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The method of route optimization of electric vehicle

Norbert Lech, Piotr Nikończuk*

West Pomeranian University of Technology Szczecin, Faculty of Maritime Technology and Transport, Al. Piatów 41,71-065 Szczecin, Poland

Abstract

Effective trip planning should consider the location of vehicle charging stations. Optimizing the route of electric vehicles should be carried out taking into account the location of the charging stations. The article presents a proposal of a method for optimizing electric vehicle journeys with the use of genetic algorithms. The method developed by the authors considers the range of the electric vehicle, the location of the charging stations and the parameters of the slow / fast charging station. Initial verification of the method was carried out on the example of a travel route in Poland, taking into account the actual locations of fast and slow charging stations. The criterion adopted was the minimization of the traveled distance.

Keywords:,Electic vehicle, route optimisatiom, genetic algorithms, emission of carbon dioxide

1. Introduction

Due to the minimization of carbon dioxide emissions to the atmosphere, more and more electric vehicles appear on the roads. In tourist areas, the emission of carbon dioxide is an important indicator of their attractiveness [1], therefore various actions are taken to reduce emissions through resource sharing services [2], including car sharing. Models of the impact of transport on the environment were also created [3], social platforms related to communities,

* Corrsponding author.
Email address: piotr.nikonczuk@zut.edu.pl

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aimed at signaling local problems [4], including environmental problems related to the emission of exhaust gases into the atmosphere and other, even unnoticeable emissions, e.g. 3D printers [5].

The authors conducted research on the optimization of electric vehicle routes in the regions of the Uznam and Wolin islands to improve their environmental conditions. In the initial phase, the authors verified the developed method to optimize travel between two large cities.

Unlike internal combustion vehicles, at present, further travel with an electric vehicle may be difficult due to the number and location of charging stations. Vehicle charging time is also a significant element of the travel. Electric vehicle route optimization is a complex topic that requires many factors to be considered. Due to the specificity of the issue and the variety of factors influencing the route, it is possible to observe in the literature and research many methods and algorithms aimed at designing optimal models of use and route selection for electric vehicles.

In one of the studies [7], an advanced route optimization model was presented, considering battery charging at charging stations and battery replacement by appropriately adapted vehicles at a specific place and time. To solve the complications related to the simultaneous consideration of these two options, the Non-Dominated Path Identification algorithm was used, allowing for the effective use of the model.

Article [8] focuses solely on charging stations. An Improved Whale Optimization Algorithm was used to solve the problem of low accuracy and stability while optimizing the locating and sizing of charging stations for electric vehicles. Whale Optimization Algorithm (WOA), which mimics the social behavior of humpback whales. The algorithm is inspired by the bubble-net hunting strategy. WOA is tested with 29 mathematical optimization problems and 6 structural design problems. Optimization results prove that the WOA algorithm is very competitive compared to the state-of-art meta-heuristic algorithms as well as conventional metods. [9]

An approach in which the problem of route optimization is placed on a par with environmental protection has also been observed in the literature. The publication [10] presents the impact of electric vehicles on the protection of the environment and microgrids used by these vehicles. To properly illustrate this issue, a model was created that takes into account economic and environmental factors. Moreover, annealing particle swarm optimization algorithm was used, whose task is to solve multi-criteria optimization problems. It is also important to consider the factors affecting the condition of the battery and its degradation.

The publication [11] presents a model in which, in addition to charging stations, the impact of battery degradation is described, however, these studies were carried out only for public transport vehicles.

Another method used to search for optimal routes for electric vehicles considering the possibility of charging during the route is the algorithm for optimizing an ant colony presented in the publication [12]. Ant colony optimization algorithm is a probabilistic technique for solving computational problems which can be reduced to finding good paths through graphs. Artificial ants stand for multi-agent methods inspired by the behavior of real ants. The pheromone-based communication of biological ants is often the predominant paradigm used. [13] This algorithm was used in the aforementioned article to solve the problem of electric vehicle routes with time windows based on two charging methods. Factors such as the minimization of transport and vehicle operating costs as well as power costs were taken into account in the study.

The article [14] uses a modified Bellman-Ford algorithm known as the Yen algorithm, which is an algorithm for finding all the shortest routes from all nodes to a given destination in general N-node networks [15]. This publication uses a different approach than in the previously described cases, because in addition to examining the battery degradation state, the influence of topography on the route selection was also considered. With significant changes in the terrain, it is an extremely important factor due to the additional loads associated with energy consumption.

