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MULTI-CRITERIA DECISION METHODOLOGY FOR THE OPTIMIZATION OF PUBLIC ELECTRIC VEHICLE CHARGING INFRASTRUCTURE

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Abstract

The growing interest for electric vehicles requires an efficient infrastructure for vehicle charging. The usual approach for the charging station optimal location is the minimization of trip costs with constraints concerning the public electricity network capacity. In this paper, the new – multi-criteria approach for the charging station location is presented. The optimization objectives include: minimization of walking distances from the charging station location, minimization of electric grid power losses, and the maximization of drivers comfort and security. The greedy heuristic and AHP methodology are used for the location optimization. The proposed methodology is tested on illustrative example.

Key words*: AHP, electric vehicles, greedy heuristic optimization, median*

1 INTRODUCTION

Development of Electric vehicles (EV) is driven by one multidisciplinary industry segment that consists of EV manufacturers, battery industry, grid operators, spatial planning, etc. The full acceptance of this concept requires the existence of an appropriate network of charging stations (EVCS - EV charging stations) [1]. Efficient, reliable and cost-effective EVCS network would affect the increase in demand and enable the growth of industry in this segment by eliminating concerns about lack of autonomy of users.

Taking into account the specificities of EVCS, such as technical limitations of locations and possible future user requirements, selection of the optimal location for EVCS is becoming an increasingly important topic. The way charging stations are organized represents the basis for the development of auto industry in this segment. Above all, the selection of proper locations has a positive impact on reducing the cost of implementation of EVCS projects. On the other hand, a bad choice of location would have a negative impact on safety and the protection of the environment and thus to the popularization of EVs and reducing investment in infrastructure development [2].

Until now, authors have dealt with the problem of locating charging stations indirectly, mainly through the development of methodologies for designing charging infrastructure [3],[4]. Given the importance of solving the problem of location selection, defining proper methods for selecting EVCS site locations gets crucial importance [5],[6].

Choosing the best location for EVCS requires decision making process and in the literature, two methodologies for solving this problem can be identified:

- Multiple Objective Decision Making (MODM)
- Multiple Criteria Decision Making (MCDM)

The factors that are considered in the application of this methodology for the selection of optimal locations can be quantified: construction cost and running cost, traffic status, impact on power grid. On the other hand, EVCS impacts on ecology and urban development are not taken into account.

This is the main reason for criticism of this approach for determining optimal locations of EVCS. These models consider quantitative criteria, but are not able to analyze the subjective factors that also have a major impact on the choice of locations, such as the environment and ecology.

MCDM methodology explicitly considers multiple conflicting criteria when selecting the best alternative for a particular problem [7]. It can compensate for deficiencies of MODM, taking into account both quantitative and qualitative criteria for determining optimal locations for EVCS (optimal site of electric vehicle charging station).

In this paper, the new – multi-criteria approach for the charging station location is presented. The criteria for the optimization includes: walking distances from the charging station location, distribution network capacity, access to the parking with EVCS and parking security. The greedy heuristic (first step) and AHP methodology (in the second step) are used for the location optimization. The proposed methodology is tested on illustrative example.

2 METHODOLOGY

In the case of p median problem, it is necessary to locate one or more objects on the network in order to minimize the average distance (or the average travel time or the average transport costs) from the object to the user or from the user to the object. P median problem is significant especially for transport systems, considering that this group of problems occurs during the design of different distribution systems. Consider an unoriented transport network G - (N, A) which has n nodes. Denote with a_i the number of requests for the service from the node *i*. Also denote the distance between node *i* and node *j* with d_{ij}, and the number of objects to be located on the network with *p*.

It is possible to locate objects in any of *n* nodes. In [8] it is proved that there is at least one set of *p* medians in the nodes of the network *G*, meaning that *p* optimal locations of the objects in the network must be located exclusively in the network nodes [9]. This fact considerably facilitates the procedure of finding the *p* median, because it is necessary to examine only locations that are in the nodes.

The location problems on the networks of minisum type are reduced to discrete location problems (discrete location problems appear when the points, at which the new object can be set up, are the elements of a final set). *P* median problem of *n* nodes in the network has p solutions - the median's locations, so it can be written:

$$\binom{n}{p} = \frac{n!}{p!(n-p)!} \,. \tag{1}$$

For example, for the *n* = 10 number of nodes and *p* = 3, there are 120 solutions; for *n* = 100 and *p* = 15, there are 2.5 e^{17} solutions. Taking into account than the scope of computing rapidly increases with the number of nodes in the network and number of *p* (locations of the median), different heuristics for finding a solution for the problem of *p* median are often used in practice.

