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The dial-a-ride problem with electric vehicles and battery swapping stations

Mohamed Amine Masmoudi[a,*], Manar Hosny[b], Emrah Demir[c], Konstantinos N. Genikomsakis[d], Naoufel Cheikhrouhou[a]

[a] *Geneva School of Business Administration, University of Applied Sciences Western Switzerland (HES-SO), 1227 Carouge, Switzerland*
[b] *Computer Science Department, College of Computer and Information Sciences (CCIS), King Saud University (KSU), Riyadh, Saudi Arabia*
[c] *Panalpina Centre for Manufacturing and Logistics Research, Cardiff Business School, Cardiff University, Cardiff CF10 3EU, UK*
[d] *ERA Chair 'Net-Zero Energy Efficiency on City Districts, NZED' Unit, Research Institute for Energy, University of Mons, Rue de l'Epargne, 56, 7000 Mons, Belgium*

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ABSTRACT

The Dial-a-Ride Problem (DARP) consists of designing vehicle routes and schedules for customers with special needs and/or disabilities. The DARP with Electric Vehicles and battery swapping stations (DARP-EV) concerns scheduling a fleet of EVs to serve a set of pre-specified transport requests during a certain planning horizon. In addition, EVs can be recharged by swapping their batteries with charged ones from any battery-swap stations. We propose three enhanced Evolutionary Variable Neighborhood Search (EVO-VNS) algorithms to solve the DARP-EV. Extensive computational experiments highlight the relevance of the problem and confirm the efficiency of the proposed EVO-VNS algorithms in producing high quality solutions.

1. Introduction

The Americans with Disabilities Act (ADA) states that people with disabilities should have the same rights with respect to ease of access to public transportation as other people (ADA, 2009). Such legislations, besides an increase in public awareness to facilitate the lives of the disabled, have led to a substantial demand for specialized transport services that cater for the needs of these people.

Arguably one of the most challenging problems of specialized transport services is the well-known Dial-a-Ride Problem (DARP), which consists of determining vehicle routes for a set of customers (or patients) who need special transport services. In the DARP, it assumed that each user requests transportation from a specific origin to a specific destination. In other words, we have a pair of requests that are connected to the same user: the outbound request (from origin to destination) and the inbound request (from destination to origin). However, it is not mandatory that the customer is transported directly to the destination (i.e., customers may share rides) (Muelas et al., 2013). These requests are also specified within certain desired pickup or drop off times.

Real-life applications of the DARP may have additional requirements, depending on the vehicle fleet characteristics. This research incorporates several such requirements, namely, (*i*) a fleet of electric vehicles; (*ii*) recharging stations with battery-swap services; and (*iii*) a realistic energy consumption function. In what follows, we explain these requirements in detail.

First, in most DARPs, the transport is executed by a fleet of gasoline-fueled internal combustion engine vehicles. However, these vehicles are known to be a main source of harmful emissions (i.e., air pollution and greenhouse gases (GHGs)) (Demir et al., 2015). In

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[*] Corresponding author.

E-mail addresses: mohamed.masmoudi@hesge.ch (M.A. Masmoudi), mifawzi@ksu.edu.sa (M. Hosny), DemirE@cardiff.ac.uk (E. Demir), konstantinos.genikomsakis@umons.ac.be (K.N. Genikomsakis), naoufel.cheikhrouhou@hesge.ch (N. Cheikhrouhou).

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order to tackle the emissions problem, the use of electric vehicles (EVs) has received considerable attention over the past few years in the field of the Vehicle Routing Problem (VRP) (see, e.g., Schneider et al., 2014; Hof et al., 2017; Schiffer and Walther, 2017). This relatively new research problem is well-known as the Electric Vehicle Routing Problem (E-VRP). This has inspired us to consider electric vehicles in the context of DARP, which, to the best of our knowledge, has not been previously studied in the literature.

The Dial-a-Ride Problem with Electric Vehicles and battery swapping stations (DARP-EV) arises specifically in healthcare services that concern non-emergency transportation of patients, where different patients are transported from certain origins (e.g., homes) to certain destinations (e.g., healthcare service locations) to receive treatment, medical examination or physical therapy. One such real world transport application service for the transportation of the elderly and the disabled is operated by the company FlexCité, France. FlexCité is a private transport that offers services for the exclusive use of people with limited mobility. FlexCité has a fleet of electric vehicles (type: Electron II TPMR), where each one contains different capacity modes of transportation, with nine seats place for the disabled person and/or for his/her accompanies and three additional wheelchairs places. Other different types of electric vehicles (for example, ambulances and mini-buses) is used by the company “Cruise Car” in the US and the company “PAM75” in France, with electric vehicle type Nissan e-nv200.