A completely different approach to the issue of route optimization can be found in this publication [16]. To find optimal solutions to determine the real energy demand of an electric car, macro- and micro-simulation software was used, and tests were carried out on a simulator and on the real road network.

A graph-based shortest path algorithm was used in paper [17] to optimize the usage of dynamic wireless charging for electric vehicles. Wireless charging methods proposed in the work are intended to extend the driving range of electric vehicles without the need for larger batteries or overly costly infrastrucure.

2. Proposed method of optimization

As presented, there are multiple articles providing valuable information about usage of electric vehicles and possibilities of route optimization involving many variables. However each approach and the factors taken into account vary. In addition, the number of publications presenting various types of charging stations and their impact on the travel time of a given route and the impact of temperature on the range of the vehicle is negligible. This paper presents the implementation of the optimization task, which considers the use of fast and slow charging stations, their location along the route and the influence of temperature on potential losses in the range. To achieve the intended result, it was decided to execute the genetic algorithm using MATLAB software. In computer science and operations research, a genetic algorithm is a metaheuristic inspired by the process of natural selection that belongs to the larger class of evolutionary algorithms. Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems by relying on biologically inspired operators such as mutation, crossover and selection [18]. The goal of the study is to determine the fastest route between two set points and to investigate the impact of the location of the charging station and temperature on the battery charge status, which in turn translates into travel time.

In the calculations, each population of individuals is presented in the form of a matrix, where each row is a vector of a single individual. The length of the vector is *2n*, with half of the vector being *n* points represented by the position number in the table containing data on charging stations, and the second part of the vector represented in binary form whether there is a need to charge at the points indicated in the first half of the vector. Figure 1 shows the vector of an individual for optimizing the path through n points. In the vector, the symbols *P1-Pn* denote items in the table with data about charging stations, specifying travel points in the form of integers, while the symbols *L1-Ln* inform about charging at these points in the form of binary values.

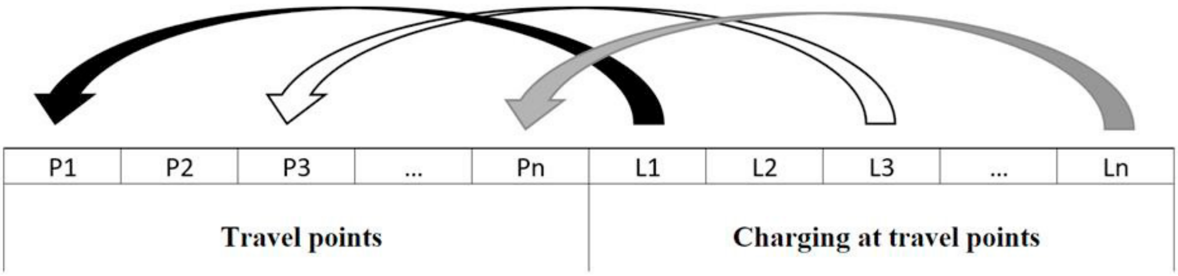

Fig. 1 - structure of an individual in the proposed solution to optimize the route of an electric vehicle

Due to the diversified representation of an individual (integers and binary numbers), for the simulation purposes, own functions of generating the initial population, crossing, mutation and other operations carried out in genetic algorithms were developed.

3. Simulation

To verify the operation of the algorithm, test data have been prepared based on actual charging points in Poland. The starting point was the charging station in Szczecin, and the end point was the charging station in Warsaw. 25 points were selected between the cities, which are actual charging stations. The genetic algorithm, prepared in the MATLAB environment, determines direct connections between points, which means that the obtained results are not adequate to the actual values, because the program does not consider roads. However, it was decided to choose the actual points because with the further development of the algorithm and the potential integration of the program into a map or navigation software, it is possible to calculate actual routes.

For the purposes of the simulation, an appropriate reference system was implemented to locate information about given points. The zero meridian and the equator were assumed as the coordinate axes. To transfer the data about the location of the charging stations, geographic coordinates were converted to metric values using the following formulas:

• For latitude:

$$x = 111{,}32\text{km} * \text{SG} \qquad (1)$$

For longitude:

$$y = \frac{40075km*cos(SG)}{360} * DG \qquad (2)$$

where: SG - latitude
DG – longitude.

The list of geographic and converted coordinates is presented in Table 1. Simplified formulas were used for the conversion, so the obtained results are estimated and may slightly differ from the real coordinates. The table also contains information on the type of slow / fast charging station. The following notation has been adopted: 1- fast charging, 2- slow charging.

