The Issues with the Electric Vehicle Routing Variants

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ABSTRACT: *Electric vehicles (EVs) reflects the viable solution but have some limitations especially in terms of autonomy. We advocate that the efficient routing of EVs is crucial to encourage their use. This article surveys the existing research related to electric vehicle routing problems (EVRP) and their variants. It examines EVRP in terms of their definitions, their objectives, and algorithms proposed for solving them.*

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1. Introduction

Although, electric vehicles face several challenges such as: the low energy density of batteries compared to the fuel of combustion engined vehicles, the long recharge times compared to the relatively fast process of refueling a tank and the scarcity of public charging stations, they contribute to a sustainable and environmental friendly freight transportation by reducing the air pollution.

Electric vehicle routing problem and variants are considered as optimization problems and, more specifically, they belong to the combinatorial optimization problem that can be solved by two types of solution methods: exact methods and approximate ones.

This paper presents an overview of different problems related to the electric vehicle routing, different variants and solution methods found in the scientific literature. The rest of the paper is structured as follows. First, Section 2 gives the main characteristics of EVRP. Then Section 3 enumerates the electric vehicles drawbacks. Section 4 describes the variants of EVRP presented in the literature. Finally, Section 5 reports on different solution methods for EVRP.

2. Characteristics of EVRP

The electric vehicle routing problem aims at routing a fleet of EVs on a given network, or a subset of a network, to serve a set of customers under specified constraints in order to optimize one or several fixed objective(s). So, an EV routing problem can be defined in terms of the following components:

• **Network:** The network can be represented as a graph composed of nodes referring to cities, customers and depots and arcs standing for connections. Sometimes, we assign to each arc the cost considering that the distance is known and given for each arc. Time windows associated with nodes or arcs may also be defined in some problems.

• **Demand:** The demands are either given for each node and are known in advance in the case of deterministic problem or given by probabilistic formulas.

• **Fleet:** The fleet refers to a set or a group of EVs. In fact, it is associated to the electric vehicles available to the routing problem, hence we can either have a homogeneous or a heterogeneous fleet.

• **Electric Vehicles Recharging Technologies:** Unlike the combustible vehicles, the electric vehicles are charged by plugging the car to the electric grid. There are four main technologies:

- **Household Charging:** EVs can be charged by a conventional household plug using a cable and a connector in the vehicle. This technology is slow.
- **Fast Charging:** This technology is a conductive charging method. It's faster than the previous one.
- **Wireless Charging Systems:** also known as inductive charging is an emerging technology that allows EV recharging without the use of a cabled connection.
- **Battery Swap:** It's a high-speed method.

• **Cost:** The cost is a term that depends on different parameters. It depends on the distance traveled, the energy consumed and the time of the travel. In addition, in the case of the time window variant, there are some penalties that could be added if the window isn't respected. Moreover, the cost changes from one recharging technology to another.

• **Objectives:** It could be a single-objective problem or a multi-objective problem according to the number of objectives considered. The objectives are very diversified because the EVRP has a lot of components in its definition, for instance, minimizing the total travelling distance, the delay time and the waiting time, the total cost, etc.

3. Electric Vehicles Challenges

To combat environmental and energy challenges, electric vehicles may provide a clean and safe alternative to the internal combustion engine vehicles. However, electric vehicles are still facing several weaknesses:

3.1 Autonomy Limitations

The vehicles have a much smaller driving range due to the limited battery capacity. The range of an electric vehicle depends on the number and type of batteries used but generally the driving range varies between 80 and 130 km for light duty EVs according to [13].

3.2 Long Charging Times

EVs often have long recharge times compared to the relatively fast process of refueling a tank which takes just a couple of minutes. Its charging time ranges between 0.5 and 12 hours as mentioned in [12]. Hence, the user must think about refueling at night for example.

3.3 Scarce Charging Infrastructure

The number of electric recharging stations is still very small compared with that of conventional fuel stations as the electric fuelling points are still in the development stages. So, the driver must do a research about the plug-in stations localisation to know where and when he will have the opportunity the recharge his EV.

4. EVRP and Variants

Several versions and extensions of the basic electric vehicle routing problem have been presented in the literature.