Hakimi proved that *p* median problem on the networks belongs to the NP-hard problem group. *P* median problem is often analyzed in solving problems both at the macro and micro level. The decision where to locate the warehouse which receives goods from multiple factories with well-known locations or which should distribute the goods to retail stores network is an example at the macro level. At the micro level, the typical use of *p* median problem is finding the optimal location for a new machine inside the factory.

Mathematical formulation of the *p* median model is reduced to a problem of linear programming that is centered on symmetric distance matrix d_{ij}, respectively distance between locations *i*, which should be serviced and candidate j for the optimal solution. In the context of the specified model *p* median can be defined with the following parameters:

i = 1, 2, 3, 4,….*I* – set of nodes in which the demand is located,

j = 1, 2, 3, 4,…*J* – a set of nodes in which it is possible to locate objects,

a_i – requirement for the service from the node *i*, coefficient of availability,

p – the number of objects which should be located on the network,

d_{ij} – distance between node *i* and node *j*

Consider the binary variables which are defined as follows:

$$x_{i,j} = \begin{cases} 1, \text{ if the demand of the node } i \text{ is covered in the node } j \\ 0, \text{ if the demand of the node } i \text{ is covered in another node} \end{cases} \tag{2}$$

$$X_j = \begin{cases} 1, \text{ if the node } j \text{ is selected location for the service object (median)} \\ 0, \text{ if not} \end{cases} \tag{3}$$

P median problem can be formulated using the criterion function, since during locating *p* objects we strive to minimize the total distance between objects and users:

$$\min F = \sum_{i \in I} \sum_{j \in J} a_i d_{ij} x_{ij} \,. \tag{4}$$

For restrictions:

$$\sum_{j \in J} x_{ij} = 1, \quad \forall i \in I \,, \tag{5}$$

$$\sum_{j \in J} X_j = p \,, \tag{6}$$

$$X_j \geq x_{ij}, \quad \forall i \in I, \forall j \in J; i \neq j \,, \tag{7}$$

$$X_j \in \{0,1\}, \forall j \in J, \forall j \in J \,, \tag{8}$$

$$x_{ij} \in \{0,1\}, \quad \forall i \in I \tag{9}$$

Defined criterion function (4) tends to minimize the total distance between objects and users. In the expression (4), *I* and *J* are upper limits of integer variables *i* and *j*, and in both cases it is the number n, since each of n locations is at the same time a potential candidate for the optimal solution. Restriction (5) allows that each node can be serviced from a single object. Restriction (6) defines that the number of objects that should be located is equal to the number p and represents a natural limit to the number of objects, but also requires that all p locations must be placed. Constraint (7) represents the control restriction, which allows allocation of the clients only to located objects (allocation variable). Restrictions (8) and (9) reflect the binary decisions, which should be defined by the model and according to which the problem is introduced in the field of integer arithmetic. Restrictions of (5) to (9) can be changed if it is justified from the aspect of problem solving. In fact, some of the restrictions may be mitigated or even omitted, and the abandoning or easing of restrictions in practice is being called the problem "relaxation".

On the other hand, intensification of existing and introducing new restrictions is conditioned by the problem and goals definition. *P* median models are used for determining the locations of the various industrial plants, warehouses, storage facilities, public buildings, distribution systems etc.

The algorithm of determining the optimal location is as follows:

Step 1. Suppose *m* charging stations of *n* parking spaces in the city

Step 2. Select the desired number of locations with the *m* number of stations by using the methods of the *p* median

Step 3. Apply the AHP method for ranking selected locations from the previous step, according to the following criteria:

- access to the parking lot,
- power network capacity,
- parking lot security.

Step 4. Avoid the worst locations obtained from the previous step and select other locations as the solution

In the case of EVCS, the goal is minimization of total walking distance between real charger location and driver's

preferable location, so the optimization problem is following:
n - the total number of parking spaces in the city
a_i - the number of vehicles parked in the parking space i during the day (demand of node i)
d_{ij} - the distance between nodes i and j
x_{ij} - binary variable equal to 1 if the vehicles parked in the parking space i, would have to charge in the parking space j

$$\min F = \sum_{i=1}^{n}\sum_{j=1}^{n} a_i \cdot d_{ij} \cdot x_{ij} \, . \tag{10}$$