Table 1. Charging points, geographic and converted coordinates and charging speed

No.	Charging point data	Distance from the zero meridian (x axis) [km]	Distance from the equator (y axis) [km]	Charger type - fast (1) or slow (2)	Geographic coordinates
1.	Al. Wojska Polskiego 74A 70-482 Szczecin	964,00	5 948,44	2	53.435509988440685, 14.538131798478451
2.	ul. Bukowska 46 62-081 Wysogotowo	1138,39	5834,62	1	52.41314283549806, 16.76440049844565
3.	ul. Wilkońskich 1 60-543 Poznań	1146,94	5835,02	1	52.41670493602726, 16.890235198445705
4.	ul. Świętego Michała 62 61-005 Poznań	1150,04	5834,88	2	52.41543852355243, 16.965916898445723
5.	ul. Szwedzka 10 61-285 Poznań	1154,34	5831,27	2	52.3829581283651, 16.987662140774045
6.	ul. Warszawska 246 61-055 Poznań	1155,24	5834,26	1	52.409821303157194, 17.008686998445576
7.	ul. Zjednoczenia 118 65-120 Zielona Góra	1062,03	5783,58	1	51.954538315727056, 15.478888127266412
8.	ul. Lwowska 2 65-225 Zielona Góra	1065,16	5781,5	1	51.93591882396004, 15.5176398272658
9.	ul. Rozwojowa 7 66-002 Nowy Kisielin	1072,24	5780,36	1	51.925664629255934, 15.617293028397723
10.	ul. Gorzowska 2 65-127 Zielona Góra	1065,84	5784,07	2	51.95901329098988, 15.534522798431224
11.	ul. Chałubińskiego 2 67-100 Nowa Sól	1080,46	5767,18	1	51.80729544714457, 15.695175127339027
12.	ul. Grunwaldzka 142 85-429 Bydgoszcz	1197,53	5915,25	1	53.13739346099393, 17.962203098545494
13	Al. Jana Pawła II 123 85-001 Bydgoszcz	1203,71	5911,55	2	53.10416276230423, 18.009371327380112
14.	ul. Łęczycka 6 85-737 Bydgoszcz	1206,37	5913,61	2	53.12268775675912, 18.05760991388771
15.	ul. Mariana Rejewskiego 3 85-791 Bydgoszcz	1209,95	5915,19	1	53.1376731522724, 18.116718869709857
16	ul. Fordońska 419 85-790 Bydgoszcz	1212,37	5916,05	1	53.14455458535053, 18.155794227381396
17.	ul. Chemików 7 09-411 Płock	1320,15	5854,18	1	52.588000543387935, 19.6501742561993
18.	ul. Bielska 67 09-400 Płock	1333,79	5851,3	2	52.56297882370724, 19.709023685034072
19.	ul. Wyszogrodzka 150 09-410 Płock	1338,19	5848,12	1	52.53439368458794, 19.76046336969068
20.	Stary Rynek 1 09-400 Płock	1332,44	5849,35	2	52.54535963069917, 19.68461389852656
21.	Dalanówek 43A 09-100 Płońsk	1383,49	5854,23	1	52.58922247982733, 20.452641027363637
22.	ul. Innowacyjna 11 95-050 Konstantynów Łódzki	1332,82	5760,08	1	51.74346862279287, 19.36512079850133
23.	ul. Kasprzaka 8 91-073 Łódź	1338,19	5763,3	2	51.772404818542036, 19.4259487985022
24.	ul. Jana Kilińskiego 296 93-160 Łódź	1343,12	5759,28	1	51.736272168027156, 19.480316856172433
25.	ul. Brzezińska 27/29 92-001 Łódź	1343,33	5765,64	1	51.79343182276562, 19.50929552733857
26.	ul. Byszewska 3a 92-701 Łódź	1349,06	5765,79	1	51.794748450835186, 19.59256819850297

27.	ul. Złota 59 00-120 Warszawa	1431,99	5814,36	1	52.2310575780651, 21.002330112009766

In the proposed optimization method, the optimization of the route was assumed, considering the range of the electric vehicle and the distance to the next charging station. It was also taken into account that quick charging does not allow the battery to be charged to full capacity, which reduces the range of the vehicle. In the optimization task in the proposed method, the total travel time Tt is minimized:

$$T_t \to \min \tag{3}$$

The assumptions made in the simulation are as follows:

o Maximum real range - 285km,

• The vehicle is traveling at an average speed of 60 km / h,

• "Fast" chargers allow you to charge the battery up to 80%, while "slow" chargers allow you to charge the battery up to 100%,

• Charging time with the "fast" charger is eight times shorter than with the "slow" charger,

• The algorithm assumes driving through four charging points, however, in a situation in which the generated results have a given point duplicated, it means that it was not necessary to use four points for the generated route,

• If one of the charging points is duplicated, it also means that the number of charging operations at that point does not exceed 1.