4.1 Green Vehicle Routing Problem (GVRP)

Erdogan and Miller-Hooks [3] are the rst to introduce the Green VRP which consists of alternative fuel-powered vehicle fleets with limited driving range and limited refueling infrastructure. The objective is to minimize the total distance traveled by the vehicles while allowing them to visit stations when necessary.

In [10], Ko‘c et al. proposed the same problem as Erdogan and Miller-Hooks with the motivation of saving the ecosystem and the health of humans while serving and executing the transportation and good distribution process.

More recently, J. Andelmin et al. [8] also studied the green vehicle routing problems taking into account the several particularities of autonomy and charging process of this type of vehicles. Hence, the refueling stops are allowed. Their model aims to find optimal routes while minimizing the total distance and by using a homogeneous fleet of vehicles. Contrary to Erdogan and Miller-Hooks, they didn’t put the restriction on the number of vehicles that must be used.

4.2 The Green Vehicle Routing Problem with Multiple Technologies and Partial Recharges

Felipe et al. [4] presents a variant in which different charging technologies are considered and partial EV charging is allowed in recharging stations when needed in order to ensure the continuity of the route.

4.3 Electric Vehicle Routing Problem

Lin et al. [7] presents a general Electric Vehicle Routing Problem (EVRP) that seeks to optimize the routing problem while minimizing the total cost related to the distance as well as to the energy consumption by the battery. The proposed EVRP nds the optimal routing strategy in which the total cost is minimized such that each customer is visited exactly once by one vehicle on its route, the total demand of the customers served on a route does not exceed the vehicle capacity.

4.4 Electric Vehicle Routing Problem with Non-Linear Charging Functions (EVRP-NL)

Montoya [12] extended current EVRP models to consider partial charging and non-linear charging functions which is more realistic for the charging process. In EVRP-NL, the task consists of minimizing the total traveling distance as well as the charging time since it does not depend on the total tour distance.

4.5 Electric Vehicle Routing Problem with Time Windows (EVRP-TW)

This variant seeks to satisfy the order of customers within certain time window. Many researches have been interested in studying this variant. Some of works found in the literature are outlined below.

4.5.1 EVRP-TW with Recharging Stations

In fact the time window variant of EVRP was first introduced by Schneider et al. [14]. They studied the electric vehicle routing problem with time windows and recharging stations (E-VRPTW) which incorporates the possibility of recharging at any of the available stations considering that the required recharging time depends on the state of the charge. Hence, electric vehicles, which have a restricted capacity, must reach cutomers within a time window while minimizing the number of vehicles used and the total travel distance.

4.5.2 Electric Vehicle Routing Problems with Time Windows

Desaulniers et al. [2] tackled the routing problem in which route planning has to take into account the limited driving range of EVs and the customer time window. The authors studied four variants of this problem. The first one allows a single recharge per route knowing that batteries must depart fully recharged from the station, the second one permits multiple recharges but only full rechargement are allowed unlike the next one where partial battery recharges are allowed but just one time and the last one with partial but multiple recharges permitted.

4.5.3 The Electric Fleet Size and Mix Vehicle Routing Problem with Time Windows and Recharging Stations

Hiermann et al. [6] aim to optimize the fleet and the vehicle routes including the choice of recharging times and recharging stations as the refuelling operation is assumed necessary for EVs because of the limited capacity storage of electricity by batteries. They considered that the fleet is heterogeneous which adds complexity to the problem. Furthermore, they incorporate the time windows constraint where customers have to be reached within a specified time interval.

4.5.4 The Recharging Vehicle Routing Problem with Time Window

Conrad and Figliozzi [1] introduced the recharging vehicle routing problem wherein vehicles with a limited range must service a set of customers, but may recharge at certain customer locations instead of using only dedicated recharging stations while operating within customer time window. In other words, the battery of a vehicle can be recharged while servicing the customer if needed. Also, the authors showed the impact of the customer time windows on the tour distance taking into account that the driving range is limited and the recharging time is long.

4.5.5 Electric Vehicle Routing Problem with Time Windows and Mixed Fleet

Goeke et al. [5] proposed to study a mixed fleet of electric vehicles and internal combustion vehicles. They consider that the energy consumption function isn't linear and follows a realistic model depending on multiple parameters like the speed of the vehicle and the load distribution. Hence, EVs can recharge anytime en route to enhance the driving range.