Restrictions:

$$\sum_{j=1}^{n} x_{ij} = 1, i = 1,2,...,n \, , \tag{11}$$

$$\sum_{j=1}^{n} x_{jj} = p \, , \tag{12}$$

$$x_{jj} \geq x_{ij}, \quad i, j = 1,2,...,n; i \neq j \, , \tag{13}$$

$$x_{ij} \in \{0,1\}, \; j = 1,2,...,n \, . \tag{14}$$

3 EXAMPLE

Suppose that the city authorities analyze 10 potential parking locations dedicated to electric chargers. The objective is to find best number and location of charging stations according to 4 criteria (walking distances, power network capacity, trafic congestions - access to the parking lot and parking security). Prior to this analysis, a survey among existing EV owners about their preferences has been carried out. The survey results are presented by vector V, describing the prefferable number of EVs on each location.

$$V = \begin{bmatrix} 5 & 10 & 10 & 5 & 5 & 10 & 10 & 20 & 5 & 5 \end{bmatrix} . \tag{15}$$

Walking distances (in kilometers) between locations are presented in matrix D (symmetrical matrix).

$$D = \begin{bmatrix} 0 & 2 & 1 & 3 & 0.5 & 0.2 & 0.4 & 3 & 4 & 2 \\ & 0 & 1 & 2 & 0.5 & 0.2 & 3 & 2 & 4 & 5 \\ & & 0 & 0.2 & 0.4 & 3 & 4 & 1 & 4 & 1 \\ & & & 0 & 2 & 2 & 2 & 2 & 1 & 3 \\ & & & & 0 & 0.5 & 1 & 3 & 4 & 2 \\ & & & & & 0 & 2 & 1 & 3 & 0.5 \\ & & & & & & 0 & 4 & 2 & 5 \\ & & & & & & & 0 & 1 & 3 \\ & & & & & & & & 0 & 2 \\ & & & & & & & & & 0 \end{bmatrix} , \tag{16}$$

The optimal EV charger locations selection is performed in two steps. In the first step, we are choosing criteria for the mutual comparison of alternative locations. The pairwise comparison of criteria importance is given in (Table 1).
The second step is the selection of the initial number of EV parking lots with chargers $p \leq 10$. For the sake of simplicity, we are starting with $p = 5$ possible locations. Using the minimization function (10), the optimal obtained locations are: 3, 6, 7, 8 and 9. The alocation of EVs from other location is represented in Table 2.

Table 1. Comparison of criteria importance

	Access to the parking lot	**Power network capacity**	**Parking lot Security**	**Weights**
Access to the parking lot	1	1/3	1/5	0.1047
Power network capacity	3	1	1/3	0.2583
Parking lot Security	5	3	1	0.6370
λ_{max} = 3.0385	**CI = 0.0193**		**CR = 0.0332 < 0.10**	

Table 2. The alocation of EVs from 10 locations

Charger locations	3	6	7	8	9
Belonging locations	3,4,5	1,2,6,10	7	7	9

In the next step, the multicriteria analysis of proposed locations is performed using the AHP methodology. Results are presented in Tables 3 -5.

Table 3. Pairwise comparison of alternatives according to the criteria: *Access to the parking lot*

	6	**8**	**7**	**3**	**9**	**Weights**
6	1	1/2	2	3	1/7	0.1048
8	2	1	2	3	1/7	0.1385
7	1/2	1/2	1	2	1/8	0.0701
3	1/3	1/3	1/2	1	1/9	0.0450
9	7	7	8	9	1	0.6415
λ_{max} = 5.1623			**CI = 0.0406**		**CR = 0.0362 < 0.10**	

Table 4. Pairwise comparison of alternatives according to the criteria: *Power network capacity*

	6	**8**	**7**	**3**	**9**	**Weights**
6	1	1/2	1/5	1/4	2	0.0766
8	2	1	1/6	1/5	2	0.0946
7	5	6	1	2	7	0.4644
3	4	5	1/2	1	6	0.3152
9	1/2	1/2	1/7	1/6	1	0.0493
λ_{max} = 5.1470			**CI = 0.0368**		**CR = 0.0328< 0.10**	

Table 5. Pairwise comparison of alternatives according to the criteria: *Security*