It was decided to choose the following parameters when trying to determine the optimal route:

• number of individuals in the population (population size) – 2000,

• number of populations – 2000,

• probability of crossing - 0.3,

• probability of mutation - 0.2.

In the numerical experiments 20 simulations were made. The obtained results are presented in a tabular form, which includes information about the charging point, which is used, whether the vehicle was charged at a given point and what time it took to cover the full route. Table 2 shows the best individual from each such simulation.

Due to the form of calculation, the resulting total travel times are presented in decimal *hh.m*. For the correct time format, the following conversion is performed:

$$hh.\min \to hh:60m \tag{4}$$

The conversion is rounded to two decimal places (to whole minutes) neglecting seconds.

The simulations show that there are two solutions in which the travel time differs slightly.

In addition to the data presented in the table, the program generates detailed data from the route, which is as follows:

• For a route with a total travel time of 9h 11min. (9,1891h):

o The vehicle traveled the route from the starting point to the charging station at point no. 3. The distance traveled on this section is 215.02 km, and the time needed to cover this distance is 3h 35min. (3.5836h). Charging took 45 minutes. (0.7544h).

o The distance traveled between the charging station No. 3 and the charging station No. 4 is 3.1 km. The time needed to travel between points was 3 minutes. (0.0517h). The vehicle was charged in point 4 for 5 minutes. (0.0871h).

o Distance between charging point 4 and end point is 282.73km. The required time to cover this section is 4h 43min. (4.7122h).

o The total driving time - 8h 21min. (8.3475h)

o Total charging time - 50min. (0.8415h)

o Total distance traveled - 500.85 km

• For a route with a total journey time of 9h 13min. (9,2176h):

o The vehicle traveled the route from the starting point to the charging station at point No. 12. The distance traveled on this section is 235.82 km, and the time needed to cover this distance is 3h 56min. (3.9303h). Charging took 50 minutes. (0.8274h).

o The distance traveled between the charging station No. 12 and the charging station No. 13 is 7.2 km. The time needed to travel between points was 7 minutes. (0.12h). The vehicle was charged in point 4 for 12 minutes. (0.2022h).

o The distance between the charging point 13 and the end point is 248.26km. The required time to cover this section is 4h 8min. (4.1376h).

o The total driving time - 8h 4min. (8.0679h)

o Total charging time - 1h 2min. (1.0296h)

o Total distance traveled - 491.28 km

Table 2. Simulation results

simulation number	Numerical designation of point No.1	Numerical designation of point No.2	Numerical designation of point No.3	Numerical designation of point No.4	Vehicle charging at point 1 (0 = no charging, 1 = loaded vehicle)	Vehicle charging at point 2 (0 = no charging, 1 = loaded vehicle)	Vehicle charging at point 3 (0 = no charging, 1 = loaded vehicle)	Vehicle charging at point 4 (0 = no charging, 1 = loaded vehicle)	Total travel time [h]
1.	12	12	12	13	1	1	1	1	9.2176
2.	12	12	13	13	1	1	1	1	9.2176
3.	3	3	4	4	1	0	1	1	9.1891
4.	3	3	3	4	1	1	1	1	9.1891
5.	12	12	13	13	1	1	1	1	9.2176
6.	3	3	3	4	0	0	1	1	9.1891
7.	3	4	4	4	1	1	0	1	9.1891
8.	12	12	12	13	1	0	1	1	9.2176
9.	3	3	3	4	1	1	0	1	9.1891
10.	3	3	3	4	0	1	1	1	9.1891
11.	12	12	13	13	1	1	1	1	9.2176
12.	12	12	13	13	1	1	1	0	9.2176
13.	12	13	13	13	1	1	1	0	9.2176
14.	12	12	12	13	1	1	1	1	9.2176
15.	12	12	13	13	1	1	1	0	9.2176
16.	3	3	3	4	0	1	0	1	9.1891
17.	3	3	4	4	1	1	1	1	9.1891
18.	3	3	3	4	1	1	1	1	9.1891
19.	3	3	4	4	0	1	1	0	9.1891
20.	3	3	3	4	0	0	1	1	9.1891

The best available route fallows through the charging point no. 3 (ul. Wilkońskich 1 60-543 Poznań, fast charging) and the charging point no. 4 (ul. Święty Michała 62 61-005 Poznań, slow charging). The vehicle on this route is charged twice and the total journey time is 9h 11min. Figure 2 shows the selected route.

