technologies (e.g. global positioning system, geographical information systems, mobiles, and smartphones). As real-time information is now available at low-cost, transportation companies might react to unexpected events in real time using automatic recovery tools. Several algorithms were developed for disruption management in airline (Clausen et al., 2010) and railway (Cacchiani et al., 2014) transportation. However, in bus-based public transit, because of the smaller costs involved,