The e-VRPTW with deliveries while charging

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1 Introduction

Recent research in logistics had given more and more importance to utilization of Electric Vehicles (EVs) and its benefits. Not only because current supply chains seem to not be sustainable in long-term [5], but also because year to year new laws are passed to regulate the greenhouse gas emissions in transportation and logistics operations [1]. Into this field, transportation of goods is one of the activities that is called to be greener due to the negative effects on the environment represented as pollution, congestion and noise. For this reason, present-day studies of green vehicle routing problems (GVRP) are increasing.

As [2] resume, some VRP variants aim to minimize : the total emission produced by the routing operation, the total energy consumption, the total number of vehicles used to perform the distribution, among others. Among them, a category is well known as the electric vehicle routing problem (e-VRP), where the fleet is composed by electric vehicles. It means vehicles have a limited autonomy due to the battery capacity and the energy consumption model. By consequence, recharging stations (RS) have to be considered to allow the vehicle to extend its driving limit at some points of the route. Additionally, recharging time plays an important role because it becomes representative in the total operational time.

The problem is studied by different authors who consider mixed fleet with non-electric vehicles, time windows, different recharging models, different energy consumption models and even decisions related to location of RS [1][3][4][5]. In this paper a variant of the e-VRP is studied where visiting a customer by bike or by walking is allowed while an electric vehicle is at a RS, that is pertinent for small-package shipping or maintenance services industries. This variant allows to take advantage of the recharging time and reduce the total distance performed by the EVs without extra costs, understanding that the driver cost time is a fixed cost.

2 Problem statement

The problem is defined on a graph $G = (V'_{0,N+1}, A)$ with a set of vertices $V'_{0,N+1} = \{V \cup F' \cup \{0, N+1\}\}$ and a set of arcs given by $A = \{(i,j)|i,j \in V'_{0,N+1}, i \neq j\}$. Let be $V = \{1, ..., N\}$ the set of customers, $F = \{0, ..., M\}$ the set of recharging stations, F' the set of dummy vertex that represents the visits to vertices on F. The depot vertex is denoted as 0 for departing vehicles and for arriving vehicles by $N + 1$.

Energy consumption and recharging times are assumed linear which, depend on distances and current charge level. Also, time windows, vehicle capacities, fixed fleet and the well-known constraints of the CVRPTW are considered into the model. Finally, the objective function aims to minimize the total recharging time, including the time to prepare the fleet before the operation and the recharging time during operation, because minimizing distance aims to guarantee the minimal fuel consumption while in this model the time during visiting a customer by foot or bike, also, represents a cost measured in time at the RS. Thus, the problem is formulated as a linear mixed-integer program (MIP).

3 Computational results and conclusions

The model was compared with public benchmark instances from [5] by carrying out a computational study and finding which are the difference by allowing the visits while charging. Tests are run on IBM ILOG CPLEX Optimization Studio Version : 12.6.3.0 on a machine with Intel(R) Core(TM) i5-5300U CPU @2.30GHz 2.30GHz and 8 GB RAM.

Preliminary results show important reductions in terms of total charging time and total distance by EV's. On average, allowing visiting while charging could reduce the total charging time up to 7% and total distance up to 8% as shown on Table 1. The results are shown by groups of instances as Schneider divided : *r* for random customer distribution, *c* for clustered customer distribution and *rc* as a mixture of both.

		Proposed model				**e-VRPTW (Min total charging time)**				**% Variation**			
Instance	# Customers	Rech. Time	Total Dist.	Routing Time	t (s.)	Rech. Time	Total Dist.	Routing Time	t (s.)	Rech. Time	Total Dist.	Routing Time	t (s.)
cXXXc5	5	555.39	156.75	1071.81	0.82	711.23	204.75	1190.86	0.75	-20.98	-22.94%	-8.48%	44.39%
rXXXc5	5	72.87	147.25	227.36	2.17	73.10	148.11	248.55	4.42	-0.33%	-0.54%	-4.20%	-52.86%
rcXXXc5	5	216.14	173.56	883.88	1.53	234.35	182.73	854.07	1.74	-3.31%	-5.80%	1.40%	12.64%
cXXXc10	10	824.09	236.88	1965.73	2411.96	998.71	284.71	1971.28	1893.71	-16.38%	-16.53%	-0.34%	416.58%
rXXXc10	10	108.46	217.82	410.30	2214.31	109.85	221.16	315.51	2009.60	-1.39%	-1.64%	-1.33%	142.96%
rcXXXc10	10	145.86	369.72	480.46	2016.28	142.38	362.45	490.47	1126.08	-0.47%	-0.96%	-3.89%	663.95%
									Average	-7.14%	-8.07%	-2.81%	204.61%

TAB. 1 – Comparison between Proposed model versus e-VRPTW

In this paper a novel variation for the VRP is proposed. Allowing visiting customers from RS by foot or by bike while charging demonstrate reach interesting solutions where the total distance performed by EVs is less. According to the preliminary tests, routing time (since the first vehicle departs until the last vehicle arrives to depot) does not have a representative change ; also the improvement is even more important when the customers are clustered. However, we aim to generate more efficient exact solution techniques to compare larger instances, and heuristic methods are going to be designed.

Références

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