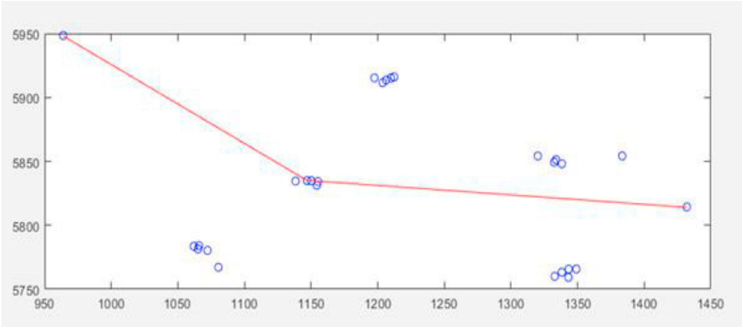

Fig.2 The obtained route of the electric vehicle in the *x, y* coordinates

Calculations were also carried out for the range of the vehicle reduced to 200 km, the best available route runs through the charging point No. 7 (Unia 118 Street, 65-120 Zielona Góra, fast charging), and the charging point No. 3 (Wilkońskich Street 1, 60-543 Poznań, fast charging), charging point No. 4 (ulica Święty Michała 62 61-005 Poznań, slow charging) and charging point No. 17 (ul. Chemików 7 09-411 Płock, fast charging). The total travel time is 12h 10min. (12.1646h), and the detailed route is as follows:

• Between the starting point and the charging point no. 7, the vehicle covered a distance of 191.43 km in 3h 11min. (3.1904h). The vehicle charging time at this point was 57 minutes. (0.9571h)

• The distance between points 7 and 3 is 99.28 km, and the time required to cover it is 1h 39min. (1.6546h). Charging in point 3 took 30 minutes. (0.4964h)

• From point 3 to point 4, the vehicle covered a distance of 3.1 km in 3 minutes. (0.0517h). The vehicle charging time at this point is 7 minutes. (0.1241h)

• The distance between points 4 and 17 is 171.2 km, and the time required to cover it is 2h 51min. (2.8534h). Charging at point 17 took 51 minutes. (0.856h).

• The last section of the route to the end point is a distance of 118.85 km, and the time needed to cover it is 1h 59min. (1.9808h).

• Total driving time - 9h 44min. (9.7309h)

• Total charging time - 2h 26min. (2,4336h)

• Total distance traveled - 583.86 km.

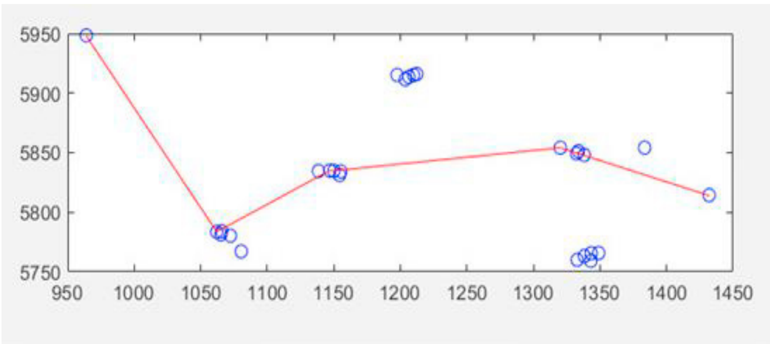

Fig. 3 Obtained route for a vehicle range of 200 km.

4. Conclusion

The proposed method of route optimization using genetic algorithms has been verified because of example calculations using information about actual charging points located along the planned route. The obtained results for two different ranges of the electric vehicle indicated optimal routes. The authors concluded that satisfactory results were obtained.

The presented method requires further improvements related to the prediction of travel time and actual energy consumption on individual route sections. This will refine the vehicle range prediction, which will have an impact on the final result of trip points optimization.

The presented optimization results clearly show the influence of the electric vehicle range on the total distance traveled and the total travel time. This issue is analyzed by the authors in parallel studies.

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