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A heuristic approach for the green vehicle routing problem with multiple technologies and partial recharges

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ABSTRACT

This paper presents several heuristics for a variation of the vehicle routing problem in which the transportation fleet is composed of electric vehicles with limited autonomy in need for recharge during their duties. In addition to the routing plan, the amount of energy recharged and the technology used must also be determined. Constructive and local search heuristics are proposed, which are exploited within a non deterministic Simulated Annealing framework. Extensive computational results on varying instances are reported, evaluating the performance of the proposed algorithms and analyzing the distinctive elements of the problem (size, geographical configuration, recharge stations, autonomy, technologies, etc.).

1. Introduction

Electric vehicles (EV) represent a promising opportunity for reducing costs and pollution caused by transport and mobility operations. Although their diffusion is still hampered by a number of limitations, such as limited driving range, long recharging times and high initial cost, there is continuous technological progress to improve the reliability and durability of batteries, charging infrastructures and plug-in solutions. Analogous progress is needed on the side of fleet management and logistics optimization. As pointed out by Touati-Moungla and Jost (2010), whereas the development of EV through battery autonomy grows extensively, the research dedicated to EV routing, recharge stations location and vehicles redistribution has not been significant until the last years. Some works concerning charging network planning can be found in Frade et al. (2011),Chen et al. (2013), Nie and Ghamami (2013) and Cavadas et al. (2014), among others.

Nevertheless, routing is a major aspect of EV management, because efficient EV routing plays a major role for encouraging EV use (for a survey on vehicle routing problems see, for example, Toth and Vigo (2002) and Golden et al. (2008)). One of the new challenges is the EV routing problem, which in addition to the traditional issues of the routing problems, must also consider the particularities of autonomy, charge and battery degradation of the EV.

Among the works dealing with EV routing, in Touati-Moungla and Jost (2010) the authors present a mathematical formulation of the energy shortest path problem and the energy routing problem and expose some relationships between these problems and other well-known routing problems. Barco et al. (2013) present a scheme that coordinates the routing, scheduling of charge and operating costs of EV. Conrad and Figliozzi (2011) introduce the recharging vehicle routing problem (RVRP) wherein vehicles with limited range must service a predetermined set of customers but may recharge at certain

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customer locations in order to continue a tour. The problem is introduced as an extension of the distance-constrained VRP (DCVRP) and theoretical bounds are derived to predict and test solution behavior. Instead of performing recharges only at customer locations, Erdogan and Miller-Hooks (2012) consider the existence of locations devoted only to recharge stations. The problem introduced in their paper is called the Green Vehicle Routing Problem (GVRP). It is a variation of the VRP in which the fleet is composed of alternative fuel powered vehicles with limited autonomy in need for recharge during the execution of their duties. This means that the computation of an optimal set of routes must also take into account the problem of deciding where and when each vehicle is recharged (if needed). GVRP considers a limited fuel capacity of the vehicles and the possibility to refuel at alternative fuel stations. The maximum duration of a route is restricted, and for each refueling operation, as well as for each customer visit, a fixed service time is considered.

The model introduced in Erdogan and Miller-Hooks (2012) is, to the best of our knowledge, the first routing model that considers recharge stations. Schneider et al. (2014) extend their work by introducing the Electric Vehicle Routing Problem with Time Windows and Recharge Stations (E-VRPTW), which incorporates the possibility of recharging at any of the available stations with non fixed recharging times, but dependent on the battery charge of the vehicle on arrival at the station. Moreover, capacity constraints on vehicles and customer time windows are included. E-VRPTW aims at minimizing the number of employed vehicles and total traveled distance. More recently, Lin et al. (2014) present a survey of green vehicle routing problems, pointing out that the research on GVRP deals with the optimization of energy consumption of transportation. Some of the GVRP works deal with computing and minimizing fuel consumption, (see Kara et al. (2007),Kuo (2010), Preis et al. (2012),Xiao et al. (2012); or Küçükoolu et al. (2013)), whereas Erdogan and Miller-Hooks (2012) and Schneider et al. (2014) address problems related to optimizing when and where to refuel or recharge the vehicles in order to minimize total energy cost. The authors of this survey suggest that those last models should be extended in order to introduce additional constraints.