One important difference between the E-VRP and the traditional VRP, though, is that EVs have limitations in terms of driving range, and thus they need to be recharged during their service route. The limitation in the driving range of EVs and considering the need for recharging at specialized stations have been studied in the literature (see, e.g., Erdoğan and Miller-Hooks, 2012; Schneider et al., 2014). The main objective of the studied E-VRPs is to plan routes efficiently while considering both customers’ visits as well as frequent visits to recharging stations during the working day. Our research is similar to the studied E-VRPs, where we incorporate EVs as well as the recharging stations in the route planning while serving users in the context of DARP.

Second, to employ EVs in route planning, the battery recharging strategy becomes an essential aspect of the problem, due to many underlying challenges. For example, one challenge that arises in this respect is the low energy capacity of batteries, which usually cannot satisfy the needs of general transport customers (Fuller, 2016). Another challenge is that the battery may need several hours (e.g., 2–6 h) to be fully recharged from an empty-level (Agrawal et al., 2016). In the majority of E-VRPs, the charging strategy can be full recharging with a linear charging function in each visit to a recharging station (Goeke and Schneider, 2015; Hiermann et al., 2016), or partial recharging with a linear charging function (Felipe et al., 2014; Schiffer and Walther, 2017; Desaulniers et al., 2016), or partial recharging with a nonlinear function (Montoya et al., 2017; Froger et al., 2017a,b).

Fortunately, there is a sound alternative recharging mechanism that allows an EV to be recharged faster in only one to two minutes (Mak et al., 2013). This is done by swapping its battery instead of recharging it at a battery-swap station (Hof et al., 2017). Many researchers have recently considered the battery-swapping model in VRPs (see, e.g., Liao et al., 2016; Hof et al., 2017; Xu et al., 2017; Liu and Wang, 2017). The battery-swap strategy is particularly useful in the context of the DARP due to the user satisfaction constraints that require limiting the user’s ride time. In fact, due to the hard temporal constraints in DARP (time windows, ride time and maximum route duration) (Cordeau and Laporte, 2007; Parragh et al., 2008), which makes it hard to effectively design the planning to satisfy the users requests, it is more effective to use the battery swapping recharging mechanism, since it allows EVs to be recharged very quickly. In addition, the battery-swapping strategy improves the productivity of vehicles and reduces the charging costs (Yang and Sun, 2015). Actually, the adoption of battery swapping recharging mechanism for electric vehicles, especially for mini-buses and buses, has been realized in many real cases. For example, around 174 battery-swap stations are implemented in China (Hua, 2015), and more than 200 electric buses using battery-swapping are operated for transportation in the eastern Chinese harbor city of Quigdao (Li, 2016). Also, many companies in China provide battery swapping technology, such as, the Xj group company that invests in battery swapping for buses and Shuttle buses (Hua, 2015). In addition, in recent years, there have been several projects that promote battery swapping for electric (mini) buses in several countries (PMGROW Corp.). For other real applications and projects using battery-swap vehicles and battery-swap stations, interested readers are referred to Earley et al.(2011), Kim et al.(2015), Wan et al.(2015), Mahmoud et al.(2016), Zhou et al.(2016), Shao et al. (2017), and He et al.(2018).

In this paper, we consider intermediate stops for battery swapping of EVs. In fact, today EVs are quickly entering the market, and as a result public recharging stations are increasingly in demand and are becoming more available. Thus, rather than full/partial recharging, we can consider that in each visit to any recharging public station, the depleted battery will be replaced by a full one as followed by Li (2013).

Finally, we note that recent studies of EVs with battery-swap feature consider that the new battery is deployed after around 100 miles in a single trip (see, e.g., Adler and Mirchandani, 2014; Liao et al., 2016; Xu et al., 2017). Nevertheless, this assumption might not be realistic, since the service time to deploy the battery depends on the energy consumed by the vehicle during its journey. These factors include engine efficiency, regenerative power, road slope, etc. (Wu et al., 2015). To include these factors, we apply a realistic energy consumption model of Genikomsakis and Mitrentsis (2017), in order to determine the service time when the depleted battery should be replaced by a full one.

To sum up, the problem at hand is so-called the Dial-a-Ride Problem with Electric Vehicles and battery swapping stations (DARP-EV), which can be considered as a combination of the traditional DARP and the E-VRP. In addition, we consider that different types of users need to be transported. For example, a user may need a stretcher or a wheelchair. Thus, the EVs fleet considered in our work is a heterogeneous fleet; i.e., it consists of vehicles having different capacity resources, such as passenger seats, stretchers and wheelchairs. Hence, our problem belongs to the heterogeneous DARP category, as studied by Parragh (2011), Braekers et al. (2014), Braekers and Kovacs (2016), and Masmoudi et al. (2016, 2017). Using different capacity resources as well as different types of users is considered more complex and more general than the traditional DARP (with homogeneous capacity vehicles and single type of users) (Parragh, 2011).

Since our DARP-EV is a combination of the classical DARP, which is NP-hard (Cordeau and Laporte, 2007), and the E-VRP, which