4.5.6 Partial Recharge Strategies for the Electric Vehicle Routing Problem with Time Windows

In their work, M. Keskin et al. [9] relax the full recharge restriction and allow partial recharging in order to minimize time. Therefore, shorter recharging durations are allowed especially when the customer time window is set. The objective of the model proposed is to minimize the total distance while respecting the time constraints. Concerning the partial recharge scheme, the charging process is identified by a continuous decision variable.

4.5.7 Heterogenous Electric Vehicle Routing Problem with Time Dependent Charging Costs and A Mixed Fleet

Sassi et al. [13] studied a new real-life routing problem in which they consider a number of realistic features such as: different charging technologies, coupling constraints between vehicles and charging technologies, charging station availability time windows, and charging costs depending on the time of the day. Also, partial charging is allowed and the cost of vehicles as well as the total travel and charging costs.

5. Solution Approaches Toevrp from Literature

In the literature, many studies work on finding sophisticated and efficient solution methods that can be applied to EVRP.

5.1 MCWS and DBCA

Two heuristics were proposed by Erdogan and Miller-Hooks [3] with the goal of finding a set of routes that represents the feasible solution of the green vehicle routing problem knowing that the authors have formulated it as a mixedinteger linear program (MILP). Actually the first one is the modified Clarke and Wright savings (MCWS) heuristic as the original Clarke and Wright algorithm was developed to tackle the classical vehicle routing problem and its variants, thus it was modified to take into consideration the need to visit stations that have to be inserted in the routes while avoiding redundant. Meanwhile, the second heuristic is the density-based clustering algorithm (DBCA) that consists of forming clusters in a clustering step dedicated for that and then the MCWS algorithm is applied for each single cluster.

5.2 Exact Algorithms

Desaulniers et al. [2] decided to solve the different variants of EVRP-TW presented in their paper using exact methods. They used the exact branch-price-and-cut algorithms adapted to each variant. Hence, for each variant a set of routes is generated and for that monodirectional and bidirectional labeling algorithms are presented.

Branch-and-price is a metaheuristic that was used by Hiermann et al. [6] to solve the E-FSMFTW which is formulated as a mixed-integer linear program (MILP). In fact, the algorithm has to insert the charging constraints in its procedure.

Exact methods were also used by J. Andelmin et al. [8] to solve set partitioning (SP) formulation of the green vehicle routing problem where each variable corresponds to a simple circuit of a route, thus each SP contains a limited subset of routes. The authors proposed an exact method composed from two phases: Phase I computes the lower and upper bounds, while Phase II executes the set partitioning heuristic and the dynamic programming algorithm.

Koc & Karaoglan [10] implemented the B & C (branch and cut) algorithm for the exact solution of the GVRP where the initial solution is generated using the classical simulated annealing. In addition, the authors adapted the simulated annealing to the problems related to the electric vehicle routing problem by adding the GVRP constraints to improve the results. At each step of the method the new solution is compared with the current one so that the best solutions is accepted.

5.3 Local Search Heuristics

In [4], some constructive and local search heuristics have been proposed by Felipe et al. to find feasible routes while considering the recharge constraints as well as the real-world size problems. In addition, the authors used the 48A algorithm in which they consider 48 combinations of improving algorithms with different neighborhood structures.

In their study, Sassi et al. [13] formulated the Heterogenous Electric Vehicle Routing Problem with Time Dependent Charging Costs and a Mixed Fleet (HEVRP-TDMF) using a Mixed Integer Programming Model. And to solve it, they worked with a Charging Routing Heuristic (CRH) in order to find feasible routes. This algorithm is based on two main steps: the first one manages the charging of EVs in depot and the second one solves the problem starting from the depart of EVs from the depot. Moreover, a Local Search Heuristic based on the Inject-Eject routine with three different insertion strategies has been introduced.

5.4 Hybrid Heuristics

5.4.1 Hybrid VNS/TS Heuristic

To solve the E-VRPTW, Schneider et al. [14] used a combination of Variable Neighbourhood Search (VNS) and Tabu Search (TS) heuristics in order to make use of the diversification of the search provided by the VNS algorithm and the efficiency of TS as many combinatorial problems have proved that this last heuristic is very strong. This combination has the aim to find feasible solutions while respecting all the constraints.