<table>
<tr><th></th><th>6</th><th>8</th><th>7</th><th>3</th><th>9</th><th>Weights</th></tr>
<tr><td>6</td><td>1</td><td>4</td><td>1/4</td><td>1/3</td><td>2</td><td>0.1412</td></tr>
<tr><td>8</td><td>1/4</td><td>1</td><td>1/5</td><td>1/4</td><td>2</td><td>0.0711</td></tr>
<tr><td>7</td><td>4</td><td>5</td><td>1</td><td>2</td><td>7</td><td>0.4425</td></tr>
<tr><td>3</td><td>3</td><td>4</td><td>1/2</td><td>1</td><td>6</td><td>0.2935</td></tr>
<tr><td>9</td><td>1/2</td><td>½</td><td>1/7</td><td>1/6</td><td>1</td><td>0.0517</td></tr>
<tr><td colspan="3">λ_{max} = 5.2239</td><td colspan="2">CI = 0.0560</td><td colspan="2">CR = 0.0500< 0.10</td></tr>
</table>

Applying the Eq (17), we obtain the final ranking of first 5 alternatives:

$$\begin{bmatrix} 0.1048 & 0.0766 & 0.1412 \\ 0.1385 & 0.0946 & 0.0711 \\ 0.0701 & 0.4644 & 0.4425 \\ 0.0450 & 0.3152 & 0.2935 \\ 0.6415 & 0.0493 & 0.0517 \end{bmatrix} \begin{bmatrix} 0.1047 \\ 0.2583 \\ 0.6370 \end{bmatrix} = \begin{bmatrix} 0.1207 \\ 0.0842 \\ 0.4092 \\ 0.2731 \\ 0.1128 \end{bmatrix}, \quad (17)$$

From previous equation, it is visible that location 8 has the worst result (0.0842), and the final list of adopted locations is 3, 6, 7 and 9. The complete procedure can be repeated for the reduced number of locations (p = 4, or p =3), and the iteration procedure stops when no decrease in total walking distance weights is observed.

4 CONCLUSION

Selection of the optimal location for EVCS is becoming an increasingly important topic, and a bad choice of location would have a negative impact on safety and the protection of the environment, reducing investment in infrastructure development. Unlike the usual, single criteria approach for the EV charging station optimal location selection, the new – multi-criteria approach is presented. The main contribution of the proposed methodology is the simultanious optimization of both number and locations of EV charger stations. In the first step, minimization of walking distances from the charging station location is performed using the greedy heuristic approach. In the second step, using AHP methodolgy, and selected locations are mutualy compared and the worst location is taken out of consideration. The procedure is repeated for the reduced number of locations and the iteration procedure stops when no decrease in total walking distance weights is observed. The application of this methodology is succefully illustrated on an example of selection among 10 possible EV charging stations.

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REFERENCES

1. Gartner, J., Wheelock, C., 2009, *Electric Vehicles on the Grid*, Research Report (Pikeresearch LLC).
2. Wu, Y.; Yang, M.; Zhang, H.; Chen, K.; Wang, Y., 2016, *Optimal Site Selection of Electric Vehicle Charging Stations Based on a Cloud Model and the PROMETHEE Method. Energies*, 9, p. 157
3. Gavranovic, H., Barut, A., Ertekc, G, Yuzbasıoglu, O.B., Pekpostalcıc, O., Tombu, O., 2014, *Optimizing the Electric Charge Station Network of EŞARJ*, in 2nd International Conference on Information Technology and Quantitative Management, ITQM 2014. Procedia Computer Science, edited by Yong Shi, Alexander Lepskiy, and Fuad Aleskerov, 31, pp. 15–21.
4. Chen, D., Khan, M., Kockelman, K., 2013, *The Electric Vehicle Charging Station Location Problem: A Parking-Based Assignment Method for Seattle*, Transportation Research Record 1254: 28-36
5. Antunes A.P., Gonçalves G., Ribeiro A., Frade I., 2011, *Optimal location of charging stations for electric vehicles in a neighborhood in Lisbon, Portugal*. Transp Res Rec., 2252, 91–99.
6. Sadeghi-Barzani P., Rajabi-Ghahnavieh A., Kazemi-Karegar H., 2014, *Optimal fast charging station placing and sizing*, Appl Energy, 125, 289–299.
7. Janjic A., 2015, *Two-step algorithm for the optimization of vehicle fleet in electricity distribution company*, Electrical Power and Energy Systems, 65, pp. 307–315
8. Hakimi, S.L., 1964, *Optimal Locations of Switching Centers and the Absolute Centers and Medians of a Graph*, Operations Research, 12, pp. 450-459.
9. Teodorović, D., 2007, *Transportne mreže*, Saobraćajni fakultet Univerziteta u Beogradu.

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