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DYNAMIC ELECTRIC VEHICLE ROUTING PROBLEM

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Abstract

Increased use of electric vehicles requires the development of new services related to their charging and rational use while driving. One of these problems is the optimal choice of charging station while driving – dynamic EV routing problem. This paper presents the main challenges related to this service. After presenting the state of the art in this field, an analysis was performed and a method of multicriteria dynamic programming for solving this problem was proposed.

Key words: *Electric vehicle, optimal charging station selection, dynamic programming, multi criteria decision making*

1 INTRODUCTION

Fast economic and technological progression that cause nowadays climate change force economies to provide global reaction to prevent further environmental degradation. *EU* initiative to mitigate negative effects of climate change due to greenhouse gas (*GHG*) emission includes challenging targets. The 2050 goal towards preventing global warming is to reduce the total amount of *GHG* for 80-95% compared to the time before 1990 [1]. It is discussed that this target can be feasible by changing the way energy is being produced and used [2]. While the special attention in reaching out this goal is given to the transport sector as the most problematic one. Adopted target for transport sector in the next few decades predicts *GHG* decrease for 20% below the 2008 score and long-term target by the year 2050 predicts *GHG* decrease by 60 % [1]. Expansion of activities in the transport sector is followed by increase in passenger and freight road transport and predictions by the year of 2050 [3] reveal that passenger car will count for 67% of the total passenger transport. *EU* is putting many efforts to enhance efficiency of transport system by planning to half the number of vehicles that are using fossil fuels by 2030 and eliminate their use in the urban areas by 2050. In order to fulfill *EU* targets the transport industry needs to focus on designing and producing new low-carbon technology that can replace traditional transport alternatives on fossil fuel. Future development of transportation is addressed to electrification of the sector powered by clean energy sources in order to mitigate further climate change and environmental degradation [4].

Many international studies on carbon footprint and energy consumption highlight the fact that transport sector, especially in urban areas, cause excessive *GHG* emission and it is differentiated as the only sector that fails to decrease its environmental degradation over the years [5]. Large emission is the direct consequence of increased demand for logistic services due to fast industrial development [6]. Even now, transport sector heavily depends on the use of fossil fuels with more than 90% of all participants that relay on conventional non-renewable fuels [1]. In a contemporary research, authors [7] reveal that transport sector is responsible for almost a quarter of the global amount of produced carbon emission. High share in the global pollution is expected since the transport industry is in the core of every economic activity [8, 9] and it is forcing government to rethink about incentives to adopt clean environmental solutions [10]. Consequently, with large share of *GHG* emissions produced by transport activities, transport industry emerges as one of the key factor in shaping the future outcome of environmental protection initiatives. As a part of transport sector, logistic industry constantly seeks possibilities to develop modern and efficient transport solutions that could contribute to the development of the traditional transportation system in a sustainable manner [11]. The conceptual framework of sustainable transport system is described as the phenomena of green logistics. Green logistics represent environmentally friendly and efficient transport that aims at decreasing pollution caused by everyday transportation activities [12]. The core idea behind the green logistics is to integrate realization of logistic activities and economic progression while simultaneously protecting resources and environment [6]. The idea of green logistics can be accomplished by the use of electrical vehicles (*EVs*) that are fundamental part of green logistic. EVs are defined as decarbonized vehicles that use electrical energy from electrical charging stations to start their engines [7]. Unlike traditional vehicles that use conventional fossil fuels, *EVs* initiate novelty in automotive industry that propose low-carbon transportation. *EVs* are ecologically sustainable and modern technological solution because they can use clean energy generated from solar or wind renewable sources and achieve zero-emission [8]. Therefore, *EV* are independent from the use of fossil fuels and represent environmentally acceptable alternative in transportation. *EVs* are perceived as advanced technological response to arising climate change and environmental pollution issues [13].

2 ELECTRIC VEHICLE ROUTING PROBLEM (EVRP)

Fast Besides benefits they brings in terms of their environmental/social impacts on the city, *EV* introduces some challenges like battery capacity limitations, recharging time, charging services, cruising range etc. that influence their operation efficiency [14]. Considering particular features of the transportation activity, contemporary research reveals different clusters of problems where one that increasingly gain attention is Electric Vehicle Routing Problem (*EVRP*). The *EVRP* is created by introducing the issues of recharging scheme and restricted driving range of EVs into the traditional vehicle routing planning [15,16]. The *EVRP* belongs to the group of *NP*-hard problems where the routing and recharging issues are jointly optimized [17].

In comparison to hybrid models battery based *EVs* (*BEV*), due to the limited battery capacity, has much lower driving range (up to 240km [18]) which directly relates to recharging frequency. Currently, although steadily increasing, the share of *BEVs* on the market is relatively low, and respectively a density of installed charging stations (*CS*). In process of development of future infrastructural plans, mentioned issues opens up research opportunities both for the optimization of routing – traveling time to *CVs* and recharging time at the *CS*, and energy demand.

Besides recharging frequency an important issue in *EVRP* is the recharge time. It can be conducted in two ways: 1) by regular charging at the *CS*, or 2) by swapping empty batteries with charged ones [19]. Charging time can vary significantly (form few minutes to several hours) due to the battery state of charge level, battery capacity and charging technology [19]. Today, several charging technologies are available: slow (6-8 h); fast (1-2 h); and rapid (5-30min) [20]. Therefore one family of *EVRP* considers partial charging where optimization of energy network performance and economic side can be maximized. *BEV* should be recharged during the day enough only to complete the planed task and arrived at the final destination where the rest of the charging can be performed during the night when energy network load and electricity costs are generally lower [21]. The same logic stands for the battery swapping [22].