5.4.2 Multi-space Sampling Heuristic + Hybrid Metaheuristic

Montoya [12] adapted the multi-space sampling heuristic (MSH) used before to tackle the VRP with stochastic demand [11] to the green vehicle routing problem by designing a tailored route extraction procedure. MSH is a heuristic that consists of two main phases: the sampling phase and the assembling phase. Furthermore, a hybrid metaheuristc is proposed to tackle the EVRP with non linear charging function. The metaheuristic combines two heuristics: the iterated local search and heuristic concentration.

5.5 Adaptive Large Neighborhood Search Algorithm

The ALNS algorithm was also used by Hiermann et al. [6]. In order to optimize the location of the refueling stations during the routing process, a hybrid heuristic has been proposed. This heuristic is a combination of the Adaptive Large Neighbourhood Search (ALNS) and an embedded local search procedure that uses different neighbourhoods. Indeed, the local search was used to intensify and strengthen the search operation guided by the ALNS.

Moreover, like Hiermann et al., Goeke et al. [5] developed the Adaptive Large Neighborhood Search algorithm to address the Electric Vehicle Routing Problem with Time Windows and Mixed Fleet. They also enhanced the algorithm by a local search for intensification.

Also, the ALNS algorithm was proposed by M. Keskin et al. [9] to solve the EVRP with time window. The authors formulated the problem as a mixed integer linear program.

6. Conclusions

Over the last several years, the green vehicle routing problem has been widely studied. This survey lists the main works that exist in the scientific literature since its appearance in 2011 by Erdogan and Miller-Hooks.

Based on this paper, the models that have been proposed are single-objective. Yet, most of real problems in industry are multi-objective by nature, so a multi-objective variant of EVRP must be proposed.

References

[1] Conrad, R. G., Figliozzi, M. A. (2011). The recharging vehicle routing problem. *In*: IIE Annual Conference. Proceedings, p. 1-8. *Institute of Industrial Engineers-Publisher*.

[2] Desaulniers, G., Errico, F., Irnich, S., Schneider, M. (2016). Exact algorithms for electric vehicle-routing problems with time windows. *Operations Research*, 64 (6) 1388-1405.

[3] Erdogan, S., Miller-Hooks, E. (2012). A green vehicle routing problem. Transportation Research Part E: *Logistics and Transportation Review*, 48 (1) 100-114.

[4] Felipe, A., Ortu~no, M. T., Righini, G., Tirado, G. (2014). A heuristic approach for the green vehicle routing problem with multiple technologies and partial recharges. Transportation Research Part E: *Logistics and Transportation Review*, 71. 111-128.

[5] Goeke, D., Schneider, M. (2015). Routing a mixed fleet of electric and conventional vehicles. *European Journal of Operational Research*, 245. 81 - 99.

[6] Hiermann, G., Puchinger, J., Ropke, S., Hartl, R. F. (2013). The electric fleet size and mix vehicle routing problem with time windows and recharging stations. *European Journal of Operational Research*, 252 (3) 995-1018.

[7] Lin, Jane., O. W., Zhou, Wei. Electric vehicle routing problem. The organization, Transportation Research Procedia, 2016. The 9th International Conference on City Logistics, Tenerife, Canary Islands (Spain).

[8] Andelmin, Juho. E. B. (2017). An exact algorithm for the green vehicle routing problem. *Transportation Science*, 71.1288 - 1303.

[9] Keskin, M., Catay, B. (2016). Partial recharge strategies for the electric vehicle routing problem with time windows. Transportation Research Part C: *Emerging Technologies*, 65. 111 - 127.

[10] Koc, C., Karaoglan, I. (2016). The green vehicle routing problem: A heuristic based exact solution approach. *Applied Soft Computing*, 39. 154 - 164.

[11] Mendoza, J. E., Villegas, J. G. (2013). A multi-space sampling heuristic for the vehicle routing problem with stochastic demands. p. 1503-1516.

[12] Montoya, J.-A. (2016). Electric Vehicle Routing Problems : models and solution approaches. Computation and Language. PhD thesis, Universit–e de Nantes Angers Le Mans.

[13] Sassi, O., Oulamara, A. (2017). Electric vehicle scheduling and optimal charging problem: complexity, exact and heuristic approaches. *International Journal of Production Research*, 55 (2) 519-535.

[14] Schneider, M., Stenger, A., Goeke, D. (2014). The electric vehicle-routing problem with time windows and recharging stations. *Transportation Science*, 48 (4) 500-520.