This paper approaches the Green Vehicle Routing Problem with Multiple Technologies and Partial Recharges (GVRP-MTPR). It extends the GVRP introduced by Erdogan and Miller-Hooks (2012) in an alternative way as in Schneider et al. (2014), by including several realistic considerations. First, we consider the possibility of performing a partial recharge at a station. This implies that for each vehicle we have to decide where and when to recharge, but also how much. This extension is motivated by the potential cost savings that can be obtained by using partial recharges, because they could save recharge time and thus facilitate meeting the maximum duration constraint and reduce the number of vehicles needed, and also the energy that was not recharged *en route* could be recharged at the depot at a much cheaper cost.

The cost due to battery amortization is also considered in the objective function. Besides, a battery recharge operation can be done in different ways with different technologies, implying different recharging time and cost. A charging point is comparable to a petrol pump, but in the case of EV it is done by plugging the car to the electric grid. With the kind of recharge on a conventional household plug, the charging usually takes several hours, and thus it is usually used to recharge the vehicles at the depot during the night. This is the cheapest technology available and, as a consequence, vehicles will usually depart from the depot with fully charged batteries. There are, however, some existing technologies that allow for faster, though more expensive, recharges. One example is the CHAdeMO protocol (see, for example, Paschero et al. (2013)), that allows for full battery recharges in around one hour. Furthermore, there are also some wireless charging systems that work while the vehicles stand on a platform and allow for recharges around twice as fast as CHAdeMO, at the expense of a higher cost. In any case, this area is highly research active nowadays.

To the best of authors' knowledge, a problem with the above described characteristics, the GVRP-MTPR, has not been approached in the literature yet. In this paper a mathematical programming formulation for the GVRP-MTPR is proposed, which can be used to solve small instances of the problem. However, since solving it to optimality for realistic sized instances is prohibitive, we decided to focus on heuristic approaches. Many different heuristics have been successfully applied to vehicle routing problems with additional constraints, providing near optimal solutions within a short computational time. A good example of this is the heuristic presented in Pisinger and Ropke (2007), that can be applied to different versions of the vehicle routing problem. In Vidal et al. (2012), a survey on heuristics and metaheuristics for different versions of the Vehicle Routing Problem can also be found. Furthermore, previous approaches to problems similar to the one approached in this paper also focused on heuristics: Erdogan and Miller-Hooks (2012) proposed two constructive heuristics, a modified Clarke and Wright savings heuristic and a Density-Based Clustering algorithm, and Schneider et al. (2014) used a hybrid approach combining Variable Neighborhood Search and Tabu Search. This paper introduces several constructive and local search heuristics that are exploited within a Simulated Annealing (SA) algorithm. Simulated Annealing has been successfully applied to many different kinds of problems (Suman and Kumar (2006), provide a survey on applications of SA), and in particular to vehicle routing problems (see, for example, Kuo (2010), where a SA algorithm is proposed for finding the vehicle routing with the lowest total fuel consumption).

The main contributions of the paper can be summarized as follows. We study a routing problem with electric vehicles (the GVRP-MTPR) that extends previously formulated problems by considering additional realistic elements, such as the use of different recharge technologies and the possibility of performing partial recharges. Both of them have a wide potential to provide energy consumption savings. A mathematical formulation for this new problem is provided, together with several fast heuristics that are able to construct good quality solutions for real size instances. Finally, a comprehensive computational study to evaluate their performance and the impact of the new elements of the problem is presented. For this purpose, we have created a benchmark for the GVRP-MTPR, including instances with different configurations, and we have also considered some additional instances available in the literature for similar problems: the E-VRPTW instances of Schneider et al.