There are two main approaches to *EVRP*: heuristic and exact methods. Heuristics methods are suitable in solving large-scale problems when the objective is to find close enough to a satisfactory (optimal) solution in rational amount of time [23]. Constructive heuristics is frequently applied for finding initial solution usually 10-15% far from the optimal one [24]. Some examples includes the sweep algorithm [25], nearest neighbor heuristic (*NNH*) [26] or the modified savings method of Clarke and Wright (*MCWS*) [27]. Oftentimes, after achieving initial solution, metaheuristic approaches are applied for finding optimal one. Some of the well known neighborhood-oriented metaheuristics (iterative methods) are Tabu search [28], Simulated annealing [29], Iterated local search [30], Variable neighborhood search [31], Adaptive large neighborhood search [32].

The other widely applied group of methods in *EVRP* is population metaheuristics that considers multiple candidate solutions, inspired by the natural. Some of frequently used methods are evolutionary algorithms like selection genetic algorithm non-dominated sorting genetic algorithm [23], and population-based approaches, e.g. bee colony [33], ant colony (*ACO*) [34], particle swarm optimization [35]; scatter search [36].

In contrary to heuristic methods, exact methods are used for solving smaller scale problems, with a restricted number of cases because of the combinatorial nature of these *VRP* [37]. However, these methods are used to provide optimal solution at the given scale. As in case with heuristic approach, there is a number of algorithms in play but few of them like dynamic programming, *MIP*, branch-bound-cut-and-price (*BBCP*), set partitioning etc. are most frequently used [38]. For instance *BBCP* algorithm is used for developing model for nonlinear charging times [39]. Employing *BBCP* on customized one-way and two-way labeling algorithms [40] examine possible *EVRPs* with time windows, while [41] solve scenario with multiple charging stations and hundred costumers. Exact methods are often combined with some of the heuristic algorithms. Solving an on-road charging problems [42] employed dynamic modeling and integer programming algorithm, while [43] solved a model of utilization of different energy sources in combination with heuristic routing-first-distribution-later algorithm.

3 EXAMPLE

The *EV* driver must select a route from his current position *A* to arrive at the desired location *B*. During his trip, he must stop at the charging station to recharge the *EV* battery (*EV* chargers are marked in red in Fig. 1).

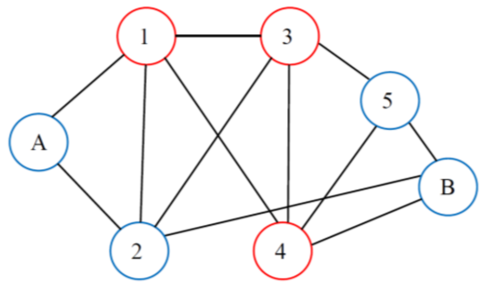

***Fig. 1** EV routing problem*

The driver receives the information about how long to wait at certain charging stations. The optimization function is then a combination of three criteria: the shortest route, the total driving time and waiting time at the charging station. The problem can be solved by dynamic programming.

A recursive relationship for computing the optimal-value function by recognizing that, at each stage, the decision in a particular state is determined simply by choosing the minimum total delay. Let the decision variables x_n be the immediate destination at stage *n*, $f_n(s,x_n)$ the the total delay (the combination of three criteria) for the remaining stages. given that the EV is in location *s*, ready to start stage *n*. x_n^* is a value that minimizes $f_n(s,x_n)$. Then:

$$f_n^*(s) = \min_n f_n(s, x_n) = f_n(s, x_n^*) \,, \tag{1}$$

$$f_n(s, x_n) = c_{sx_n} + f_{n+1}^*(x_n) \,. \tag{2}$$

The distances between the locations in Figure 1 are shown in Table 1.

Table 1 Distances between the locations (km)

	A	**1**	**2**	**3**	**4**	**5**	**B**
A	-	1	2	-	-	-	-
1	1	-	1	2	1	-	-
2	2	1	-	3	-	-	2
3	-	1	3	-	1	2	-
4	-	1	-	1	-	2	1
5	-	-	-	2	2	-	3
B	-	-	2	-	1	3	-

The assumed waiting times in the charging station 1, 3, and 4 are 10, 20, and 30 minutes respectfully, while the speed of movement between locations is equal to v = 40km/h. The cost function between two nodes can be described with (cost of going from stage k, state i to stage k+1, state j):

$$d(k,i,k+1,j) = w_1 \frac{l_{i,j}}{L} + w_2 \frac{t_{i,j}}{T} + w_3 c_j \,, \qquad (3)$$

where L=10km, T=120 min, $l_{i,j}$ is the distance between locations in km, $t_{i,j}$ indicates the time required to get from one location to another ($t_{i,j}= l_{i,j}/v$), whereas c_j waiting time at the charging station. Weight factors are marked with w_1, w_2, and w_3 and in this example are equal to 0.33. By minimizing the given function, the optimal solution is determined, which in our case, for such a defined example and given values, shows that the ideal route is equal to A-1-2-B.

4 CONCLUSION

In this paper, one of the main problems that occur when using electric vehicles is considered, which refers to the optimal choice of charging station while driving. This example shows that multicriteria dynamic programming can be a great solution for solving this problem.

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